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AUTHOR Starkweather, John A.
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ABSTRACT

With emphasis on man-machine relationships and on machine evolution, computer-assisted instruction (CAI) is examined in this paper. The discussion includes the background of machine assistance to learning, the current status of CAI, directions of development, the development of criteria for successful instruction, meeting the needs of users, requirements for a computer system to handle conversational interaction, feedback and adaptation of machine systems, the choice of man or machine for educational tasks, and the likely results of increased machine intelligence on instruction. (SP)

Adaptive Machine Aids to Learning

by John A. Starkweather *

Instructional technology is a topic which includes consideration of a wide array of devices developed as aids to learning. Some of these, most notably those which make use of computers, have the capacity to interact with their users. They may make use of feedback information to adapt to the user's needs and to improve their future performance. It is with this emphasis on man-machine relationships and on machine evolution that I address the question: "What is the outlook for the development and application of cybernetics in instructional technology?"

In comparison with man's evolution, the presently observable rate of change of machine capability is many times faster. We must assume that there will continue to be a rapid reduction in size and cost of computers, for example, while at the same time they increase in speed, reliability, and functional capability. It seems possible that machines will become self-sustaining, with self-regulated growth, automatic repair, and reproduction of further related machines. A machine system will make use of information about the needs of its users to regulate its functioning in a self-adaptive manner. Computers and their related

* John A. Starkweather is director of the Office of Information Systems, San Francisco Medical Center, University of California.

end-organs and communication devices will in turn become simulated counselors, mathematicians, clerks, designers, reference librarians, tutors, etc. as the specific need for assistance changes.

The background of machine assistance to learning.

The present level of interest in programmed instruction and automated teaching received its major impetus from a paper by B. F. Skinner in 1954 (Skinner, 1954), although Pressey had been attempting to arouse interest in the field since the 1920's (Pressey, S.S., 1926, 1950). At a symposium in 1958, Rath, Andersen, and Brainerd reported work done by them at the IBM Corporation Watson Research Center in which a digital computer was used not as a teaching device itself, but as a means of simulating teaching machines (Rath et al, 1959). They felt at the time that the idea of putting a student in direct contact with a computer was economically unsound. Only a year later Lumsdaine, in referring to their work said, "This may seem like a fantastic degree of instrumentation, but it actually has practical possibilities for future development." (Lumsdaine, 1960).

Work did continue towards relating the computer to teaching not only at IBM, but at such places as Bolt Beranek and Newman and Systems Development Corp. At the University of Illinois, Bitzer and Alpert began designing learning stations which linked the student or curriculum author with the computer. In 1961 a conference on computers and education was sponsored by Systems Development Corp. and the Office of Naval Research. Zinn (1968) counted 11 curriculum packages finished or underway at the time of the conference.

Today, with developments in computer design and construction and in systems programming, there has been a great amount of work both in this country and abroad in this field which has come to be called "Computer-assisted Instruction" (CAI). A recent survey (Hickey, Newton, 1967) listed 240 publications concerning

CAI that had appeared between 1959 and 1967, and identified 20 major centers in the United States where large digital computers were dedicated for instructional systems.

Ten years back, when the ideas for computer teaching were first materializing, placing a student in real-time communication with a large scale computer for purposes of learning was thought wildly unfeasible on economic grounds. Now the hardware exists to accomplish this relationship at a cost no greater than that of an individual tutor. Ten years from now, it seems safe to predict, the cost of providing computer-assisted instruction will be no greater than the cost of instruction in classes of ten or less.

This optimism is reflected in the August 1, 1968 issue of Forbes magazine, its reporter claims CAI will become big business, bigger in fact than textiles, rubber, or paper. He notes: "...But the sharpest rate of gain (in educational expenditures) is almost certainly going to be in spending for machines and programs to enable teachers to teach more effectively and efficiently. At present, total spending in this area is only about $2 billion a year, most of it in textbooks. That $2 billion could easily swell to $10 billion within the next six years, with old-fashioned textbooks getting a smaller and smaller proportion."

A number of writers have noted that tomorrow's education will become less and less a matter of imparting facts to be learned and it will more and more involve teaching the skills of inquiry and problem solving. To do this we must have ways to give the student practice in inquiry and in problem solving and we must have ways to give him greater initiative in the teaching and learning process. Three potential characteristics of computer-based systems will be particularly relevant in providing greater control to the student. These are: a.) the capacity to analyze and respond to relatively unconstrained input from the student; b.) rapid access to extensive capabilities for information storage and retrieval, graphic displays, mathematical analyses and transformations; c.) potentially unlimited competence in the field of instruction by access to the collected insight, experience, and creativity of large numbers of teachers.

As we delve deeper for the potentials of CAI, it will be increasingly useful to look at the teaching-learning process. This process involves the presentation to a student of the material to be learned, the evoking of an active participation by the student in response to this presented material, the evaluation of the student's response, a decision on the part of the teacher as to what material should be presented next, and finally, in good teaching, an evaluation of the teaching process and modification of the whole scheme in light of the outcomes attained. This process may be represented briefly as a seven-stage process:

1) Initial presentation.
2) Student response.
3) Evaluation of response.
4) Modified presentation.
5) Collection of outcome data.
6) Analysis of outcome data.
7) Modification of the teaching program.

We can evaluate each of the common teaching techniques in each phase of the teaching-learning situation. The devices we shall consider are: books, lectures, non-computerized teaching machines, individual tutorial relations with a live instructor, and computer-assisted instruction. Chart 1 presents a summary comparison of the various phases of the teaching-learning process. If ranks (the numbers in parentheses) are assigned in terms of relative merit at handling each phase and summed over seven phases, computer-assisted instruction appears to have an advantage over the next best method, tutorial or seminar presentation. Of course, this result is achieved only by introducing functions that the tutorial method has not traditionally attended to in an explicit way. Variations in weighting the different phases could alter this conclusion, but the potential advantages of computer-assisted instruction are sufficient to warrant considerable efforts at exploration.

Chart 1

	TEACHING METHOD				
	Books	Lecture	Tutorial or small group	Noncomputerized programmed instruction	Computer-Assisted learning
1. Initial Presentation	Efficient maybe elegant (1)	Efficient may e elegant (2)	Costly, maybe elegant (3)	Inefficient, few elegant examples (4)	Potentially as efficient and elegant as books & lectures since they may be used (1.5)
2. Student response	Un-programmed (4)	Un-programmed (4)	Optimal, but subject to un-programmed variations (1)	Limited (3)	Minimum limitations (2)
3. Evaluation of student response	None (5)	Limited to gross evaluation (restlessness, sleeping) (4)	Limited only by teachers ability to divide attention (1)	Linear programs, student compares his response with answer(s) given; branching programs, some flexibility (3)	Substantial flexibility (2)
4. Modified presentation possible to accommodate individual student needs	No (4)	No (4)	Can be modified (1)	Linear programs, "tracking"; Branching programs, some modification (3)	Can be modified (2)
5. Collection of outcome data	Tests only (4)	Tests only (4)	Tests, teacher's memory of participation (3)	Recording of responses on paper (2)	Recording of responses in computer compatible form (1)
6. Analysis of outcome data	Typically, test statistics may be compared with those from other years, other courses, other schools (3)	(3)	(3)	Typically item statistics examined frequently during development. (2)	On line analysis possible (1)
7. Re-design of teaching	Select different book or revise (5)	Revise lectures for next year, or next week (4)	Intuitive changes in course design. (3)	Revise program frames where difficulties have been pinpointed (2)	On line modifications could be built into system. Students can be prompted to "challenge" the program in order to improve it. (1)
Sum of ranks	26	25	15	19	10.5

Chart 1

Current status.

Computer-assisted instruction is suffering some ill effects in reputation as a result of the overpromotion which occurred with programmed instruction (booklets, multiple-choice filmstrips, branching books, etc.) in the last few years. For example, a former principal of a school where many new methods were tried, recently wrote that "...programmed learning has been oversold, overrated, overpriced and underproductive." (Meyer, 1968). As a result of early predictions that programmed learning would offer individualized instruction for those with different abilities and match or exceed the efficiency of teachers, almost a third of all secondary schools now use some form of programmed instruction. These materials were promoted, however, long before carefully developed programs were designed. Individualized instruction was usually sacrificed to a standard instructional sequence and to the use of standard, centrally produced materials. The mismatch of materials and students has led to complaints of boredom and frustration by students, and the materials have not been built with internal mechanisms capable of response to such problems.

Computer assistance to learning, or computer-assisted instruction, is presently suffering from some similar problems. The methods of program development are cumbersome and still costly in relation to other learning aids. The programs do not handle free conversational interaction as easily as responses which are rigidly formatted as true-false or multiple-choice. Once the programs are specified, they are not easily changed to fit local needs. Most examples of computer instruction in present use are therefore characterized by multiple-choice responses which engage a student in drill of basic skills. Such operation is not a great advance beyond a programmed instruction booklet, though the computer can be used to collect automatically a great deal of information about individual student progress and to analyze it for secondary data on program efficiency.

A book of readings on computer-assisted instruction is currently in press, to be published by Academic Press in the first half of 1969. The editors, R. Atkinson and H. Wilson, have included a paper of their own which is probably the most extensive study to date of student progress as seen in automatically collected data.

Directions of development.

The development of methods of interaction with computers which are more global, more problem-centered and more human-like is coupled with the development of remotely connected terminal hardware or separate small computers. The combined effect is to make more likely the personal use of the computer, perhaps in some ways like we make personal use of the automobile. Orr (1968, preface) describes an imaginary development of the internal-combustion engine as if it had been developed in a way analogous to what is happening with computers. He imagines that transportation methods remained very primitive until about 1944. Then, as part of wartime needs, someone invented the internal-combustion engine and hitched it to a huge trailer to carry big guns for the Army. Engineers then began to use it for heavy laboratory equipment. Next business developed uses for it, perhaps about 1953, and highways, service stations, and related facilities were built. The technology then rapidly improved to the point that it became practical to provide individual transportation. Quite aside from the mixed blessing represented by the personal automobile, its assimilation on this kind of timetable would have produced a good deal of cultural shock, perhaps similar to what we will experience with the computer. Like the automobile, computer systems used for aids to learning will not require that the user know very much of what goes on "under the hood."

To carry the analogy a step farther, we seem to put up with many disadvantages of the automobile, mostly physical problems, because it offers a measure of personal autonomy, freedom, and mobility. We can feel that we drive the machine rather than the reverse. As we develop a personal relationship with an adaptive computer assistant, we may be able to have similar feelings about it. While past frontiers for man have been physical ones, and our heritage has emphasized values of independence and individual initiative in overcoming them, the new frontier for man has to be seen in the area of intellectual rather than physical effort. Man's initiative will be applied to adaptation to increasingly complex technology, a pretty good description of the challenge facing education in general.

Can educational technology assist in meeting the educational challenge which is largely the result of technology? Those who work in technological areas and who face the need for constant learning of new skills, techniques, and knowledge are those most likely to answer positively. During the same time that employment figures for scientists, engineers, technicians, and science teachers has been growing at a rate more than three times that of the United States population, an engineer's knowledge has been estimated to be sufficient for only 50 percent effectiveness after between five to ten year post graduation. Unless an engineer continues to re-educate himself, he may find himself unemployable. Technology's rapid growth thus creates a direct need for continuing education. As we increase the amount of computer-aided thinking, we will increase the rate of technological growth, and also increase the demand for technically trained people, who, of course, use computer-aided thinking. They are most likely to seek their education by similar means. A report by The Commission on College Physics (1965) serves as an example.

It appears that computer-based access to self-assessment as well as instructional material has particular usefullness at the continuing education level. Areas of weakness or gaps in knowledge are likely to be individually different, and a professional who is already at work may be much more comfortable in exploring his own competence in private than in public. At other levels of education as well, an especially effective use of computer assistance will likely be through the development of short programs which will be used as the student needs them and chooses them to fill discovered gaps in knowledge. It is one way that education may become more flexible and responsive to the needs of students. It is also a way that education will find many more "students" in the general public than are now apparent.

The mass market of the general public provides a potentially huge spectrum of possibilities and problems. The public has a tremendous appetite for learning and has a clear need for easy access to increasing amounts of information. The availability of television receivers is so widespread that it seems most likely that public access to information technology in the future will develop with some relationship to television. Information of special interest to the viewer is of course currently a matter of station scheduling and a viewer's ability to match that schedule. Even modest attempts to involve television viewers, such as the self-administered testing used in the nation-wide driver tests during 1967 and 1968, seemed to increase the television viewer's motivation and his ability to learn the material. While there is undoubtedly a motivational aspect to live television there will be considerable advantages to the viewer-learner with the advent of easily handled videotape cartridges which he can schedule to meet his own needs. If this technology further develops without undue expense to allow fairly rapid random access to different portions of such videotape material, the more individual aspects of computer-assisted instruction then become possible.

The development of criteria.

Anyone who sets out to improve instructional methods soon realizes that objectives and criteria for successful instruction are seldom specified in sufficiently specific terms that they can be useful for measurement and evaluation of the instructional process. When the process is an experimental one, such as various means by which the computer is involved in learning and instruction, a specific listing of objectives and criteria of performance is especially valuable. Such information can be fed back to a program author who may be in a position to compare more than one method of persentation of the curriculum materials. If the criteria are sufficiently objective and measureable then statistical techniques such as discriminant function analysis or factor analysis may be used to discover which items of input are especially relevant to the outcome. Such measures are also of course necessary to make comparisons of methods which have different costs, and to develop a relationship between costs and outcomes.

A good case can be made for the belief that instructional objectives should be stated in terms of observable behavior that can be expected from a student at the completion of the sequence. During the course of learning, a student should be in a position to practice the behavior which he is trying to master. This may seem to be a platitude, but medical students for example, are too often asked to give a list of signs and symptoms associated with a disease, and get less practice in attempting to solve a diagnostic problem on the basis of presented symptoms. Interactive instruction can allow a student to practice behavior which is closer to his eventual goal.

Meeting the needs of users.

Corrective feedback can be a powerful mechanism in the control of any dynamic process and an especially valuable one in the development of new procedures which cannot be completely predicted in advance to their operation. In developing a programmed interaction between man and machine we must be particularly cautious in settling on a method which seems to work well in one instance. A change in context and setting seems to have a powerful effect on such interaction, and sometimes with disruptive results. This concern can be addressed by arranging for such systems of man-machine interaction to have a mechanism by which the user can record comments about its handling of his responses or comment on its occasional malfunction. Such comments should be put to use as rapidly as possible with a resulting improvement in succeeding interactions. A developer of such systems should leave matters of curriculum content in the hands of professionals in the specific subject matter area, but he should provide them with methods by which they can receive corrective feedback information from students who face the material and with methods which make it easy for them to review such feedback and take corrective action. It is possible and usual for human instructors to make use of centrally produced standard text books and other curriculum aids and it is possible for them to interpret such materials in a specific local context and assist the student to understand them. It is exceedingly difficult, and it seems to me impossible, for computer programs in their present stage of development to accomplish this same task. We should therefore not expect to produce centralized standard curriculum materials for computer presentation except in very basic areas of routine drill. We may produce examples and a point of departure for the local instructor by providing centrally-produced materials. He should be in a position, however, to test these materials and modify them easily to meet the needs of local context and local customs.

An interesting variety of this problem occurs in arranging for a computer program to recognize and "understand" the language produced by a student or other user in a conversational situation. We may assume that the author of such a program will have such versatile mechanisms at hand. Even so, he cannot predict the entire range of possible responses to a question which does not severely limit the format of the reply. If the situation is such that the author can expect feedback from test subjects who face his program, then it is sufficient for him to write only an initial skeleton which he expects will fail on first attempts. Information from the user will then let him quickly add other elements of recognition so that the program rapidly improves.

One can imagine improving this process in a way which might make program development much less painful form the author's standpoint. Future versions of an author language might have provision for an active monitor or proctor terminal where an author-instructor would sit and converse with a student who sits at a separate terminal. It is conceivable that a program could be written to not only record appropriate protions of this interaction but also abstract, from the spontaneous return from the author, elements necessary for the construction of automatic replies. On successive runs with new students the program would first attempt to recognize the student's reply by virtue of these previously recorded elements and in the event of failure indicate at the monitor terminal that the author should insert a new human response. An iterative process of this sort might result in the building of a functioning program which would progressively handle more and more responses. Before long the author could step aside from the process.

If a program were to be transplanted and used in a context where the language characteristics of students were different from its original location, then a similar process would have to be undertaken in order to bring the program into line with the new setting. For example, it is clear that the language background of students in central city schools is likely to be quite different from those found in suburban districts. A computer program which recognizes the language in one setting will quite likely fail in the other. The required process of translation for such a program may result in new knowledge about language habits in the two environments. In any case, the program should be readable and easily modified by someone who is on the scene in the new setting.

Requirements for a computer system to handle conversational interaction.

The preceeding discussion suggests that a language for writing conversational interaction, built to recognize appropriate elements of naturally occuring language, should have a high level of readability and editing methods which make it as easy as possible for a person who has curriculum concerns at the local level to make changes in the program to meet local needs. He should have a means to record comments about its operation from students and users and make use of these to change and improve the program. It would be especially valuable for the system to have a subset of mechanisms for simple operation and easy entry to its use. With such mechanisms, a local teacher or a curriculum coordinator could make use of the language with little effort. We expect that the system should itself instruct new users in learning the basic aspects and initial operation that would be necessary. The system should be capable of handling and storing text in a very flexible fashion and at the same time should make use of rapid recognition methods in tracking the meaning of responses from subjects. Basic recognition methods should be sufficiently rapid so that the pace of conversational interaction is not badly distorted. While it should be possible to designate a specific sequence of program responses to subjects, there also exists a need for a random choice mechanisms so that an author can call on a varied output. Future systems should probably have the development of adaptive mechanisms to improve their responses as a result of increased experience with many subjects.

PILOT is a language being developed for the recognition of conversational interaction and for the control of computer programs by means of such interaction (Starkweather, 1968). It is initially being used for the development of demonstration instructional programs, simulated diagnostic interviews and specialized inquiry systems. It is also being explored for its usefulness in assisting a remote user of the computer to avoid the complexities of job control language or the control statements required for operation of prepackaged statistical programs. We also expect to explore a variety of terminal devices and the possible interaction of PILOT as a communication link to many other programs useful to a variety of people who need computer services.

As executive monitors for time sharing systems become more elaborate they tend to develop rudimentary language facilities to allow easier interaction with their users. Our approach is from the opposite side, to build upon our history of developments since 1962 in constructing a programming system which is flexible in the handling of language recognition problems. PILOT is now adding control functions so that the system can aid users in gaining access to other programs and computer facilities which now require cumbersome coding and knowledge of computer complexity. Our future goal is an ability to handle the problem of a naive user who makes a request for computer assistance, perhaps one of an arithmetic nature or perhaps an information retrieval request from a remote point. If he does not know the appropriate coding for obtaining the use of a program necessary for his purpose the computer will be capable, via PILOT, of understanding his request and teaching him what he needs to know to accomplish his purpose.

Feedback and adaptation of machine systems.

Mechanisms described in the previous section suggest that means can be provided to program an instructional sequence so that feedback and appropriate reinforcement to a student may be immediate and progressively more accurate. A somewhat less immediate feedback has been arranged for improvement of the program itself but it was not imagined that this feedback circuit could be made automatic and self-correcting. I have no doubt, however, that self-regulatory machines will eventually be capable of this kind of self-improvement. Wiener (1948) and Ashby (1960) described a variety of systems operating under different forms of feedback control, and more recently Miller (1965, a,b,c) has worked out an organized terminology for systems which he has applied across a wide range of system levels. These are attempts to abstract general principles about feedback and cybernetic devices. The use of feedback implies a measureable criterion, always a difficult matter to specify for instructional efforts. Criteria for instructional materials are often found to differ markedly between three involved people: the author of the materials, the teacher who hopes it will assist in his instructional endeavors, and the pupil who hopes it will aid him to learn something relevant to his needs. For each such person in the situation, we must consider some form of judgment and measurement of results to be necessary. Teachers have often been reluctant to have such criteria developed, because such specification implies the requirement that something measureable be produced by their activity. The schools have not often liked to be judged on measured results, and they have a valid point that such measurement is often misinterpreted.

J. R. Pierce (1968) has recently pointed out that increasing need to find means with which to assess educational technology has increased the urgency for developing methods of measurement for older methods of instruction.

> "Computerized instruction has raised a clear challenge in all of instruction. We cannot afford either poor teaching or expensive teaching. How good are various means of teaching and for whom? What do various options cost? For example, what are the objectives of a given textbook? Can a student with some specified preparation, intelligence or other measurable prerequisite reach the objectives by reading the textbook? Or must a teacher make up for deficiencies of the book or of its use? Such questions must be raised and answered concerning all courses and all modalities of instruction if we are to evaluate computerized instruction."

As has been pointed out in a recent review of papers on computer simulation and artificial intelligence (Hunt, 1968), there are very few programs which have been written to simulate directly the presumed mechanisms of human cognition. On the other hand, there have been a number of attempts to construct artificial intelligence systems to augment human intelligence, and while the programs are not psychological models, they may provide analyses of cognition which have implications for psychology and the understanding of human cognition. Fogel and his colleagues (1966) have developed a rather extensive system of programs which may be described as evolutionary machines. Such a machine is in the form of a computer program, thought of as a simulated and somewhat arbitrary logical organism. A supervisory program then initiates a random mutation of the existing organism, producing a number of offspring, that is, new simulated organisms with somewhat different properties from their parent. These offspring, acting as new machines, are observed (by the supervisory program) while reacting to the existing variables and their available history. They are each evaluated in terms of their individual ability to accomplish a given goal. The best of the offspring is selected to serve as the new parent, and such mutation and selection is continued to the point of some predetermined level of cost or the point at which a real-time decision is required. The authors hope that their method will open the door to self-programming of computers with methods which improve themselves. They would probably look upon adaptive instructional programs as a special case of this principle.

The choice of man or machine for educational tasks.

Whatever generalizations we make about the advantages of human authorship, human tutoring, and human review of student performance, or about the advantages of a machine doing any of these, there are likely to be special types of students who might benefit from one or the other. We usually expect that elementary school pupils will perform best in response to a human teacher, but our schools contain some youngsters who for a variety of reasons have given up trying to communicate with adults, particularly those who are in positions of authority. Their general suspicion of adults is coupled with a belief that teachers single them out for harsh treatment. I have watched seventh and eighth grade pupils with this kind of problem respond with remarkable motivation and interest to instructional material presented by machine. The machine seems to be seen as utterly impartial, communicative and yet unemotional. Colby (1968) has described some interesting and encourging effects of a computer-based method for aiding language development in nonspeaking mentally disturbed young children. These children reject the use of linguistic communication with people, but he hoped that they would find the computer keyboard and display to be more acceptable as a way to practice and play with language. Colby makes the point that disturbed children are not resistant to learning, but to being taught by people, particularly people who are inconsistent, or who become angry or bored in the course of communication. The computer, on the other hand, is patient, consistent, and unreactive to emotional display.

If the computer can be made truly adaptive to the special needs of individual users, and adaptive to the particular language habits which may make a pupil especially difficult for a human teacher, then it may have a decided advantage over the teacher for serving such a pupil. Landers (1966) suggests that the telephone appeals to many people because talking on the telephone is almost like talking to an intelligent machine. Two women who barely speak to each other when they meet on the street will spend hours doing so on the telephone. In this situation they need pay no attention to the other person's facial expression or gestures, and they are free to carry out minor tasks while listening. Landers believes that when conversation machines are developed, many people will prefer them as conversational partners to humans, particularly when the machines become "tunable" to one's personality.

It appears to me that when the machines have reached this stage of development, then they will no longer necessarily serve us very well as a first step in talking to those who we hope will move on to communicate better with other people. Such pupils may not have any desire to talk with difficult and variable humans after developing a satisfying relationship with such a paragon machine. It will clearly become trustworthy, loyal, helpful, friendly, courteous, kind, obedient etc.

We have not yet reached this state of affairs, however, and man's greater variability is still linked with greater adaptiveness. The choice between using men or machines can perhaps be seen today in its most advanced stage in the space program. Man's adaptiveness to the unexpected has so far kept him an active participant. In the instructional arena, the computer will more and more become an intellectual partner for learning, but processes of feedback will work best for the human learner's advantage if he, in the role of teacher or pupil, is a part of the feedback loop.

It may be a particular advantage to use the computer to allow students to play the role of teacher or the author of instructional materials early in his career of learning. If the mechanisms of program authorship are sufficiently easy to handle, then even pupils in the early primary grades can benefit from writing the machine side of a conversation with their classmates. Such a program author should receive feedback information from the system and from the students, and be motivated to improve the program's operation. In an elementary school setting where I have seen pupils involved both as authors of computer-presented instruction and as responding students, the total interaction has appeared to prompt a refreshing spirit of self-directed inquiry and exploration of the subject matter. As automation continues to lead us to describe more of our future time as "leisure" rather than "work", then it will be helpful to foster attitudes about learning that will lead us to classify it as a leisure activity. Involvement of students with adaptable machine assistants to self-directed learning is likely to help in developing this attitude. Future students will learn to use the computer as an intellectual partner early, and it will be a great advantage throughout their lives.

Likely results of increased machine intelligence on instruction.

Major improvements of methods by which a computer system can better recognize the messages of a user, understand his requests and adapt itself to them, are required and can be expected. These improvements will be found in the area of human engineering, and do not require marked additions to computer technology.

Individualized instruction will be possible, and students who are poorly prepared in specific areas will be able to learn material which is required for advanced work. This will be possible where basic curriculum materials are matched to the local need and the local context. Instructors will find that their role has changed when the use of instructional technology is widespread. They will place more emphasis on a definition of goals and an accompanying development of criteria with which to measure student performance. It may be possible for schools to interchange their materials more directly and meaningfully, and it may be possible for teachers at different schools to collaborate in the development of course sequences better than they could produce independently. When the programming systems become truly adaptive in their ability to profit from new experinece with new students in a new setting, then the movement of materials from one school to another will result in steadily increasing value of the materials. Adaptive machines of the future will have a problem similar to that which men face today: how can they be secure while in the process of constant change, rather than secure while relying on fixed belief, knowledge, and procedures?

References.

1) Ashby, W.R. Design for a brain. New York: Wiley, 1960.

2) Colby, K.M. Computer-aided language development in nonspeaking children. Arch. Gen. Psychiat., 1968, 19, 641-651.

3) The Commission on College Physics. The computer in physics education. Report of a conference on the uses of the computer in undergraduate physics instruction. University of California, Irvine. November, 1965.

4) Forbes Magazine, August 1, 1968. Tools for Teaching. pp. 38-44.

5) Fogel, L.J., Owens, A.J., & Walsh, M.J. Artificial intelligence through simulated evolution. New York: John Wiley & Sons, 1966.

6) Hickey, Albert E. and Newton, John M. Computer-Assisted Instruction. A survey of the Literature. ENTELEK, Inc., Newburyport, Mass., 1967, 2nd edition.

7) Hunt, E. Computer simulation: Artificial intelligence studies and their relevance to psychology. Ann. Rev. Psychol., 1968, 14, 135-168.

8) Landers, R.R. Man's Place in the Dybosphere. Englewood Cliffs, N.J.: Prentice-Hall, 1966.

9) Lumsdaine, A.A. 1960. Teaching machines: an introductory overview. In Lumsdaine, A. and Glaser, R. (Eds.), Teaching Machines and Programmed Learning. National Education Association, Washington, D.C.

References con'd.

10) Meyer, J.A. Programmed learning: education's turkey? The Amer. Sch. Board J., 1968, V. 156, No. 4 (Oct.), 26-27.

11) Miller, J.G. Living Systems: Basic Concepts. Behavioral Science, 1965, 10, 193-237.

12) Miller, J.G. Living Systems: Structure and Process. Behavioral Science, 1965, 10, 337-379.

13) Miller, J.G. Living Systems: Cross-level hypotheses. Behavioral Science, 1965, 10, 380-411.

14) Orr, W.D. Conversational Computers. New York: John Wiley and Sons, 1968.

15) Pierce, J.R. What really works to help learning-- The Challenge of Computers to Education. Address to the American Educational Research Association. Feb. 9, 1968.

16) Pressey, S.L. A simple apparatus which gives tests and scores -- and teaches. School and Society, 1926, 23, No. 586 (March 20).

17) Pressey, S.L. 1950. Development and apparatus of devices providing immediate automatic scoring of objective tests and concomitant self-instruction. J. Psychol. 29: 417-47.

18) Rath, G.J., Andersen, N.S., and Brainerd, R.C. 1959. The IBM Research Center Teaching Machine Project. In Galanter, E.H. (Ed.), Automatic Teaching: The State of the Art. John Wiley & Sons, New York.

References Con'd.

19) Skinner, B.F. 1954. The science of learning and the art of teaching. Harvard Educ. Rev. 24: 86-97.

20) Starkweather, J.A. A common language for a variety of conversational programming needs. Paper presented at IEEE International Conference on Communications, Philadelphia, June, 1968.

21) Wiener, N. Cybernetics. New York: John Wiley & Sons, 1948.

22) Zinn, K. L. Instructional Uses of Interactive Computer Systems. Datamation: 1968, 14, 22-27 (September).