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A GENERIC CLASSIFICATION FOR TEACHING MACHINES

APPROVED FOR PUBLIC RELEASE

by

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A GENERIC CLASSIFICATION FOR TEACHING MACHINES

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G. J. Simmons

ABSTRACT

This paper develops a classification for teaching machines based on the nature of the interaction between the student and the programmed instructional material. This approach makes it possible to functionally classify devices of widely different complexities without being misled by the sophisticated device design (or lack of it). Four basic machine types are identified and discussed:

1. Linear
2. Recyclical
3. Remedial-cyclical (branching)
4. Adaptive

A GENERIC CLASSIFICATION FOR TEACHING MACHINES

The first decade of activity in programmed instruction has produced a spate of devices, indiscriminately called teaching machines, to implement the programs. These machines come in a confusing variety of sizes and complexities. Compatible with a number of teaching philosophies, they range from simple linear devices based on micro-programming to complex multi-million dollar simulators which instruct through simulated experiences.

An obvious question arises. Can these apparently widely dissimilar devices be classified on the basis of some common and distinctive feature? What is alike in all the mechanical, electrical and electromechanical machines that have been produced for teaching?

Since there has been some confusion in the literature concerning just what a teaching machine is, or even just what a teaching machine is not, yet another definition may be useful. The definition we will use here will at the same time give us our classification criterion. Looking at teaching machines in this fashion will let us see that no matter how simple or complex they might be mechanically, they have a common generic function. A teaching machine, then, is a mechanization of an instructional servo loop which is closed in some manner through student responses. The genuine teaching machine permits the student to progress through a programmed learning sequence in a manner and at a pace determined by the student's individual dynamic learning performance. It is this feature of feedback control in the development of the learning sequence that is the essential concept for our classification purposes.

The devices most often confused with teaching machines in the popular press are audiovisual aids. Audiovisual aids are open-ended in function, in that they assist or supplement instruction but cannot instruct in the same manner that a teaching machine does since the student is not an active element in the control of the presentation. Audiovisual aids may be very complex and the programming may be well developed; however, the student remains a passive receptor of the information presented.

In this paper we shall consider the interplay of the student and the teaching machine to be a sequence of logical decision points, at each of which one of a set of alternatives is chosen to be executed either by the student or by the machine. Such a sequence of decisions is precisely an

analogue of the execution of a program in a modern stored-program digital computer. Hence, it is only natural that we adopt the symbolic language developed for programming--flow charting. Ultimately the generic classification developed in this paper for teaching machines will be based on a geometric description of the types of flow charts which a given machine can realize. Since this paper is not restricted to any single teaching philosophy nor to any single machine, it is necessary to examine the basic teaching process as it is carried on in the classroom to illustrate the functions which need to be implemented. To do this, we shall analyze in a cursory manner the activities and objectives of the classroom instructor in the two fundamental areas of instruction, i.e. the teaching of conceptual material and motor skills.

In presenting conceptual material, an instructor generally makes use of some or all of the following devices:

1. He breaks new concepts down into small, easily assimilated ideas. This analysis will vary from subject to subject. However, there are several commonly-used techniques:
 - a. Historical, in which the material is developed chronologically as it was originally discovered--a technique dear to physical scientists;
 - b. Associational, where a simile or comparison with known concepts is made. This prompting of the learning processes by association is widely used, for example, in the teaching of languages where a large, reasonably well-organized discipline exists to which reference can be made;
 - c. Structural, in which an underlying structure or organization is used to impose an ordering on the conceptual development. This is traditionally the approach used in mathematical instruction;
 - d. Linear, in which major concepts are developed by "atomic" build-up of small conceptual units not necessarily in logical or chronological order. This type of analysis represents the approach of many educational and behavioral psychologists who are working with machines.
2. He organizes the sequence of presentation and hence of learning so that the ideas presented complement each other and thus reinforce the individual learning stimuli.

3. He periodically interrogates a sample of the student group to determine the extent to which the material has been assimilated and then uses this information to decide what his next step should be.
 - a. If a new concept has been misunderstood, missed, or not assimilated, the instructor will return to that concept, rephrase it, break it down into smaller conceptual units, or illustrate it with a different example.
 - b. If the remedial information served its purpose or if the group's comprehension is better than anticipated in the study plan, the instructor may decide to jump ahead to material which is more challenging.
4. Finally, the student is presented with constructive situations which require the application (extrapolation) of concepts presented in the lesson. The first type of question noted above (3) was concerned with the student's understanding and retention of the material. This latter type is concerned with the application of concepts, which is an area much more difficult to evaluate.

In the teaching of motor skills, there are steps which differ somewhat from those used in teaching conceptual skills. In acquiring a motor skill, proper drill is essential. Proper drill may be interpreted broadly as a drill which challenges the student's ability to perform an act while exercising him at his present level of development. Since motor skills are frequently dependent on the time taken to perform an act, time becomes an essential variable, as for an example a speed drill in typing. The basic instructional approach, though, is similar. A new task element is introduced and its performance is then tested in context with previously learned skills.

1. Just as with conceptual skills, the item to be learned, for an example the operation of a complex machine, is analyzed into many simple actions by the instructor. These may be related actions, i.e. for stimulus enhancement as for conceptual skills, or independent acts. The student is periodically tested in the performance of a new act or skill sequence to determine if it has been acquired.
2. Repetitive drill is used to strengthen the response and to make the act itself "second nature."

3. The act is tested in context with other motor skills to form a meaningful composite act.
4. Finally, in mechanical or motor skills, there is a test of facility. The speed with which responses can be made and the accuracy of these responses are ordinarily used as a test of the thoroughness with which the skill has been mastered.

There are undoubtedly other equally meaningful subdivisions of the educational process; however, the foregoing analysis identifies some general functions which may have to be realized by a teaching machine to implement a programmed learning sequence.

The simplest program, insofar as organization is concerned, is the linear. This is a realization of the micro-programming procedure which breaks each concept down into minuscule bits, so self-contained in conceptual content, that no simpler sequence need be devised to convey the desired ideas. If this is indeed the case, then no branching or program choices are required since there are no subroutines or alternate learning situations, and the machine has only to prompt the student through the program sequence. At its simplest, the flow chart for a pure linear program could be constructed in the following form:

In this example the student's response in each frame causes him to progress to the next learning situation as soon as he has finished the preceding one. This simple, paced, tutorial presentation mechanizes Steps 1 and 2 of our analysis of conceptual materials with a weak type of interrogation (Step 3). We say weak because the interrogation is not crucial to the program development. Although undoubtedly a programmer will wish to use tutorial situations such as these, in which the student is given information and is not interrogated to test his understanding of the material or his ability to apply it at that time, only a very weak programmed learning sequence can be constructed using tutorial frames alone. In general, it is necessary to determine the student's readiness to proceed by requiring a response which indicates whether he has assimilated the material. In a linear program servoed to the student's learning rate, an incorrect response will not advance the student to the next learning situation, but will leave him in the uncompleted instructional frame, with the original task still to be successfully completed.

Figure 1 schematizes several frames from a general flow diagram of a linear machine. The vacuous (closed) loops returning the student to the same learning situation are the incorrect response options which produce no change. Only a correct response can cause the student to progress to the next frame. In general there will be a single correct response; however, this need not be the case as the multiple transition from Frame II to Frame III indicates. Again the figure indicates that the programmer may elect to use some purely tutorial frames, intermixed with frames which have a multiplicity of permitted responses. The "linear" teaching machine, however, is completely characterized by:

1. Predetermined sequence of learning situations
2. Student-determined rate of progress through the sequence
3. Micro-programming of instructional material

The mechanization of such devices can, as noted in the introduction, vary widely. In determining the proper exit choice for a given frame the student may grade his own response against the correct response as revealed by the machine, or the grading may be done automatically. The student response may be as simple as choosing one of several preformed responses using a multiple choice type of machine, or it may allow considerable freedom in constructing an answer with only the correct one being recognized. Perhaps the simplest example of a linear teaching machine is the film sequence projector built by A. J. Hoehn and A. A. Lumsdaine in which the material is all tutorial, with the presentation rate controlled by the student. Several multiple choice machines with automatic grading have been constructed; however, the type is well illustrated by Pressey's self-grading machines (circa 1926-1927).

The next level of complexity in program organization is encountered in programs which mechanize Step 3-a, i.e. interrogative control of remedial cycling so that material which has already been presented can be re-exposed if a student response at some later time indicates a need for such a memory jog. Basically, this can be flow charted in the following form:

An incorrect response in Frame III indicates (as determined by the programmer's classroom experience) a failure to use or understand the material given in Frames I and II.

Figure 2 exemplifies a few frames from a general flow diagram of a recyclical machine, in which several sizes of remedial steps are indicated. Obviously a machine with this flexibility subtends a linear machine, i.e. can implement any program compatible with a linear machine. The recyclical machine is characterized by:

1. Programmed provision for re-exposure to learning situations;
2. Student-determined sequence of learning situations;
3. Macro-programming for the recyclical loops;
4. Cumulative memory of the student's responses (re-exposures) in many cases.

There have been several devices of this type constructed; however, two of the most interesting examples are Pask's SAKI and the Rheem-Califone keyboard teaching machine. Both of these are recyclical machines with a memory to store the student's past performance.

The inclusion of Step 3-b, i.e. wash ahead and pace adjustment, gives rise to the next level of organizational complexity. Conceptually both of the machines just discussed are linear devices in that there is only a single linear sequence of frames to which the student may be exposed. The organizational complexity of a machine to implement the additional capabilities of Step 3-b is based on a requirement for a multilayer program so that enrichment or remedial materials can be made available. Logically, such a device is called a remedial-cyclical or branching machine, and may in its simplest form be flow charted as follows for a two-level program:

In this example, Frames III and IV are remedial material prepared by the programmer to provide supplemental instruction to the student when he makes an incorrect response to Frame I to prepare him for the material to be presented in Frame II. Obviously programs of this type, especially if prepared with several levels of programming, can be very sophisticated and provide an extremely flexible tool to the programmer.

Figure 3 diagrams several frames from a remedial-cyclical machine with four levels of programming depth. Obviously a machine with this degree of flexibility subtends both linear and recyclical machines. The remedial machine is characterized by:

1. Learning situations at several levels of programming, with student responses controlling transitions between levels;
2. Student-determined individual learning sequence;
3. Remedial programming - alternative or amplified programs;
4. Error analysis required of the programmer to choose transitions.

The current state of the art in device technology makes it possible to construct flexible devices of this type. Surprisingly, however, few true remedial-cyclical machines have been marketed. Good examples of remedial-cyclical (branching) machines are provided by Crowder's Visual Auto-Tutor and the ERA Audiovisual 501. These machines permit the programmer a free choice over the gamut of instructional steps outlined in the beginning, and in this sense are remote controlled "classrooms" for individual instruction of each student.

The last category of organizational complexity for teaching devices is ordinarily referred to as an adaptive system. In these machines, a program does not exist in the sense that we have used it above to refer to a sequence of prepared learning experiences and an algorithm which governs the student's progress through the sequence. Rather the adaptive teaching machine is capable of reacting to the student's input to provide the appropriate response situation. A good example of such a system would be a machine to teach a student pilot to handle a jet aircraft. In this case, the inputs available to the student are the cockpit controls, while the outputs of the teaching machine are the aircraft instruments. The student can (barring a catastrophic error) certainly learn to "fly" an aircraft through actual training in the cockpit. However, sitting at an

adaptive teaching machine the student could "fly" the aircraft in exactly the same manner. Each control setting, in conjunction with the past history of control positions (flight history), would determine the proper instrument outputs. Obviously, this approach to instructional machines is radically different from the organization of those which we discussed earlier in which fixed learning sequences were programmed. In this case the student's dynamic learning behavior determines an individual "trajectory" of learning situations. Again, for severely limited situations an adaptive machine subsumes all the previously discussed machines.

Adaptive machines are characterized by:

1. Dynamically determined sequences of learning situations--dependent on present and entire past history of student responses;
2. Student determined "trajectories" as opposed to programmed sequences;
3. Cumulative memory for student responses;
4. Indeterminate program--learning by simulated experience;
5. Game-like student-machine interaction.

Many examples of adaptive teaching systems are in existence--mostly in the form of multimillion dollar simulators for training by simulated experience. The Mercury trainer developed by McDonnell Aircraft and used with laudable success in training the American astronauts is a well known example. Another example of an adaptive system, more easily recognized as a teaching machine, is the Edison Responsive Environment Instrument (computerized typewriter) which has been used to teach reading to five-year-old kindergarteners. In this experiment each child's responses, used as entrance points into an extensive and flexible computer-stored program, determined an individual learning trajectory. Again the technique proved to be extremely effective insofar as the individual student was concerned, but very ineffective in the utilization of the computer, and hence would be prohibitively expensive for a mass educational aid. Currently the high cost of constructing adaptive systems restricts the application of these devices to training problems which can justify the initial investment. Considerable work is now underway on simple low cost associatively addressed distributed memories suitable for these applications which would make adaptive teaching machines competitive with other devices for a wide range of educational tasks.

There are two channels of communication potentially available between the student and the machine: audio and visual. In any single machine either of these media can be organized into one of the four generic types discussed above, irrespective of the organization of the other channel. Ordinarily the two are closely related; however, this need not be the case. For an example, since it is possible to realize audio branching quite inexpensively, a low cost machine (not marketed) was designed by Fairbanks-Morse which coupled a linear visual machine with a branching audio. This is flow charted for several typical frames in Figure 5. An erroneous response by a student would cause him to branch into a new audio channel where his error would be discussed and prompting for the correct reply provided. During this period (remedial cycle of audio instruction) the visual presentation did not change. Thus in the analysis of any multi-media, multi-channel teaching machine the individual channels of communication would each need to be classified.

In summary, we have found that there are four basically different organizations possible for teaching machines:

1. Linear
2. Recyclical
3. Remedial-cyclical (branching)
4. Adaptive

The first two types operate with linear program sequences in which the student is exposed to all instructional frames, in the first case in a programmer-determined order and in the second in a student-determined order. In the third type the programs have grown to be multilevel, with the student's performance determining which frames he is exposed to. In the last category no pre-programmed sequences exist; instead the student's responses generate an individual learning trajectory. These generic classifications are based therefore only on the nature of the instructional servo which exists between the student and the machine, i.e. the program, and not on the complexity, or the lack of it, in the machine itself.

GJS:bd

LINEAR

Characterized by:

1. Predetermined sequence of learning situations;
2. Student-determined rate of progress through the sequence;
3. Micro-programming of instructional material.

FIGURE 1

RECYCLICAL

Characterized by:

1. Programmed provision for re-exposure to learning situations;
2. Student-determined sequence of learning situations;
3. Macro-programming for the recyclical loops;
4. Cumulative memory of the student's responses (re-exposures) in many cases.

FIGURE 2

REMEDIAL-CYCLICAL (BRANCHING)

Characterized by:

1. Learning situations at several levels of programming, with student responses controlling transitions between levels;
2. Student-determined individual learning sequence;
3. Remedial programming - alternative or amplified programs;
4. Error analysis required of the programmer to choose transitions.

FIGURE 3

ADAPTIVE

Characterized by:

1. Dynamically determined sequences of learning situations--dependent on present and entire past history of student responses;
2. Student determined "trajectories" as opposed to programmed sequences;
3. Cumulative memory for student responses;
4. Indeterminate program--learning by simulated experience;
5. Game-like student-machine interaction.

FIGURE 4

Key

Audio

Video

Mixed-Mode (linear video--branching audio) Machine

FIGURE 5