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ABSTRACT

The development of learning theory and its application to computer-assisted instruction (CAI) are described. Among the early theoretical constructs thought to be important are E. L. Thorndike's concept of learning connectisms, Neal Miller's theory of motivation, and B. F. Skinner's theory of operant conditioning. Early devices incorporating those concepts included testing machines and aids developed by Pressey and Peterson in the 1920's and 1930's, and more recently by Skinner. The concept of optimization in learning systems is considered. A distinction is drawn between short-term and long-term optimization--the former having to do with the best procedures for learning a small, discrete item (e.g. how to spell a single word), whereas the latter deals with overall learning strategies. Different approaches to the derivation of optimums are discussed. Finally, it is noted that much of the work to date on CAI has been based upon the thinking of behaviorists independent of researchers in cognitive learning fields. A closer working relationship between these discipline orientations is called for now. (DGC)

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Optimizing Computer Assisted Instruction By Applying Principles of Learning Theory

Fifteen years ago the use of computers as instructional devices was only an idea that was being considered by a handfull of scientists and educators. Today the idea has become a reality. Computer-assisted instruction has undergone an amazingly rapid development (Atkinson and Wilson, 1969).

The purpose of this paper is to trace the development of learning theory application to the area of computer-assisted instruction (CAI). Not only will the historical development of the theoretical foundations of CAI be discussed, but the popular history and the early experimental research will also be presented.

The Theoretical Foundations (Learning Theory) of Computer Assisted Instruction

Modern examples of teaching machines, automated and computer assisted instructional devices owe their theoretical roots to the behaviorist tradition in psychology, generally, and specifically to the educational psychology of E.L. Thorndike. In the Thordikian theory of learning connectionism the most influential constructs were the law of effect and the revised law of exercise. The two constructs were to influence the later acceptance of both reinforcement theory and the cybernetic concept of the feedback control system, respectively.

The law of effect states that when a modifiable connection between a situation and a response is made and is accompanied or followed by a satisfying state of affairs, that connection's strength is increased; when made and accompanied or followed by an annoying state of affairs, its strength is decreased (Thorndike, 1913).

Thorndike's later development of the law of exercise emphazises the importance of knowledge of results in learning. The mere repetition of S-R connections does not facilitate the learning of that connection when there is no confirmation of the appropriateness of the response.

> Our question is whether the mere repetition of a situation in and of itself causes learning, and in particular whether the more frequent connections tend, just because they are frequent, to wax in strength at the expense of the less frequent. Our answer is no... ordinarily we reward certain of the connections leading from it and punish others by calling the responses to which they respectively lead right or wrong, or by otherwise favoring or thwarting them (Thorndike, 1932).

Thus Thorndike was to establish the theoretical foundations for a learning theory which was later to be adopted in some general form or another by the advocates and developers of automated and computer assisted instruction. The influence of these general principles would not only support the concept of auto-instructional devices, but as far as computer assisted instruction is concerned, it shaped the design of the symbolic programming languages constructed just for CAI.

Moving along the historical survey of relevant theorists one encounters Neal Miller (1941) who added another dimension to the stimulus-response reward continuum: motivation. First, the student must want something (motivation); secondly, there must be a cue, the student must notice something (stimulus); thirdly, the student must do something (response); and fourthly, the student must get something he wants (reward). It must be admitted at the outset that there are some very subtle and sometimes profound differences between some of the theorists I have mentioned. In fact the Thorndikian notion of "satisfying state of affairs", and Skinner's concept of 'reinforcement' are all highly discriminable from a pure learning theory point of view. However, since the main interest of this paper is concerned with their affect upon the technology of pedagogy (CAI), it is not necessary to discriminate among them.

The more recent developments in computer-assisted instructional devices have been most significantly affected by the writings of B.F. Skinner. In 1938 he presented his distinctions between Pavlovian and operant conditioning. In his own words "The law of (operant) conditioning... is... if the occurrence of an operant is followed by presentation of a reinforcing stimulus, the strength is increased" (Skinner, 1938). Skinner's analysis of instruction assumes that motivation must be present, that the student must make a response, and that this response needs to be "reinforced". The increased specificity of Skinner's suggestions center around the principle of stimulus control, or the ways in which reinforcement may be used to establish both more precise and more elaborate learning by manipulation of the stimuli impringing upon the learner. Modern developments in computer assisted instruction had been grounded in Skinner's operant conditioning theory of learning. The main impetus for the adoption of this model of learning has been the extensive experimentation with laboratory animals and the compilation of a large body of empirical data which support the theory of operant conditioning or what may be called reinforcement theory.

Operant conditioning is defined as a type of learning whereby the organism assumes an active and participative role in the learning situation. Operant conditioning is so arranged that the organism will not receive any reinforcement, reward, release from punishment, or escape from imprisonment until the organism emits the correct response. The reinforcement, therefore, is contigent upon the prior occurrence of the right response. (Skinner, 1938).

The two main constructs which permeate all learning tasks are the operant response and reinforcement. The operant response is instrumental in obtaining the reinforcement because reinforcement is provided only when the appropriate response is emitted by the subject.

When this theory is applied to actual pedagogical situations, the learning task is broken down into minute stimulus-response bonds. A question or problem is presented to the learner to which he is expected to give the appropriate answer. If the answer is correct, it is reinforced with some statement or signal of approval and the next question or problem is presented.

A great deal of the rationale for accepting an operant conditioning paradigm as a model for human learning has been the accumulation of a wealth of scientific data which has been derived from learning experiments with infrahuman subjects. A substantial amount of information is known about the amount, speed, latency, and extinction of learned responses. Likewise, a substantial amount of data has been compiled with respect to extinction, generalization, and discrimination in learning as well as the effects of varying conditions of motivation and emotion on the learning process.

The use of animals in the accumulation of scientific data on learning is not without due rationale. The utilization of subjects whose genetic, environmental, social, and nutritive history can be controlled and, if need be, systematically varied, yields an experimental purity which cannot be paralleled on a human level.

In the realm of human experimentation, the attempt to achieve a similar purity in experimental design has resulted in the extensive use of paired-associate paradigms and nonsense syllables. The use of experimental controls has been exploited beautifully. Also, much of what is advanced about the efficacy of feedback, knowledge of results, reinforcement, and the like has been promulagated from human experimentation with non-verbal learning tasks such as maze learning and line drawing.

The Rationale for CAI

It has been proposed that it would be advantageous to learning and retention to require the student to respond to questions or problems by some overt act--writing, typing, pressing a button, speaking, pressing a key. Likewise, the student is provided with an immediate feedback to determine whether or not the given response was correct. It is proposed that such a process of overt responding, feedback, and reinforcement for correct responses would result in maintaining the alertness and manipulatory activity of the student and produce a thorough understanding of each question and answer set before moving to the next one. All of the above coupled with the short-frame and small-step-size approach of programming learning materials were expected to facilitate the instructional mission of the educational system.

Further Theroetical Implications

The adoption of the Skinnerian theory of operant learning, specifically, and the incorporation of a neo-behaviorist orientation, generally, also carried with them theoretical attitudes towards the nature of mental growth and mental structure. For example, all learning tasks were considered variations upon a universal learning paradigm. That is, human learning of all types is entirely an associative process- a quantitative compilations of S-R bonds with an interrated network. The individual's mental structure is the reflection of environmental intrusions upon his mental blank slate.

The Popular History of Computer Assisted Instruction

While the theoretical history was founded in the behaviorist tradition generally, and in Thorndikian connectionism, specifically (namely the law of effect and the law of exercise), the popular history of computer assisted instruction was founded in the psychometric tradition, generally, and in the need for efficient means of administering, scoring, and providing feedback from psychological tests, specifically. It might also be added that the psychometric movement in this country was also tremendously influenced by Thorndike who made such statements as: "Whatever exists at all exist in some amount. To know it thoroughly involves knowing its quantity as well as its quality" (Thorndike, 1932).

The first introduction of mechanical devices is attributed to S.L. Pressey (1927). Pressey's machines were introduced for the purpose of test administration and scoring. They were automatic testing devices which looked pretty much like the learning drum apparatuses in undergraduate experimental psychology laboratories. The machines later became more attractive in order to increase their instructive potential.

J.C. Peterson (1931) introduced another form of automated testing tools in the form of chemically treated answer sheets which provided self scoring and immediate feedback by changing color when marked by the student.

In the middle and late fifties, Skinner introduced his machines which were similar in concept to Pressey's machines; however, Skinner's machines allowed a little more flexibility in the presentation and path followed through the materials.

After Skinner introduced his devices and concepts and tock somewhat of an active role in the promotion and marketing of these devices, there was a flurry of activity to develop bigger and better teaching machines. There was an increased sophistication in the learning tasks to which the machines were adapted. Probably the best examples of sophisticated teaching machines were not to be found in the classroom of American schools, but in the training schools of the United States armed forces.

To sum up this brief discussion of the popular history of CAI, one immediately notes that Skinner was the principal proponent of this technologically oriented, pedagogical technique.

Some recent CAI projects which have utilized principles of learning in their formulations will be discussed next.

Atkinson (1967) during a workshop conference on "Computers and Education" at the University of California discussed the properties of computer based instruction. One of the advantages that is always listed for computer-based instruction is the possibility for individualized instruction. Educators today are realizing that developments in society make it increasingly more important to individualize the instructional process, and that the only hope for individualization comes within the framework of computer-assisted instruction. Furthermore, individualizing the instructional process is considered the optimal way of carrying out instruction, that is, school learning.

Atkinson distinguished between two concepts of optimality. One was what he called short-term optimization and the other, long term optimization. Most CAI programs have tried to use the notion of short term optimization. That is, these programs take advantage of current information and then try to branch or modify the instruction routine as a function of that short term information. For example, the program analyzes the type of response the subject makes; if it is an error response, the program analyzes the nature of the error and tries to give remedial instruction which is appropriate for that type of error.

In long-term optimization one utilizes the entire history of a given individual in order to make decisions about what should be done next. Atkinson clarifies history by qualifying it to"sufficient history". The history may be regarded as an estimate of the student's state of learning. One of the problems in CAI is utilizing the potential for long-term optimization and coming to some understanding of how one uses this history to define a sufficient history and optimize the learning process.

In order to understand short and long term optimization, consider the Stanford CAI Project in reading (1966). The reading curriculum for the CAI system was developed by a writing team composed of two psychologists, a linguist, two reading specialists and several teachers. The materials produced by the group have been developed within the framework of a set of theoretical propositions based on recent developments in psycho-linguistics and learning theory.

The reading curriculum incorporates a wide array of screening and sequencing procedures designed to optimize learning. These optimization schemes can be classified into either short-term or long-term procedures.

As an example of a short-term optimization procedure, let's look at one that follows directly from a learning theoretic analysis of the reading task involved. Suppose the child has to learn a list of "m" words. In essence, the problem involves a series of discrete trials where on each trail the word being taught is presented with two other words. The student makes a response from among these words and the trial is terminated by telling him the correct answer. If N trials are allocated for this instruction, how should they be used to maximize the amount of learning? If it is assumed that the learning process for this task involves the one-element model of stimulus sampling theory (Estes, 1959), then the optimal strategy is initiated by presenting the "m" items in any order on the first N trials and a continuation of this strategy is optimal if and only if it conforms to the following rules:

1. For every item, set the count at 0 at the beginning of trial N+1.

2. Present an item at a given trial if and only if its count is <u>least</u> among the counts for all items at the beginning of the trail.

3. Following a trial, increase the count for the presented item by 1 if the response was correct but set it at 0 if the response was incorrect.

In some cases these optimization schemes ca. be derived directly from learning theory, whereas others are not tied to theoretical considerations but are based on intiutive considerations. The long-term optimization procedures of Atkinson's reading curriculum are consistent with the latter considerations, and therefore they will not be discussed here.

Smallwood (1970) describes a technique that involved a very small amount of computation time for implementing truly optimal decision policies in a computer-directed teaching system.

These results are applicable to a very large class of models for human learning. In designing decision logic or branching logic into a CAI system, one can take into account the available past history of the student in some meaningful way in order to influence the future course of the student's instruction. In other words the computers role as a decision maker, selecting alternative items to create an optimal pathway for individualized learning, is a demanding part of Smallwood's proposed optimization procedures. Smallwood derives formulas based on mathematical learning models (Atkinson, et al, 1967) and the two-state all-or-none learning model (Groen and Atkinson, 1966). He uses transition probabilities and response probabilities which are uniquely associated with the student's internal states of knowledge and with the particular alternatives for presentation.

The sequence of events in Smallwood's formulation is thusly:

1. Some instructional materials are presented to the student;
2. After or during the presentation, a test is administered;
3. The student responds at his own rate;
4. The computer evaluates the response, provides feedback, and performs the decision-making act. The outcome of the decision is the selection of the next item or instructional alternative.

Smallwood's proposal to use learning models along with the description of past histories in terms of the internal states of the learner seems to be a useful method of optimizing learning through CAI.

Fishman et al (1969) were interested in finding the optimum procedures for distributing instructional material in computer-based spelling drills. The preponderance of experimental evidence indicated that, for the same amount of practice, learning is better when practice is distributed rather than massed. The authors were attempting to investigate the validity of the above axiom. They found that the massed condition is superior to the distributed condition if one looks at short-term performance, but in the long run more learning occurs when repetitions of an item are well distributed.

The data of the learning of the spelling words in this experiment can be analyzed in terms of a model that has been proposed to account for paired [illegible] learning, since there are variables in paired-associate learning that clearly are relevant to the spelling task. The model is a variation of the trial-dependent-forgetting model presented in articles by Atkinson and Crothers (1964) and Calfee and Atkinson (1965).

In this model the subject is assumed to be in one of three learning states with respect to a stimulus item: (a) state U is an unlearned state, in which the subject responds at random from the set of response alternatives, (b) state S is a short-term memory state, and (c) state L is a long-term state. The subject will always give a correct response to an item if it is in either state S or state L; however, it is possible for an item in state S to be forgotten, that is, to return to state U, whereas once an item moves to state L it is learned in the sense that it will remain in state L for the remainder of the experiment. (Fishman et al, 1969).

In this model, forgetting involves a return from the short-term memory state S, to the state U, and the probability of this return is postulated to be a function of the time interval between successive presentations of an item.

Two types of events are assumed to produce transitions from one state to another: (a) the occurrence of a reinforcement, that is, the paired presentation of the stimulus item together with the correct response, and (b) the occurrence of a time interval between successive presentations of a particular item.

The authors suggest that there is a need to generalize the paired-associate model to take account of the linguistic constraints imposed by the CAI spelling task. Such a model would provide a more definitive answer to the problem of optimizing the instructional sequence in spelling drills.

A Developmental Approach Toward Optimizing CAI

In the past, the theoretical and empirical work in computer assisted instruction has been the sole property of the behaviorists. The cognitivists, the advocates of a mental growth approach to psychological theory, have contented themselves with supplying verbal chastisements from the sidelines. The result is that there has been no serious attempt to relate developmental principles of cognitive growth to the pedagogical development of computer assisted instruction. The task here is then to briefly suggest how the developmental concepts of cognitive structure might influence educational practice in the utilization of computer assisted instruction. (Ausubel, 1968).

Advocates of computer assisted instruction have neglected relevant developmental factors in the learning process. All types of learning, in all situations, for all age levels are viewed as variations upon a universal theme. However, general developmental theories, such as those proposed by Piaget (1936) and D.P. Ausubel (1968), have pointed up important developmental variations in the areas of perception, objectivity-subjectivity, the structure of ideas, and the nature of the thinking process itself.

The advocates of computer assisted instruction have very loudly proclaimed the advantages of immediate feedback (Skinner, 1961), the necessity of making an overt demonstable response to the stimulus event, the particularization of S-R bonds, and the direct tangible experience the learner has with the learning materials (Suppes, 1966). This may very well be necessary and advantageous for learners who are not developmentally advanced. But, if we are to extrapolate from the development theorists, we must acknowledge the fact that as age increases the world is perceived more in general, abstract, and categorical terms and less in tangible, time-bound, and particularized contexts (Piaget, 1958). There is an increase in the ability to comprehend and manipulate abstract verbal symbols and relationships without the benefit of direct, tangible experience, concrete imagery, and empirical experience with particularized instances of a concept. So it seems that the promotion of CAI in its present form for all learners of all age levels is more of a regression to earlier modes of conceptualization, thinking, and perceiving the world.

Cognitive Structure and the Concept of Progressive Differentiation

The typical practice of curriculum specialists who program the learning materials for CAI is to organize the learning materials into topically homogeneous units (chapters and subchapters), (Ausubel, 1968). The resulting organization, as D.P. Ausubel observes, is accomplished without regard to the hierarchical relatedness of those units on an abstract level. Thus each unit is treated as if it enjoys an equivalent status within the learner's cognitive structure. But, this follows directly from the behaviorists view of mental structure--an interrelated associative network.

A cognitivist's view of mental structure, however, first subscribes to the orthogenetic principle, that mental growth proceeds from an amorphous, unidifferentiated, globality to a more highly integrated and particularized hierarchy through a process of progressive differentiation (Ausubel, 1968). The learner's organization of the material of a given subject consists of a hierarchic structure in which the most inclusive concepts occupy a position at the apex of the structure and progressively organize the more highly differentiated ideas and particularized data (Ausubel, 1968). This view is inconsistent with the normal practice in the programming of learning materials for CAI which actually promotes a rote learning approach to memorizing formulas, procedural steps, type problems, and the mechanical manipulation of symbols.

Prospects for CAI

The highly complex logistical task of assessing the individual learner's current performance, attained developmental level, presently available concepts, differential aptitudes and abilities, and cognitive style is rendered more manageable with the assistance of CAI. Acknowledging individual differences in attained developmental levels, following

following a cognitivist theory of the structure of thought, and applying developmental concepts to the microgenesis of verbal abilities, CAI can facilitate the pinpointing of the individual learner's level of mastery and gear the subsequent curriculum accordingly. As a result, when these learning principles, especially those of the cognitive-developmental theorists, are applied to CAI, this technological, pedagocial technique will indeed become a more potent instructional device.

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