The First Generation of Computer-Assisted Instructional Systems: An Evaluative Review[1]

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INTRODUCTION After developing machines which could automatically teach drill material and administer and score tests, Pressey (81, 82, 83) argued that the advance of a science is dependent upon the technological improvements made in that science. His contributions to the "educational revolution" were not to be realized, however, until Skinner (98) cogently argued that mechanical means were necessary to arrange the "contingencies of reinforcement" which would allow a student to learn more rapidly and effectively than he could if he were under the unsystematic—and often aversive—reinforcement schedules of the classroom. This argument was attractive to psychologists and experimental educators because it offered the opportunity to apply the psychological principles of learning, derived from the laboratory, to the classroom.

[1] This investigation was completed while the author was supported by a Public Health Service Research Fellowship (5-F1-MH-21, 734-03) from the National Institute of Mental Health. Appreciation is expressed to Dean Harold E. Mitzel; Professors Kenneth H. Wodtke, William Rabinowitz, and Keith A. Hall; Dr. Walter Dick; Mr. Bobby R. Brown; Mr. John Hancock; and Mrs. Patricia K. Gentile for their thoughtful comments and suggestions.

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Families of compatible computers are being manufactured, giving greater possibilities for multiprocessing[6] of problems, allowing optimal employment of all parts of the computer. Nevertheless, certain needs are evident: (1) increased speed of input/output systems, (2) greater storage for time-sharing systems, and (3) better display systems (37). The first two needs do not yet directly concern CAI since present input-output speeds and storage space are more than adequate for the present instructional uses. Display systems and other input-output devices are, however, a current concern. Some of the devices presently in on-line use or as experimental prototypes for future use are the following:[7]

1. Visual Communication:
   a. Typewriters are used as input-output devices under computer control (e.g., to ask the student a question or to direct him to some reading material) or under student control (e.g., to answer the question).
   b. Film Projection Devices:
      (1) The Thompson Ramo Woolridge *Mentor* selects films on the basis of on-line responses, presents auditory and visual materials, and can score student responses automatically (17).
      (2) Displays may now be created on-line by superimposing symbols on a film-projected background to highlight certain aspects of the film. As film development time is shortened (it now takes 10-15 seconds), it will be possible to photograph new information and update a display almost immediately.
   c. Cathode ray tubes are the most adaptable visual displays for on-line usage and changing display material. Using a light pen held near a screen, one can draw curves (although the present capacity for handdrawn responses is limited) or indicate answers, which can then be evaluated by the computer by plotting coordinates. These devices are being developed in color, for three dimensional displays, and with image storage capabilities.
   d. Random access slides and films are also in popular use.

computer system for different problems (35). Time sharing, as we shall see, is the most frequently suggested method of reducing cost per student and increasing total system efficiency.

[6] Multiprocessing: simultaneous or parallel functional operations.

[7] For a further discussion of these devices, see (4[illegible]

2. Auditory Communication:
   Those who work daily with CAI consider auditory communication a (if not the) major unsolved technical problem. While random access tape recorders are in general use, they are not as efficient as workers would like. Thus, prototypes are being developed for speech generation and recognition. Two types of speech generation devices being developed are the following:
   a. Compiled speech, where the computer has random access memory of prerecorded words or phrases which are then arranged as output on the basis of a student's response (e.g., the computer could tell a student the formula of a chemical).
   b. Synthetic speech, where the computer uses a set of rules to convert stored speech sounds into meaningful speech patterns.

   Speech recognition is more difficult because the acoustic cues of verbal communication are not completely understood, and the receptor must be capable of adjusting to variations such as speaker intonation, loudness, rapidity, and length of the spoken phrase. Character readers, designed to convert words or numerals into a computer code without human intervention, are also becoming commercially available, while prototypes of equipment capable of scanning a page of ordinary type and coding it for the computer have been developed (8).

   Besides the response devices already discussed, such as the typewriter and light pen, a manipulation board for children has been developed. It is capable of providing information concerning the shape and orientation of blocks and other items on its surface.

   Finally, although the present generation of computers is fairly reliable in terms of repairs, computers must become more reliable for on-line operations where "down time" will be a nuisance in addition to being costly (8).

Computer Programming[8]

While much research needs to be done on most of these technical devices to make them practically feasible, most researchers would

[8] Although computer programming is really a semantic problem from the standpoint of communicating "meaning" between programmer and machine, it has been included under the technical problem here. The reason is that for most CAI programers, the semantic problem deals with instructional programs, and the computer programs which translate these instructional programs into machine language are technological givens.

agree that programming, not equipment improvement, is the major computer problem. Time sharing, multiprocessing, mass information retrieval, and storage allocation, to name a few, are systems concepts of today and tomorrow—and they are programming system concepts (10).

Increased capabilities of computer systems have led to problems in compiling and debugging large programs and in developing executive systems to control time-shared systems. Further progress in developing these systems "... will depend very much on the work of theoreticians, and several moves have been made in recent years towards establishing a theoretical basis for programming" (45, p. 204). One such attempt is Naur's (78) conception of programming as a *tool* which interacts with *people* and *problems* in a symmetric manner.

Instructional programming can make use of the computer's calculation powers. More useful, however, may be its learning and decision-making powers, especially in systems designed to adapt to individual differences and "learn" from this "teaching experience." More about these instructional systems will come later.

E SEMANTIC PROBLEM

Arbitrarily limiting the semantic problem to meaning conveyed by the instructional program may result in some confusion, despite the qualification in footnote 8. For example, Mrs. Aiko Hormann of System Development Corporation (SDC) is developing a computer system[9] called "Gaku" (a Japanese name for learning) which is capable of learning from a human tutor, who instructs it by presenting samples of problems previously solved, general information in the form of a lecture, and suggestions as to how to solve the problem. CAI is usually involved in having the computer-tutor teach human students. Both approaches involve the conveyance of desired meaning via instructional programs. The main difference perhaps is that in the former case the instructional program involves programming the computer with a set of explicit heuristics,[10] whereas in the latter case this is not required (presumably because the student already has a set of implicit heuristics which he can use). This distinction, however, may not be applicable in all cases (e.g., with experienced computers) and is not necessarily recommended. For the purposes of this paper, then, no distinction will be made although programs utilizing the computer as a tutor will be stressed.

It is a popular, although possibly optimistic, opinion that CAI "is limited only by the imagination of the programmers" (33, p. 52). Assuming that this statement refers to the goal of achieving optimum instructional efficiency, there may be definite limits imposed upon the instructor-authors' imaginations. For example, if many of the display devices discussed in the last section prove feasible—and probably every system now in operation includes at least a typewriter, some other visual display, such as slides or a cathode ray tube, and a tape recorder—there exists a distinct possibility that communication channels could be overcrowded, leading to error and confusion on the part of the student (121). Moreover, the conclusions of Travers (118, p. 3) suggest other avenues of investigation:

> First, no advantage seems to be achieved by transmitting redundant information simultaneously through both the auditory and the visual modality except where unusually high speeds of transmission are involved. These are speeds far in excess of those ordinarily encountered. Second, switching from the auditory channel to the visual, or the reverse, occupies time which appears to be wasted insofar as learning is concerned. Third, devices which have been used to draw attention to the information transmitted through one sense modality tend to depress the information received through another. Fourth, in broad terms, the data fit well a model of information processing similar to that of Broadbent, or of Feigenbaum and Simon, which portrays the information processing system in its final level as a single channel of limited capacity which can generally handle only information from one source at a time.

Consideration should also be given to the student-subject matter interface (48) to examine the display and response characteristics by which a student can interact most effectively with a given subject matter. That is, display and response modalities may interact with type of learning required, and determination of the optimum modalities for a given subject matter should be a high priority research topic. Other student-subject matter interactions may be found with age of the student; parameters of the learning process; individual or group instruction; competition or cooperation; and individual differences in aptitude, personality traits, or physical disabilities.

[9] "Gaku: A Computer System that Learns to Solve Problems by Experience." *Naval Research Reviews*, April 1965, pp. 15-16.

[10] Heuristics: techniques or strategies by means of which the individual can solve problems. They do not guarantee a solution [illegible]lgorithmic decision procedures do.

Individual Differences

Perhaps the most interesting advantage claimed for CAI is that instruction can be individualized.[11] Stolurow (31, 102, 103, 104, 105) has suggested the name "ideomorphic programing" for this approach which, in addition to using the student's last response, uses all other available past information as well to make a decision as to the next instructional frame or sequence of frames. As an example of what he means, Stolurow argues that someone high in arithmetic computation but lower in arithmetic reasoning could receive an *inductively* organized sequence of frames, while someone with the opposite arithmetic profile might be given a *deductively* organized sequence of frames. Or, if a student were high in aggression, he could receive "social reinforcers" which were suitable for that personality trait: he cites a study by Frase which showed that aggressive people like aggressive reinforcement such as the remark from the computer, "That was a stupid mistake" (104).

By no means is Stolurow alone in advocating branching decisions which adapt to individual differences. In a series of studies, SDC researchers found three response criteria to be important for branching decisions: (1) the specific answers given by a student to certain diagnostic items; (2) the student's cumulative error record over a series of frames; and (3) the student's own assessment of his level of understanding of the concepts covered (19, 27, 96). Bushnell (12) has suggested historical and personal measures such as IQ, sex, aptitudes, and reading rate in addition to response data; Mager and Clark (64) have suggested that branching decisions be applied in determining how much a student already knows in a given subject area, so that he can begin a program at the appropriate point; and Keislar (57) has considered the problem of step size in regard to individual differences. Smallwood (100) has modeled his system after two important properties of a human tutor—namely, adaptability to the student and systematic improvement with experience—pointing out, as was mentioned earlier, the importance of a computer-teacher which can "learn." In addition, Rigney (89) makes the distinction between remedial sequencing (where a student is sent into a remedial loop on the basis of performance on test frames) and predicted sequencing (where an attempt is made to predict from the subject's characteristics the best path for him to follow through the program).

While course authors' imaginations do not have to be limited when it comes to basing branching decisions and individual difference criteria, it would be highly desirable from the standpoint of future exchange of ideas and materials (131, 132) to have a standardized taxonomy of branching logic. This would allow comparisons of courses on the basis of their logical similarities rather than on the basis of their content (120), and would certainly facilitate the study of the effects of such branching logic.

Programing Educational Material

Professional instructional programers agree that only a few good frames can be written in a day, so that preparation of a two-hour lesson may take several months (95). To add to the problem of programing a lesson (with which subject matter the teacher is familiar), the problem of writing in a form acceptable to a computer (which form may be completely foreign to the teacher) is too much to ask. Hence, the search is on for compilers compatible with natural language (see, for example, [119]) so that programing can eventually be no more difficult than writing a book.[12]

At least three levels of computer language difficulty, in terms of the course author's needed facility with the language, are in existence today (129). At the lowest level of computer language difficulty are languages such as PLATO[13] (5), which require only that the author enter his text and rules for evaluating answers. The computer has been programmed to accept the text so that the author does not need to learn a computer language. IBM's Coursewriter language (65, 66) is an example of a second level, requiring the author to specify his pattern of instruction in a relatively simple language. At the highest level of sophistication, an author writes his own computer program for his instructional strategies. This allows him to use the full capability of the computer but necessitates a high level of competence in computer programming.

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Once the program has been completed and stored in the computer's memory,[14] it can be tested by submitting it to some students. Students' responses are permanently recorded (see, for example, [4]), and these data can be subjected to statistical treatments for evaluations of difficulty and clarity of the frames and for evaluations of student performance. The program thus serves as its own quality control mechanism as well as being a teaching device.

But what happens if the student's answer does not correspond with the given answer stored in the computer memory? In more primitive systems, the author had to anticipate all correct and incorrect answers and store them in the computer. This is no longer necessary. Misspelled words can be accommodated by partial answer processing, and computers are now evaluating answers for which the word sequence is indeterminate (101). Partial answer processing appears to be necessary not only for program elegance but also for student performance. As Wodtke's research indicates (as reported in [76]), when students' answers are correct but typed in a form unacceptable to the computer (i.e., that form of the answer has not been stored in the computer memory), students often try that same answer once or twice more just for good measure and then discard the original correct answer for an incorrect response. These incorrect responses, forced on students by a "rigid computer," then have a higher probability of appearing as answers in a posttest.

One other problem, which is partly technical and partly semantic, deserves attention—namely, that courses written in one programing language for a given computer system are presently restricted to that system. That is, a mathematics program written in language A for CAI system X cannot be used on CAI system Y, which uses language B, for some of the following reasons: (1) smaller memory storage capacities in system Y; (2) different auxiliary interface equipment in system Y; (3) incompatibility of language A with language B; and/or (4) unavailability in system Y of data on which branching decisions are based in system X. While between-system incompatibilities of this nature are at least expected, if not desired, there is also often a within-system incompatibility. The latter arises from technological improvements or the addition of interface equipment and results in course material which has to be revised in order to avoid obsolescence (see, for example, [63]). If CAI is ever to have an influence on education, courses will have to be compatible with many CAI systems so that good curricula can be used by anyone with adequate facilities. There will necessarily be a great and unnecessary duplication of effort if the courses developed on an IBM system are not able to be used on a Bendix system (or even another IBM system).

CURRENT CAI SYSTEMS

The discussion of the technical and semantic problems in CAI has been concerned thus far with a "straw machine," as it were. Actual CAI systems in operation or soon to be in operation remain to be mentioned before the effectiveness problem is examined.

An earlier draft of this paper (44) included summaries of several of the CAI facilities and their research programs. Since then, however, more extensive summaries of CAI systems have been published,[15] and the reader interested in specific details about any given system is referred to those papers.

The feasibility of using a computer as a teaching machine was probably first explored at IBM by Rath and others (88), who wrote a program to teach binary arithmetic. The present IBM system has the main computer located at Yorktown Heights, New York, while there are student-author terminals spread across the country connected to it by telephone lines.

[14] System Development Corporation's PLANIT (*Programming LANguage for Interactive Teaching*) language offers the possibility of immediate write-execute capabilities, so that the course author can compose lessons while sitting at the teletype. He does not have to wait for the program to be compiled and executed. (Personal communication from B. R[illegible]wn.)

[15] a. For summaries and comparisons of most of the CAI facilities across the country, see (133) and (13).

b. For a compilation of available courses, their grade levels, course length, authors, and other information, see (131, 132).

c. For a comparison of the computer programing languages used in the several CAI laboratories, see (51) and the summary of the Office of Naval Research's March 1966 Conference on CAI Languages (79).

d. For general reviews of CAI, see (33) or (108, 110).

e. For an overview of the entire spectrum of a computerized educational technology, see (49).

f. For research and development reports of some of the major (and older) facilities, the following should give an introduction:

(1) Bolt, Beranek and Newman: (38, 40, 114, 115, 117).
(2) International Business Machines: (65, 66, 88, 120).
(3) Pennsylvania State University: (72, 73, 74, 75, 76, 127).
(4) Stanford University: (50, 52, 53, 106, 107, 111, 113).
(5) System Development Corporation: (16, 23, 24, 25, 27, 36, 94, 96).
(6) University of Illinois, Coordinated Science Laboratory: (2, 4, 5, 6, 9, 34, 63).
(7) University of Illinois, Training Research Laboratory: (70, 71, 102, 103, 104, 105).
[illegible] University of Pittsburgh: (48, 86).

More generally, equipment at a student terminal ranges from a random-access slide projector and tape recorder (e.g., Penn State) to a projector which can display randomly accessible microfilmed pages of material, a cathode ray tube (oscilloscope), and a random-access audio system (e.g., Stanford).

There is one development underway at System Development Corporation which has the goal of improving the efficiency of an entire schoolroom. Their CLASS (Computer-Based Laboratory for Automated School Systems) project is an elaborate instructional area, in which up to 20 students (although it will not necessarily be limited to that number) can receive concurrent automated instruction. Each student has his own input-output facilities which, through time sharing of the computer, allows him to receive a unique sequence of materials and proceed at his own pace. Or any number of these students could receive group instruction through television, films, lectures, or textbook, but they could respond individually to any question asked of the group. A special teacher console in each classroom area would allow the teacher to check on each student's progress by having the computer turn on a warning light for any particular student when he was not meeting some criterion of performance. This would allow the teacher to give that student the personal attention he needs (23).

Programs have been developed to teach very young children to read via a "talking typewriter" (77, 80); to teach basic economic or legislative principles to elementary (122, 123) and secondary (7, 20) school students via simulated games; and to help medical students practice diagnoses (see the references under Bolt, Beranek and Newman in footnote 15f).

Shuford and his associates (3, 91, 92, 93) are using CAI equipment to quantify confidence in a student's decisions. Multiple-choice alternatives are presented on an oscilloscope to the student, who may express his degree of certainty as to the correct answer by increasing or decreasing the length of the bars on a bar graph associated with each alternative. He does this by pointing the light pen at the alternatives for varying amounts of time, while the bars grow or shrink to the chosen probability levels of certainty. Ultimately these researchers expect to program messages appropriate to the advances made by a student in the reduction of uncertainty of a particular concept.

The author of any paper which attempts describe a field that is growing as fast as CAI finds his discussion badly outdated before it is printed. This discussion, therefore, was to be an overview of some of the highlights only. No mention has been made, for example, of many of the younger CAI laboratories, such as Florida State, Texas, and Wisconsin, which are fast gaining prominence. For the latest information on CAI systems, the reader should contact Zinn,[16] who has begun a library of materials and systems. For the purposes of this paper, this overview gives a sufficient background in types of activities in which CAI researchers are involved to allow an examination of more basic problems.

THE EFFECTIVENESS PROBLEM

The effectiveness problem in CAI focuses on the purpose of any given program. A program which is to teach German vocabulary must be judged in terms of the author's criteria for learning this vocabulary. Furthermore, comparison should be made with other methods of teaching to these criteria in order to judge the efficiency in terms of time and cost of the method. Hansen (51, p. 596), for example, reports:

> One of the most consistent findings with CAI tutorial applications is the marked saving in instructional time along with no loss in post-instructional achievement test performance.

He cites three studies to support that conclusion. More recent studies, however, showed that students using a CAI typewriter interface had increased instructional time without any compensating increase in achievement, in comparison with students who were taught via programed text (46, 125, 126).

The question of the efficiency of a CAI system, then, has not been answered but probably needs studies of the subject matter-interface interaction. That is, the typewriter interface may be less efficient than a cathode ray tube for some subject matters, but not for others.

Theoretical Considerations

Because a psychologist advocates a certain method of teaching does not necessarily imply that the espoused method is based upon uncontrovertible scientific principles. The psychologist, like other intelligent men (as Bugelski [11] points out), may simply have found a new approach to an old problem. The naive reader of advertisements for programed texts and teaching machines (and, unfortunately, many technical reports of studies with programed instruction), however, could easily be brainwashed into believing

[16] Dr. Karl L. Zinn's address is UM-CRLT, 1315 Hill Street, Ann Arbor, Michigan 48104.

that scientific psychology had finally solved all the teaching, motivation, and individual difference problems which have plagued man for centuries. Nevertheless, while there are several "theoretical orientations for CAI" (51), each of which specifies some of the components of learning via CAI, there exists no general theory of CAI from which we can deduce learning principles appropriate to the CAI situation. Is there such a theory in the broader body of programed learning literature?

Since Skinner (98) gave programed learning its present impetus using techniques analogous to those used to shape the behavior of pigeons, it is not surprising that he and his colleagues have emphasized the scheduling of reinforcement for an emitted response. In practice, this has led to the use of small-step linear programs with heavily prompted frame sequences, in which these prompts are assumed to become discriminated stimuli which set the occasion for a student's response. Seeing that his response was correct is assumed to reinforce the student's response so that empirically there is an increased probability of that response occurring again in the presence of the discriminated stimulus. Some researchers (e.g., Lumsdaine [61]) maintain that reinforcement is not necessary for these stimulus-response connections to be formed but only that, following Guthrie, the stimulus and response occur contiguously.[17]

If it were not sufficient to have two learning models clash in interpreting the same datum, Hilgard (54) argues that cognitive theorists would interpret it in yet another way—namely, that a process, not a response, may be what is learned. The purpose of this discussion is not to take sides in the controversies of learning theory, but to emphasize with Hilgard (54, pp. 136-37) that

> ... advances made in programmed learning have been based very little upon a strict application of learning theory, regardless of what devotees of the different theories may assert.

Is programed learning, then, just another gimmick being perpetrated on unsuspecting educators as a scientifically sound method of teaching? The answer lies in research on the advantages claimed for it.

[17] An interesting theoretical issue which has been raised is whether the proper paradigm for programed learning is classical, free operant, or controlled operant conditioning (see [61] or [128] for the arguments involved). Practically speaking, however, this issue has little, if any, bearing on actual programing practices, especially CAI practices, and a resolution will not be attempted here.

Programed instruction has been based on four basic tenets that are assumed to be significant for learning: 1) The subject matter is systematically presented in small bits to the student, who is required to 2) become an active participant in the learning situation by constructing an answer to a question; 3) he receives immediate information about the quality of that response; 4) then he continues at his own rate to the next frame (33, p. 41).

Research on all of these points is inconclusive (examples of studies of these assumptions can be found in [32] and [62]); by no means are findings sufficient to provide an authoritative formula for programed learning.

The conclusion to be drawn from this brief digression into the theoretical and research basis of programed instruction is that there is no comprehensive theoretical base for it. There is, however, a specialized theoretical approach which investigators at Stanford have been pursuing—namely, focusing on specific learning situations and developing quantitative learning models which, when related to optimal instructional sequences, can be used to maximize learning. (For examples, see [50, 52,[18] 106, 109, 112].) These investigators build curricula on the basis of specific models of the learning process within that given subject matter. Their instructional sequences then become hypotheses of optimal learning and can be compared to other sequences. In sum, the curriculum is viewed as a theoretical statement of the best way to learn the subject matter. As such, it is to be tested experimentally and changed accordingly.

Task Specificity

Even if there were systematic data collected in programed learning, generalizability to CAI cannot be assumed without replication of studies. The following three examples indicate the difficulties involved in generalizing the results of non-CAI studies to CAI systems.

Licklider (60) found that poor typists learned more rapidly when they responded implicitly (when they just pushed a button telling the computer to go on) than when they responded explicitly (when they typed the response), while good typists showed no difference in learning rate between implicit and explicit responding.

Silberman and others (96) found that students exposed to a branching technique (using a textbook format) had higher criterion test scores than students who received a fixed-sequence

[18] Dr. Hansen is now at Florida State University.

[illegible] raises serious question as to whether we are right when we urge teachers to adapt to individual differences. If the teacher has a standard plan, well fitted to the average of the group, he should hesitate to depart from it. Marked alteration of the plan to fit individuals appears to be advisable only when individual differences are validly assessed and their implications for treatment clear.

Few psychologists would maintain that we can validly assess any given individual differences; fewer still would recommend an educational treatment based on that assessment. Until parametric investigations of these individual difference variables are undertaken in CAI settings to make clear their educational implications, programing energy might best be expended in the development of one good program aimed at the mean of the population who will use the program.

For those who would object that this procedure is wasting the special powers of the computer to make on-line branching decisions, two points should be raised. First, it has yet to be demonstrated that branching sequences which are unique to criteria based on individual differences produce superior learning to some other simpler remedial technique, such as repetition of the difficult frame sequences. Second, the burden of proof rests with those who would replace existing teaching techniques with CAI systems. Thus, if it is claimed that adapting to individual differences through CAI would improve some aspect of learning, then parametric studies of variables deemed important should be undertaken. Yet studies of this sort are almost nonexistent. Almost all funds allotted to CAI projects are being spent on the development of courses or equipment to the exclusion of research on teaching-learning variables, where research is needed most.

Other Effectiveness Issues

1. To compare adequately the effectiveness of an instructional program on different students, control must be maintained over their prior experience with the concepts to be taught. This is difficult to accomplish with most subject matter since students generally have some knowledge—more than they realize—about any given area (64). One solution to this problem might be to use invented material in the program (e.g., the imaginary science of Zenograde Systems used by Merrill [70, 71]) or else to use standardized materials such as paired associates (as did Licklider [60]). Use of such materials, however, may limit the generalizability of the results to education. Regardless of the materials, it would be advisable as standard practice to have students respond to a pretest, [illegible] prior knowledge of the subject matter.

One solution to this perennial problem might be longer range experiments.[19] Variables which are posited to be important educationally could be explored first with standardized materials. When the effects of a variable are known in this laboratory situation, the experimenter will then be in a better position to make predictions of the effects of that variable in the more complex teaching program.

2. The criteria of learning are also a problem. Some of the measures which have been used have been error rate, response latency, percent improvement from pretest to posttest, time to learn, retention scores, and transfer scores. In many cases, one measure is not predictive of another (43) but, more importantly, one measure should not necessarily be expected to be predictive of another. Selection of measures of learning should be based on the theoretical expectations of the study. For example, highly test-anxious students might be expected to be no different from low test-anxious students in number of errors or trials to some preselected criterion, but might be expected to show longer response latencies. Therefore, if branching decisions are to be based on some individual difference construct, such as test anxiety, the branching criteria should be selected on the basis of their theoretical (with empirically demonstrated) relevance.

3. Motivational concerns are a continuing problem in learning theory and remain so in CAI. It has been suggested that the Hawthorne Effect may be operating in the highly atypical CAI laboratories (33), which may help to account for the generally favorable attitudes of students found by Wodtke and others (127). Lest the conclusion be reached that we can capitalize on the Hawthorne Effect and the students' resultant favorable attitudes, it must be remembered that attitudes must somehow be shown to affect performance in some way, if they are to be important as learning variables. In what may be the only study on this question, Wodtke (124, p. 53) found that "attitude towards CAI did not appear to affect performance when the effects of aptitude were partialed out." Of course, even if attitude were predictive of performance, the effect over long periods of time (so the Hawthorne Effect could have worn off) would have to be assessed (84).

[19] Cronbach (29) gives an excellent discussion of the necessity of long-term experiments in education.

It has been pointed out repeatedly that the present costs of CAI are prohibitive for all uses except research. The section on current CAI systems, however, has indicated that quite a few groups across the United States are very concerned with more than "pure" research. Indeed, it is clearly implied that these systems are expected to be operable in the near future. To keep costs down, Coulson (23) suggested that the computer could be used during normal school hours for instruction for large numbers of students, counseling, and displays for teachers and administrators. At night the same machine could perform the routine processing of payrolls, attendance records, cost accounts, and other administrative duties.[20]

More important obstacles than costs must be surmounted, however. One of these is the negative attitude of many teachers toward programed instruction. Although it is almost a cliche that teachers will not be replaced by programed instruction but that they will be "elevated" to having a motivating function, the teacher's point of view should be considered for a moment (85, p. 135):

> Educational functions are not, in practice, fragmented, and it is therefore difficult for teachers to see just how they will go about being creative in a classroom where subject matter is taught by programed material.

This, coupled with the threat of the predicted new profession of "teaching engineers," a maximum of clerks and administrators and a minimum of teachers doing the highest thinking and training (87), would be expected to raise the anxiety level of all but a few teachers. It is possibly this type of unexpected side effect which Atkyns (1) warns about.

Another problem is the rush to "mechanize" education prematurely. Glaser (47) and Lumsdaine and Glaser (62) warned that hardware production is way ahead of program production. Likewise, neither of these [illegible] should be allowed to develop faster than the psychological principles on which this technology is based (69). Or, in Skinner's words (97, p. 168):

> The "mechanizing of education" has been taken literally in the sense of doing by machine what was formerly done by people. Some of the so-called computer-based teaching machines are designed simply to duplicate the behavior of teachers . . . What is needed . . . is an analysis of the functions to be served, followed by the design of appropriate equipment. Nothing we now know about the learning process calls for very elaborate instrumentation.

It is not necessary to agree with Skinner that elaborate instrumentation is unnecessary; on the other hand, where elaborate instrumentation is advocated (as it is in CAI systems), its need should be justified. Justification, however, does not consist of citing historical maxims, such as "teachers should adapt to individual differences." Rather it consists of experimental demonstrations of the increased effectiveness and/or efficiency of teaching with this instrumentation certain courses to certain students under specified conditions.

At the 1965 American Psychological Association Convention, Coulson (26) stated that most of the remarks of the CAI symposium panel members could have been made five years ago. What worse indictment could be made of the research emphasis in CAI! The technical problem is virtually solved in the sense that more equipment is available with faster operating speeds than the educator knows how to use. The semantic problem is being solved with the development of languages which allow courses to be programed relatively easily. What kinds of programs to write in order to use the equipment *effectively* is, nevertheless, an almost untouched problem. We need, as Coulson (26) said, a model of the student. We have all kinds of flow charts for decision strategies, but how these affect students is almost completely unknown.

Parametric studies of theoretically important variables must be undertaken. The few experimental studies that were done seem to have been of the trial-and-error variety, leading to little progress through one generation of CAI systems. A suggested experimental approach is to take a current model of school learning, e.g., Carroll's (15) model, and engage in a series of studies to test some of these notions in CAI. Conveniently, most of Carroll's variables are time-dependent measures, which can easily be ex

[20] There is a great deal of activity in the development of "extracurricular" uses of the computer. For example, in the area of counseling, Cooley (22) recommended increased use of computers to obtain and collate information on students as an aid to overburdened guidance counselors. Carter and Silberman (16) at System Development Corporation have, in fact, begun to develop such a program. At Penn State, Impellitteri (56) is launching a program designed ultimately to use a CAI system to present students with information concerning vocations relevant to a student's interests. In the area of computerizing many administrative functions, the Iowa Educational Information Center (67) has developed a system (CARDPAC) to process educational information more easily and quickly.

plored in a CAI system. Thus, one series of studies might explore the conditions under which high aptitude students (i.e., those students who need small amounts of time to learn a given subject matter) learn a given set of concepts best, varying the opportunity (time allowed for learning).

Another approach might be to follow the Stanford investigators' method of building curricula according to models of student learning and optimal instructional strategies.

These approaches are not being advocated over any other number of possible systematic attacks on the effectiveness problem. What is advocated is systematic parametric research on the effectiveness problem. Indeed, some systematic (if not theoretical) approach similar to these must be undertaken if we are to avoid hearing at the 1970 American Psychological Association Convention that "most of the remarks made here today could have been made *ten* years ago."

REFERENCES

1. Atkyns, G. C. "A Thalidomide Scandal in Education?" *Journal of Teacher Education* 15: 382-85; 1964.
2. Avner, R. A. *Heart Rate Correlates of Insight.* Technical Report R-198. Urbana: Coordinated Science Laboratory, University of Illinois, 1964.
3. Baker, J. D. "Contributions from the Information System Sources to Educational Systems: Computer Based Instructional Systems." Paper presented at 73rd annual American Psychological Association Convention, Chicago, September 1965.
4. Bitzer, D. L. "The PLATO Teaching System." *Automated Education Letter* 1: 13-15; 1965.
5. Bitzer, D. L.; Braunfeld, P. G.; and Lichtenberger, W. W. "PLATO II: A Multiple-Student, Computer-Controlled Automatic Teaching Device." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 205-16.
6. Bitzer, M. *Self-Directed Inquiry in Clinical Nursing Instruction by Means of the PLATO Simulated Laboratory.* Technical Report R-184. Urbana: Coordinated Science Laboratory, University of Illinois, 1963.
7. Boocock, S. S., and Coleman, J. S. "Games with Simulated Environments in Learning." Baltimore: Department of Social Relations, Johns Hopkins University, 1965. (Mimeo.)
8. Borko, H. "A Look into the Future." *Computer Applications in the Behavioral Sciences.* (Edited by H. Borko.) Englewood Cliffs, N. J.: Prentice-Hall, 1962. pp. 596-607.
9. Braunfeld, P. G. "Problems and Prospectus of Teaching with a Computer." *Journal of Educational Psychology* 55: 201-11; 1964.
10. Brooks, F. P. "The Future of Computer Architecture." *Proceedings of the IFIP Congress 65.* (Edited by W. A. Kalenich.) Washington, D.C.: Spartan Books, 1965. pp. 87-91.
11. Bugelski, B. R. *The Psychology of Learning Applied to Teaching.* Indianapolis: Bobbs-Merrill Co., 1964.
12. Bushnell, D. D. "Computer-Based Teaching Machines." *Journal of Educational Research* 55: 528-31; 1962.
13. ———. "Computer Assisted Instruction—A Summary of Research Programs." *Automated Education Handbook.* (Edited by E. H. Goodman.) Detroit: Automated Education Center, 1965. IV A, pp. 41-59.
14. ———. "For Each Student a Teacher." *Saturday Review* 49: 31; July 23, 1966.
15. Carroll, J. B. "A Model for School Learning." *Teachers College Record* 64: 723-33; 1963.
16. Carter, L., and Silberman, H. *The Systems Approach, Technology and the School.* Technical Report SP-2025. Santa Monica, Calif.: System Development Corporation, 1965.
17. Chapman, R. L., and Carpenter, J. T. "Computer Techniques in Instruction." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 240-53.
18. Clippinger, R. F. "Programming Implications of Hardware Trends." *Proceedings of the IFIP Congress 65.* (Edited by W. A. Kalenich.) Washington, D.C.: Spartan Books, 1965. pp. 207-12.
19. Cogswell, J. F., and Coulson, J. E. *Effects of Individualized Instruction on Testing.* Technical Report SP-1829. Santa Monica, Calif.: System Development Corporation, 1965.
20. Coleman, J. S., and others. *Research Program in the Effects of Games with Simulated Environments in Secondary Education.* Report No. 2. Baltimore: Department of Social Relations, Johns Hopkins University, 1964.
21. Cook, D. L. "Teaching Machine Terms: A Glossary." *Educational Technology.* (Edited by J. P. DeCecco.) New York: Holt, Rinehart and Winston, 1964. pp. 1-9.
22. Cooley, W. W. "A Computer-Measurement System for Guidance." *Harvard Educational Review* 34: 559-72; 1964.
23. Coulson, J. E. *Computers in Programed Instruction and Educational Data Processing.* Technical Report SP-950. Santa Monica, Calif.: System Development Corporation, 1963.
24. ———. *Present Status and Future Prospects of Computer-Based Instruction.* Technical Report SP-1629. Santa Monica, Calif.: System Development Corporation, 1964.
25. ———. *Automation, Cybernetics, and Education.* Technical Report SP-1966. Santa Monica, Calif.: System Development Corporation, 1965.
26. ———. Discussant of the Symposium: "Complex Learning Studies in the Computer-Based Laboratory." 73rd annual Amer-

ican Psychological Association Convention, Chicago, September 1965.
27. Coulson, J. E., and others. "Effects of Branching in a Computer Controlled Auto-Instructional Device." *Journal of Applied Psychology* 46: 389-92; 1962.
28. Cronbach, L. J. "New Light on Test Strategy from Decision Theory." *1954 Invitational Conference on Testing Problems.* Princeton, N. J.: Educational Testing Service, 1954. pp. 30-36.
29. ———. "The Logic of Experiments on Discovery." Paper presented at conference under E. Keislar, New York, January 1965.
30. Crowder, N. A. "Automatic Tutoring by Intrinsic Programing." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 286-98.
31. Davis, D. J., and Stolurow, L. M. *Computer Based Systems—the New Research Aid.* Technical Report No. 6. Urbana: Training Research Laboratory, University of Illinois, 1964.
32. DeCecco, J. P., editor. *Educational Technology.* New York: Holt, Rinehart and Winston, 1964.
33. Dick, W. "The Development and Current Status of Computer-Based Instruction." *American Educational Research Journal* 2: 41-54; 1965.
34. Easley, J. A., Jr.; Gelder, H. M.; and Golden, W. M. *A PLATO Program for Instruction and Data Collection in Mathematical Problem Solving.* Technical Report R-185. Urbana: Coordinated Science Laboratory, University of Illinois, 1964.
35. Estrin, G. "Interactions Between Future Computer Developments and Automated Teaching Methods." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 281-88.
36. Feingold, S. L., and Frye, C. H. *Users Guide to PLANIT: Programming LANguage for Interactive Teaching.* Technical Report TM-3055/000/00. Santa Monica, Calif.: System Development Corporation, July 1966.
37. Fernbach, S. "Computers in the U.S.A.—Today and Tomorrow." *Proceedings of the IFIP Congress 65.* (Edited by W. A. Kalenich.) Washington, D.C.: Spartan Books, 1965. pp. 77-85.
38. Feurzeig, W. "Conversational Teaching Machine." *Datamation* 10: 6; June 1964.
39. ———. "Towards More Versatile Teaching Machines." *Computers and Automation* 14: 3; 1965.
40. Feurzeig, W., and others. "Computer-Aided Teaching in Medical Diagnosis." *The Journal of Medical Education* 39: 746-54; 1964.
41. Flood, M. M. "What Future Is There for Intelligent Machines?" *Audio-Visual Communication Review* 11: 260-70; November-December 1963.
42. Fry, E. *Teaching Machines and Programm[illegible] Instruction.* New York: McGraw-Hill Book Co., 1963.
43. Gagné, R. M., and Dick, W. "Learning Measures in a Self-Instructional Program in Solving Equations." *Psychological Reports* 10: 131-46; 1962.
44. Gentile, J. R. *The First Generation of Computer-Assisted Instructional Systems: An Evaluative Review.* Technical Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, November 1965.
45. Gill, S. "The Changing Basis of Programming." *Proceedings of the IFIP Congress 65.* (Edited by W. A. Kalenich.) Washington, D.C.: Spartan Books, 1965. pp. 201-206.
46. Gilman, D. A. "Feedback, Prompting, and Overt Correction Procedures in Nonbranching Computer Assisted Instruction Programs." *Experimentation with Computer-Assisted Instruction in Technical Education.* (By H. E. Mitzel and others.) Semi-Annual Progress Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, June 1966.
47. Glaser, R. "Christmas Past, Present, and Future: A Review and Preview." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 23-31.
48. Glaser, R.; Ramage, W. W.; and Lipson, J. I. *The Interface Between Student and Subject Matter.* Technical Report. Pittsburgh: Learning Research and Development Center, University of Pittsburgh, 1964.
49. Goodman, E. H., editor. *Automated Education Handbook.* Detroit: Automated Education Center, 1965.
50. Groen, G. J., and Atkinson, R. C. *Models for Optimizing the Learning Process.* Technical Report No. 92. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, February 1966.
51. Hansen, D. N. "Computer-Assisted Instruction." *Review of Educational Research* 36: 588-603; 1966.
52. ———. *A Reading Curriculum for a Computer-Assisted Instructional System: The Stanford Project.* Progress Report. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, August 1966.
53. Hansen, D. N., and Rodgers, T. S. *An Exploration of Psycholinguistic Units in Initial Reading.* Technical Report No. 74. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, 1965.
54. Hilgard, E. R. "Issues Within Learning Theory and Programmed Learning." *Psychology in the Schools* 1: 129-39; 1964.
55. Holland, J. G. "Teaching Machines: An Application of Principles from the Laboratory." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 215-28.
56. Impellitteri, J. T. *The Development and Evaluation of a Pilot Computer-Assisted Vocational Guidance Program.* Research

Proposal. University Park: The Pennsylvania State University, 1965.
57. Keislar, E. "Theoretical Aspects of Automated Teaching." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 645-46.
58. Kendler, H. H. "Teaching Machines and Psychological Theory." *Automatic Teaching: The State of the Art.* (Edited by E. Galanter.) New York: John Wiley and Sons, 1959. pp. 177-85.
59. Kendler, H. H., and Kendler, T. S. "Vertical and Horizontal Processes in Problem Solving." *Psychological Review* 69: 1-16; 1962.
60. Licklider, J. C. R. "Preliminary Experiments in Computer-Aided Teaching." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 217-39.
61. Lumsdaine, A. A. "Some Theoretical and Practical Problems in Programmed Instruction." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 134-51.
62. Lumsdaine, A. A., and Glaser, R., editors. *Teaching Machines and Programmed Learning: A Source Book.* Washington, D.C.: National Education Association, 1960.
63. Lyman, E. R. *A Descriptive List of PLATO Lesson Programs, 1960-1964.* Technical Report R-186. Urbana: Coordinated Science Laboratory, University of Illinois, 1964.
64. Mager, R. G., and Clark, C. "Explorations in Student Controlled Instruction." *Psychological Reports* 13: 71-76; 1963.
65. Maher, A. *Computer-Based Instruction (CBI): Introduction to the IBM Project.* IBM Research Report RC 1114. White Plains, N.Y.: International Business Machines, 1964.
66. Maher, A., and Cook, L. *Introduction to the Coursewriter Language.* IBM 1410 Manual. White Plains, N.Y.: International Business Machines, 1964.
67. Marker, R. W. "Computer Based Educational Information Systems, the Iowa Case." Paper presented at the 12th UCEA Development Seminar, University of Iowa, April 1964.
68. Markle, S. M. *Programer, Teach Thyself.* New York: Center for Programed Instruction, 1961.
69. Melton, A. W. "Some Comments on 'The Impact of Advancing Technology on Methods in Education,' by Dr. Simon Ramo." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 660-64.
70. Merrill, M. D. *Transfer Effects Within a Hierarchical Learning Task as a Function of Review and Correction of Successive Parts.* Technical Report No. 5. Urbana: Training Research Laboratory, University of Illinois, 1964.
71. ———. "Correction and Review on Suc[illegible]ive Parts in Learning a [illegible] 225-34; 1965.
72. Mitzel, H. E., and Brandon, G. L. *Assessment of Experimental Teaching Strategies in Computer-Assisted Instruction Core Courses for Technical Education Programs.* Proposal for a Development and Training Program. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, 1965.
73. Mitzel, H. E., and others. *Experimentation with Computer-Assisted Instruction in Technical Education.* Semi-Annual Progress Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, December 1965.
74. ———. *Experimentation with Computer-Assisted Instruction in Technical Education.* Semi-Annual Progress Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, June 1966.
75. Mitzel, H. E., and Wodtke, K. H. *The Development and Presentation of Four Different College Courses by Computer Teleprocessing.* Interim Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, 1965.
76. Mitzel, H. E.; Wodtke, K. H.; and Hall, K. A. *The Development and Presentation of Four Different College Courses by Computer Teleprocessing.* Interim Report. University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, June 1965.
77. Moore, O. K. "From Tools to Interactional Machines." *New Approaches to Individualizing Instruction.* Report of a Conference To Dedicate Ben D. Wood Hall. Princeton, N.J.: Educational Testing Service, 1965. pp. 5-12.
78. Naur, P. "The Place of Programming in a World of Problems, Tools and People." *Proceedings of the IFIP Congress 65.* (Edited by W. A. Kalenich.) Washington, D.C.: Spartan Books, 1965. pp. 195-99.
79. "ONR Conference on CAI Languages." *Automated Education Letter* 1: 2-13; 1966.
80. Pines, M. "What the Talking Typewriter Says." *The New York Times Magazine*, May 9, 1965. p. 23ff.
81. Pressey, S. L. "A Simple Apparatus Which Gives Tests and Scores—and Teaches." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 33-41.
82. ———. "A Machine for Automatic Teaching of Drill Material." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 42-46.
83. ———. "A Third and Fourth Contribution Toward the Coming 'Industrial Revolution' in Education." *Teaching Machines and*

Programmed Learning: A Source Book. (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 47-51.

84. ———. "Certain Major Psycho-Educational Issues Appearing in the Conference on Teaching Machines." *Automatic Teaching: The State of the Art.* (Edited by E. Galanter.) New York: John Wiley and Sons, 1959. pp. 187-98.

85. [illegible]witz, W., and Mitzel, H. E. "Programing in Education and Teaching Preparation." *Teachers College Record* 64: 128-38; 1962.

86. Ragsdale, R. G. "The Pitt Computer-Assisted Instruction Laboratory." *Automated Education Letter* 1: 3-7; 1966.

87. [illegible] "A New Technique of Education." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 367-81.

88. [illegible], N. S.; and Brainerd, R. C. "The IBM Re[illegible] Teaching Machine Project." *Automatic Teaching: [illegible] Art.* (Edited by E. Galanter.) New York: John [illegible] 1959. pp. 117-30.

89. [illegible] Potential Uses of Computers as Teaching Ma[illegible] *[illegible] Learning and Computer-Based Instruction.* ([illegible] J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. [illegible].

90. Roberts, R.; Hauch, W.; and Lenahan, J. *The Synnoetics Laboratory: Laboratory Outline.* Madison: University of Wisconsin, [illegible].

91. Shuford, E. H., Jr. "Instructional Decisions Based on Probability Structures Rather than Choices." Paper presented at 73rd annual American Psychological Association Convention, Chicago, September 1965.

92. Shuford, E. H., Jr.; Albert, A.; and Massengill, H. E. "Admissible Probability Measurement Procedures." *Psychometrika* 31: 125-45; 1966.

93. Shuford, E. H., Jr., and Massengill, H. E. *On Communication and Control in the Educational Process.* Technical Report ESD-TR-65-568. Bedford, Mass.: Decision Sciences Laboratory, L. G. Hanscom Field, 1965.

94. Silberman, H. F., and Carter, L. F. "The Systems Approach, Technology, and the School." *New Approaches to Individualizing Instruction.* Report of a Conference To Dedicate Ben D. Wood Hall. Princeton, N.J.: Educational Testing Service, 1965. pp. 71-91.

95. Silberman, H. F., and Coulson, J. E. "Automated Teaching." *Computer Applications in the Behavioral Sciences.* (Edited by H. Borko.) Englewood Cliffs, N.J.: Prentice-Hall, 1962. pp. 308-35.

96. Silberman, H. F., and others. "Fixed Seque[illegible] Versus Branching Autoinstructional Methods." *Journal of Educational Psychology* 52: 166-72; 1961.

97. Skinner, B. F. "Reflections on a Decade of Teaching Machines." *Teachers College Record* 65: 168-77; 1963.

98. ———. "The Science of Learning and the Art of Teaching." *Teaching Machines and Programmed Learning: A Source Book.* (Edited by A. A. Lumsdaine and R. Glaser.) Washington, D.C.: National Education Association, 1960. pp. 99-113.

99. ———. "Teaching Machines." *Science* 128: 969-77; 1958.

100. Smallwood, R. D. "A Decision Structure for Computer-Based Teaching Machines." *Computers and Automation* 11: 9-14; 1962.

101. Smith, L. W. "Computer Assisted Instruction (CAI) in Elementary Mathematics and Mathematics Education." Paper presented at NCTM second Positional Conference on the Use of Educational Media, Chicago, May 1965.

102. Stolurow, L. M. *A Model and Cybernetic System for Research on the Teaching-Learning Process.* Technical Report No. 4. Urbana: Training Research Laboratory, University of Illinois, 1964.

103. ———. "Some Educational Problems and Prospects of a Systems Approach to Instruction." Paper presented at Conference on New Dimensions for Research in Educational Media Implied by the "Systems" Approach to Instruction, Syracuse University, April 1964.

104. ———. *Essential Principles of Programed Instruction.* Technical Report No. 8. Urbana: Training Research Laboratory, University of Illinois, 1965.

105. ———. "SOCRATES: System for Organizing Content To Review and Teach Educational Subjects." *Seventeenth Annual Industrial Engineering Institute Proceedings.* Los Angeles: University of California, 1965. pp. 22-27.

106. Suppes, P. "Modern Learning Theory and the Elementary-School Curriculum." *American Educational Research Journal* 1: 79-93; 1964.

107. ———. *Computer-Based Mathematics Instruction: The First Year of the Project.* Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, 1964.

108. ———. *Computer-Assisted Instruction in the Schools: Potentialities, Problems, Prospects.* Technical Report No. 81. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, October 1965.

109. ———. *The Psychological Foundations of Mathematics.* Technical Report No. 80. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, October 1965.

110. ———. "Plug-In Instruction." *Saturday Review* 49: 25, 29-30; July 23, 1966.

111. Suppes, P., and Binford, F. "Experimental Teaching of Mathematical Logic in the Elementary School." *The Arithmetic Teacher* 12: 187-95; March 1965.

112. Suppes, P., and Groen, G. *Some Counting Models for First-Grade Performance Data on Single Addition Facts.* Technical Report No. 90. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, January 1966.

113. Suppes, P.; Jerman, M.; and Groen, G. *Arithmetic Drills and Review on a Computer-Based Teletype.* Technical Report No. 83. Stanford, Calif.: Institute for Mathematical Studies in the Social Sciences, Stanford University, November 1965.

114. Swets, J. A. *Learning To Identify Nonverbal Sounds: An Application of a Computer as a Teaching Machine.* Technical Report NAVTRADEVCEN 789-2. Bolt, Beranek and Newman, Inc., 1962.

115. ———. "Some Possible Uses of a Small Computer as a Teaching Machine." *Datamation* 10: 39; June 1964.

116. Swets, J. A., and others. *Further Experiments on Computer-Aided Learning of Sound Identification.* Technical Report NAVTRADEVCEN 789-2. Bolt, Beranek and Newman, Inc., 1964.

117. Swets, J. A., and Feurzeig, W. "Computer-Aided Instruction." *Science* 150: 572-76; 1965.

118. Travers, R. M. W. "Transmission of Information to Human Receivers." *Educational Psychologist* 2: 1-5; 1964.

119. Uhr, L. E. "The Compilation of Natural Language Text into Teaching Machine Programs." *AFIPS 1964 Fall Joint Computer Conference Proceedings.* Washington, D.C.: Spartan Books, 1964. Vol. 26, Part 1, pp. 35-44.

120. Uttal, W. R. "On Conversational Interaction." *Programmed Learning and Computer-Based Instruction.* (Edited by J. E. Coulson.) New York: John Wiley and Sons, 1962. pp. 171-90.

121. Weaver, W. "Recent Contributions to the Mathematical Theory of Communication." *The Mathematical Theory of Communication.* (By C. E. Shannon and W. Weaver.) Urbana: University of Illinois Press, 1963.

122. Wing, R. L. "Computer-Controlled Economics Games for the Elementary School." *Audiovisual Instruction* 9: 681-82; 1964.

123. ———. *Status Report on Research Project.* Technical Report on Project 1948. Westchester County, N.Y.: Northern Westchester Board of Cooperative Educational Services, 1965.

124. Wodtke, K. H. "Relationships Among Attitude, Achievement, and Aptitude Measures and Performance in Computer-Assisted Instruction." *Experimentation with Computer-Assisted Instruction in Technical Education.* Semi-Annual Progress Report. (By H. E. Mitzel and others.) University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, 1965.

125. Wodtke, K. H., and Gilman, D. A. "Some Comments on the Efficiency of the Typewriter Interface in Computer-Assisted Instruction at the High School and College Levels." *Experimentation with Computer-Assisted Instruction in Technical Education.* Semi-Annual Progress Report. (By H. E. Mitzel and others.) University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, June 1966.

126. Wodtke, K. H.; Gilman, D. A.; and Logan, T. "Supplementary Data on the Deficits in Instructional Time Resulting from the Typewriter Interface." *Experimentation with Computer-Assisted Instruction in Technical Education.* Semi-Annual Progress Report. (By H. E. Mitzel and others.) University Park: Computer Assisted Instruction Laboratory, The Pennsylvania State University, June 1966.

127. Wodtke, K. H.; Mitzel, H. E.; and Brown, B. R. "Some Preliminary Results on the Reactions of Students to Computer-Assisted Instruction." *Proceedings of the 73rd Annual Convention of the American Psychological Association,* 1965. pp. 329-30.

128. Zeaman, D. "Skinner's Theory of Teaching Machines." *Automatic Teaching: The State of the Art.* (Edited by E. Galanter.) New York: John Wiley and Sons, 1959. pp. 167-76.

129. Zinn, K. "Computer Assistance for Instruction." *Automated Education Letter* 1: 4-14; 1965.

130. ———. "Functional Specifications for Computer Aided Instruction Systems." *Automated Education Handbook.* (Edited by E. H. Goodman.) Detroit: Automated Education Center, 1965. IV A, pp. 21-33.

131. ———. "Survey of Materials Prepared for Instruction or Instruction Research via On-Line Computer Systems." *Automated Education Handbook.* (Edited by E. H. Goodman.) Detroit: Automated Education Center, 1965. IV A, pp. 34-40.

132. ———. "Survey of Materials Prepared for Instruction or Instruction Research via On Line Computer Systems." *Automated Education Letter* 1: 8-16; 1966.

133. ———. "CAI—System and Projects." *Automated Education Letter* 1: 3-13; 1966.