THE EFFECTIVENESS OF VARIOUS MODES OF COMPUTER ASSISTED INSTRUCTION: A REVIEW OF RESEARCH

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The Effectiveness of CAI

Since the early work in drill-and-practice in elementary school arithmetic (Suppes et al., 1966, 1968b), the instructional effectiveness of computer assisted instruction (CAI) both in absolute and relative terms has been variously reported. The assumptions implicit in the use of CAI have been argued to be unsound (Barrett, 1968; Oettinger, 1969) although these criticisms have been said to be unfounded (Weinstock, 1973). The effectiveness of CAI drill-and-practice has found support in a number of reported studies (Suppes and Morningstar, 1968; Vinsonhaler, 1972), as have additional uses of CAI in other areas (Hedges, 1973).

Reviews of the literature on the effectiveness of CAI were generally undertaken by Bundy (1968), Fletcher et al. (1972), Jamison et al. (1974), Taylor et al. (1974), and Edwards et al. (1974, 1975).

Bundy (1968, p. 425) concluded that "Students seem to learn at least as well with CAI as with conventional classroom instruction. . . . CAI can provide learning and retention at least equivalent to conventional techniques in the same amount of time".

Fletcher et al. (1972), p. 1) concluded that "we have found strong and consistent achievement gains by students when they are given CAI over a reasonable fraction of a school year".

Jamison et al. (1974, p. 55), after comparing the effectiveness of CAI, programmed instruction, and television with traditional instruction concluded that "CAI is about as effective as TI (traditional instruction) when used as a replacement. It may also result in substantial savings of student time in some cases."

Taylor et al. (1974) reviewed CAI research under the headings of four usage modes, namely, drill-and-practice, problem solving, tutorial, and simulation, and concluded that: (1) most CAI programs have never been

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evaluated for effectiveness, (2) when evaluated, CAI is found to be effective, (3) tutorial and drill-and-practice are more effective than problem solving and simulation, (4) CAI is more efficient than traditional instruction, (5) retention is higher for traditional instruction, (6) when supplementing traditional instruction CAI is as effective as any other form of individualized instruction, (7) CAI works best with low ability students, and (8) in the absence of equipment malfunctions, CAI generates student and teacher enthusiasm.

Edwards et al. (1974, 1975) repeats Taylor's review.

CAI successes were earlier reported in science teaching at the undergraduate level. Statistically significant differences favoring CAI (p not reported) in chemistry achievement when compared with control groups receiving traditional instruction were observed by Culp (1971). In physics, CAI use improved examination performance of first-year physics students ($p>0.01$) when compared with a control group (Kromhout et al., 1969) while similar effects in undergraduate chemistry were observed by Castleberry and Lagowski, 1970)

A large CAI physics education project was conducted by Hansen et al. (1968) in which CAI was integrated with a highly individualized multimedia approach to first-year undergraduate physics instruction and compared with traditional lecture-recitation sections. Development efforts continued for three years and a complex research study was undertaken to determine instructional and cost effectiveness as well as ancillary studies on student personality characteristics, individual differences, and performance predictors.

Although volunteers were used in the experimental groups, no significant differences in student achievement were observed based either on final grade assignment or performance on the traditional examination. With respect to individual differences, however, Hansen et al. concluded (1968, p. 131):

> . . . the more striking results suggest that generally speaking, persons who are slightly less mature in their academic style, who are more sensitive and esthetic, and who are not scientifically oriented, have a higher probability of success if they take other hand, persons who are somewhat autonomous, independent thinkers, who have scientific interests and who have a mature scientifically-oriented method of inquiry will have a greater chance of success if they take the traditional mode of physics instruction.

The Educational Testing Service (ETS) undertook for the National Science Foundation (NSF) a large scale evaluation of the PLATO and TICCIT CAI systems, both of which received NSF support. The systems were evaluated by ETS in seven community colleges where they were used to teach algebra and English composition (TICCIT) and accounting, biology, chemistry, English, and mathematics (PLATO) from 1975 through 1977 to over 20,000 students (Alderman et al., 1978).

With respect to PLATO, ETS found that the project directors had overestimated how much of each course could be taught by CAI and that "exposure to PLATO had no consistent impact on either (student) attrition or achievement" (Alderman et al., 1978, p. 42). Positive and negative effects of PLATO were approximately equal in number (eighteen versus fourteen for attrition, eleven versus twelve for achievement) and "the few significant effects for either outcome could be plausibly explained by instructor differences" (Alderman, et al., 1978, p. 42).

With respect to TICCIT, ETS found negative effects on course completion rates, with sixteen percent of the students completing a TICCIT taught course as opposed to fifty percent for regular lecture sections, and ETS found positive effects on student achievement, in five out of six cases (Alderman, et al., 1978, p. 43).

EST concluded (Alderman, et al., 1978, pp. 44-45):

> ... neither CAI system had reached the potential so long claimed for this form of instructional technology. ... It would appear that computer systems themselves neither guarantee any dimension of educational effectivenss nor explain fully the results of such demonstrations.

Problems in CAI Use

Even with the reported successes of CAI, its use is not widespread. Weinstock and Wiley (1977, p. 190) concluded that "many effective computer-based educational aides have been developed in the past, but their overall impact has been slight". They identified shortages of terminals, the lack of computer oriented textbooks in subject matter fields, and the absence of transportability of computer programs from one computer system to another as the principal causes underlying the non-use of computers in instruction.

The magnitude of the transportability problem can be gauged from the fact that of twenty-seven representative computer assisted instruction projects in physics reported in 1969, twenty different computer systems were employed with seventeen different computer languages. These included FORTRAN, BASIC, PL/1, JOSS, ISIS, TELCOMP, LOGO, STRINGCOMP, COURSEWRITER I and II, TOC, ASSEMBLY, DECAL, ELIZA, ALP, and and unidentified language called "special" (Schwarz, et al., 1960). Some attempt has been made to alleviate the problem in educational applications with partial success (Nevision and Hoogendyk, 1974).

Additional difficulties, including long development times (Dowling, 1972), local conditions (Fulton, 1973), or user perceptions (Lower, 1973) may retard the introduction of computers in science education. Suppes (1967) identified machine reliability, neglect of content due to concern over programming, user boredom, and cost as impediments while Fromer (1973) stressed the problems of authoring CAI material.

Blum and Bork (1969) report that from ten to two hundred hours of programming time are required to produce one hour of computer terminal CAI instruction. Despite recent attempts at reducing that preparation time, it remains essentially unchanged, and the cost of $5280 per terminal hour for CAI development, field validation, and revision reported by Hansen, et al. (1968) may still remain a valid order of magnitude estimate.

In general, however, Anastacio and Morgan (1972, p. 11) concluded that "the lack of good, readily available computer-based educational materials (and) the fact that there are few examples of effective CAI" were the major impediments to widespread use. At the same time, they identified simulation as the most promising form of CAI and called for its extensive development.

Computer Simulated Experiments

The justifications for computer simulated experiments (CSE) in teaching were given by Braun and Visich when they were directors of the two Huntington Computer Projects which produced the most widely distributed CSE materials in science teaching during the early seventies (Braun, 1970; Visich and Braun, 1974). Visich and Braun argued (1974, p. 5) that CSE is justified as the primary learning experience when:

1) The necessary equipment is not available because of expense, or is too complex or delicate to permit students to use it (e.g., in high-energy physics).
2) The sample size available is too small to permit generalizations.
3) The experimental technique is difficult and must be developed over an extended period (e.g., in experiments in genetics, and in titration).
4) There are serious dangers to the student (e.g., where radiation and high temperatures are involved, where there may be explosive mixtures of gases, or when highly toxic materials are required).
5) The time scale is too short or too long to permit the student to make observations (e.g., the study of the dynamics of population, or the run-a-way (*sic*) of a nuclear reactor. . . .).
6) The opportunity to experiment directly is not available (e.g., in studies in ecological, economic, political, or social systems, or in studies of human genetics, or spread of disease).
7) It is desirable to measure variables which are difficult to access (e.g., the tension on a pendulum string, or the differential effects

of the gravitational forces of the earth and the moon on an orbiting satellite).

8) When measurement and other noise obscures the important phenomena (in the computer, we can create a world in which there is no noise and in which instruments are perfect, and *then* show the student how noise and imperfect instruments obscure the data of interest).

9) It is useful to underscore the significance of natural laws by comparing their results with other laws (e.g., study of non-inverse-square-law gravitational systems, or non-mendelian genetics).

Liao (1972) presented similar reasons behind the intensive use of an analog computer in the secondary school science course called The Man-Made World, which originated from the Engineering Concepts Curriculum Project (ECCP).

With respect to CSE use, Showalter (1970) identified eleven potential benefits for science education, among which were inquiry skills development, individualization, learning efficiency, reduced software development costs over tutorial CAI, and increased student creativity.

Yet the major portion of the literature of CSE consists of journalistic announcements of sample CSE applications in authors' courses. Among these announcements are applications in chemistry (Griswold, 1968; Schwendeman, 1968; Smith, 1970; Rodewald, et al., 1970; Craig, et al., 1971), biology (Norberg, 1975), earth science (Fox, 1969), and physics.

The physics literature contains statemnts of encouragement and anticipated use (Shirer, 1965; Bork, 1968; Blum and Bork, 1970; Hearn and Reid, 1970; Chesley, 1971; Martin, 1972; Yu, 1974; 1975a; Dowling, 1975) as well as specific illustrations of the employment of individual programs. (These programs can be found in the areas of mechanics (Wilkins and Klopfenstein, 1966; Bork and Luehrmann, 1968; Haddad, 1968; Baltz and Machlup, 1971; Jirgal, 1972; Peckham, 1972b; Greenslade, 1973; Lunetta, 1974; Ostrander, 1975), astronomy (Messina, 1972), optics (Grossberg, 1969; Merrill, 1971; Peckham, 1972a; Finn, 1973; Inman, et al., 1975), statistical mechanics (Anger and Prescott, 1970; Peckham, 1972d), relativity (Hickey, 1975), quantum mechanics (Merrill, 1973), laboratory data analysis (Bron, 1972), and environmental physics (Evans, 1976).

General compilations of programs are also available which cross a number of the subfields of physics (Blum, 1969; Lindsay, 1969; Braun, 1971, 1972; Merrill, 1972, 1976; Robson, 1971; Peckham, 1972, 1975; Ehrlich, 1973; Jones, 1973). A major but not exhaustive bibliographical listing of computers in physics teaching through April of 1975 (Cox, 1975) lists some seventy books, one hundred forty-five journal articles, and twenty-five miscellaneous publications covering twenty-two areas of undergraduate physics instruction. Almost all of these computer uses are unevaluated by other than author observation or user judgment.

Review of Research on CSE

Boblick (1972a, 1972b) reported that CSE as a tutorial mode in chemistry and physics could produce achievement gains among the CSE group higher than that of control groups. The following surveys research relative to this possibility.

Lunetta's Research on CSE

In one major study of CSE involving physics students in five similar Northeastern high schools (Lunetta, 1972, 1974; Lunetta and Blick, 1973), a series of four computer simulated experiments was prepared which allowed students to generate and graph at will data dealing with force and motion (Newton's second law). CSE was associated with film loops to make the simulation more vivid. The effect of this treatment (Group II) on students were provided with already filled out data tables and problem sheets. Group II viewed the film loops but did not make use of a computer. A control group (Group III) performed traditional laboratory experiments with PSSC momentum carts in order to obtain their data. Group I was not permitted access to a human teacher except upon computer initiated request. The remaining groups were permitted free access to the instructor. Teachers were different for the three groups, and, while the film loops were seen by Groups I and II, they were not seen by the control group.

Using objective-based criterion-referenced evaluation instruments in a pretest ($KR_{20} = 0.85$), treatment, posttest ($KR_{20} = 0.78$) with attitude survey plus repeated posttest in a quasi-experimental design (Campbell and Stanley, 1963), Lunetta investigated achievement, achievement gain per unit time spend (efficiency of learning), retention, attitude towards materials used and interaction effects of IQ, verbal PSAT, mathematical PSAT, grade level, and sex. Assignment to treatment groups was not random.

While all three groups showed significant gains (posttest scores over pretest scores), the students using CSE (Group I) showed the greatest gains. Group I complted the unit 3.2 times faster than Group II and 8.3 times faster than Group III. Thus, CSE showed increased instructional efficiency over traditional laboratory style experience. Of the variables studied, only sex and entry level peerformance knowledge as measured by the pretest significantly related to achievement in the unit.

With respect to retention, all groups showed significant gains six months later, although those students who used the previously filled in data sheets showed a significant loss between the first and second posttests. Hence, use of film loops apparently did not make the data sheets memorable enough to compensate for the lack of psychomotor activity in the collection of data either by means of CSE or by actual manipulation of laboratory apparatus. This result conflicted with the results of the attitude survey which showed that the group using just the data sheets believed (wrongly) that the already filled in data sheets were more "efficient".

Lunetta's study suggests that (1) the computer terminal may act like a piece of manipulative laboratory apparatus with respect to the retention of concepts gnerated by data analysis, (2) that CSE is more efficient in terms of the time spent, and (3) that CSE can result in superior concept formation.

The role played by the film loops in providing a vicarious connection with actual laboratory apparatus as well as whether the same results could have been obtained without the intervention of the film loops are questions still unresolved. Lunetta's work does suggest, however, that a computer terminal (or any instructional method) which merely hands students the data will be less effective than a method which involves more active students participation.

Jones' Research on CSE

A second study by Jones (1972) used CSE in both chemistry and physics in a Midwestern college-town high school. Eight physics classes (four PSSC and four Project Physics) and seven chemistry classes (four high ability and four low ability) involving two hundred fifty-eight students and four teachers participated. In contrast to Lunetta's four sequential computer programs concentrated in the single area of Newton's second law, Jones wrote twenty-three discrete programs (thirteen in chemistry and ten in physics) of which only ten were used with any one group. The CSE programs mimicked representative high school laboratory experiments closely related to actual experiments in the existing program of the school.

The programs produced data tables which included small random errors. The data were either based on student selected values of the independent variables as limited by preprogrammed restrictions on the acceptable range (with the computer returning a single datum for a single student input value) or they were completely computer generated and gave both dependent and independent variables after the student selected the initial circumstances.

Jones focused on whether CSE would influence students' attitudes towards (1) the subject, (2) laboratory work, (3) the computer as a laboratory aid, or (4) using a computer terminal. He looked for an interaction between sex, IQ, and GPA and attitudes or achievement. Finally, he asked whether student achievement was affected by using CSE. No attempt was made to determine the differential effects of his two styles of computer programming nor were verbal interactions studied.

Experimental and control groups were formed by random assignment from among students within the same class, and both groups "worked in the same laboratory at the same time" although teachers "discouraged the sharing of information between experimental and control groups. Students in the experimental group were encouraged to look at the equipment, but were not allowed to use it to take data. Students in the control group were not allowed to use computer generated data" (Jones, 1972, p. 30). All students were told they were participating in an experiment involving computer usage.

Attitudes (1) through (3) were measured using a pretest-posttest control group design while achievement and attitude (4) were measured by a posttest-only control group design (Campbell and Stanley, 1963). Each of the then separate achievement posttests was administered the day following the associated experiment. No cumulative examinations were given. There was no attempt at measuring either retention or learning efficiency as was done in Lunetta's (1972) study.

Jones concluded that CSE had no significant ($p>0.05$) impact either on achievement or on attitudes towards the subject or the laboratory work generally. However, students were significantly more positive towards computer use at the end than at the start, with males significantly more positive than females.

Jones notes (p. 63):

> . . . in some experiments it was difficult for students to visualize the meaning of the output data unless they had actually worked some with the particular type of equipment involved in that experiment . . . the interaction of the experimental and control groups in the same laboratory . . . could influence results. The opportunity to watch students actually doing the same experiment undoubtably made the simulations much easier to comprehend. On the other hand, it was possible that those in the control group were able to pick up clues about the expected results from seeing computer simulated data tables.

It would appear from an examination of Jones' computer programs that they generated output which more nearlf approximated the data sheets used with Lunetta's Group II (non-computer group). Lunetta's computer programs (listings in Lunetta, 1974) were much longer, and were more complex, interactive, and conversational in character than Jones'.

The most economical interpretation seems to be that both Lunetta and Jones actually agree regarding achievement effects — data tables *qua* data tables whether handed out by human beings or computer terminals are not superior to traditional laboratory instructional methods. Rather, what these two studies suggest when combined is that more conversational CSE (i.e., CSE which more closely approximates a human being in interactions with students) or CSE coupled to sensory experiences which stimulate (either vicariously through an audiovisual presentation or kinesthetically through apparatus manipulation) may be superior to traditional methods.

Hughes' Research on CSE

This hypothesis was investigated by a subsequent study (Hughes, 1973) in which students using CSE with and without exposure to laboratory apparatus were compared with each other and with a traditional laboratory group. Hughes remarked (p. 140):

> ... working with the laboratory equipment to obtain an understanding of the physical situation, coupled with the ease of using the computer to generate data, permitted students (who used both the computer and the equipment) to progress further (*sic*) in translating the results of the laboratory situations into meaningful conclusions.

With respect to learning efficiency, Hughest found that (pp. 141-142):

> ... those students exposed to the laboratory situation treat the computer as an extension of their laboratory work, performing enough trials to permit them to investigate the relationships completely (while) students having no exposure ... perform an excessive number of trials (when using the computer alone).

In Hughes' two-factor experiment with repeated measures on one factor design (Winer, 1962), fifty-one students in two high school physics classes in Bexley, Ohio were randomly assigned to three treatment groups of seventeen students each. The students did four PSSC-style laboratory experiments (Newton's Second Law, Energy Changes in an Oscillating Spring, Coulomb's Law, and the Millikan Experiment) spread over four months. One group used CSE only (Group C), the second used CSE following a single trial manipulation of the actual laboratory apparatus (Group L-C), while the third used laboratory apparatus in the traditional (Group L).

Each of the three groups was aware of the activities of the other groups, and Hughes noted (1973, p. 141): "interaction between the students in the various groups (which) may have acted to mask the effect of the treatments".

Two days were devoted to each experiment followed by a day of postlab discussion with all students participating regardless of treatment group. Student-teacher verbal interactions during the postlab discussion were not studied. The postlab was followed the next day by a test on the laboratory activity (KR_{20} = 0.82, = 0.65, = 0.75, = 0.92 respectively for each of the four tests). A cumulative examination (KR_{20} = 0.62) and an attitude survey were administered a day after the final test.

Hughes compared (1) attainment of process skills, (2) acquisition of content, (3) number of trials performed, and (4) time involved for the three groups. He also compared attitudes towards CSE between Group C and Group L-C.

Those conclusions found to be significant ($\alpha < 0.1$) were, with respect to attainment of process skills, that Group L-C was better at developing experimental conclusions and that Group C performed more trials. No significant differences were observed for concept acquisition or time involved or with respect to attitudes towards CSE. This was in contrast to the conclusions of Lunetta (1972) regarding achievement and Jones (1972) regarding attitudes.

It is possible that the fine-grained effects sought by Hughes were smeared to noise level by the exposure of students to the different treatments in the same laboratory at the same time, the insertion of a mixed-group postlab discussion between treatment exposure and testing, and the fact that, as with Jones (1972), an analysis of the computer programs Hughes wrote shows they merely generated realistic values of a dependent variable in response to student selected values of an independent variable.

Lunetta's, Jones', and Hughes' Research Compared

If conversation in programming is a *desideratum* for success in using CSE without teacher assistance over traditional methods to improve achievement and efficiency, then these three studies are complementary rather than contradictory, Lunetta's shows the superiority of conversational CSE while all three (Lunetta, 1972; Jones, 1972; and Hughes, 1973) indicate the absence of any superiority in non-conversational CSE.

All three support the contention that previous experience (vicarious or real) with experimental apparatus enhances learning with CSE. The apparent need for real or vicarious experiences with apparatus on the part of the students, if achievement is to be higher with CSE than with traditional experimentation, casts doubt on the claim that CSE can substitute for experiments which cannot be performed in the high school laboratory because of safety, cost, or physical impossibility.

An indication of transportability problem is shown by the fact that a different computer language was used by each of the three investigators (Lunetta, 1972, 1974—Basic; Jones, 1972—PL/1; Hughes, 1973—FORTRAN).

CSE With Graphics

Inasmuch as conversational CSE appears superior to non-conversational CSE, one might ask whether a CAI computer dialogue is more effective with a supporting laboratory experience which is real than when the same computer dialogue is supported with a laboratory experience that is merely simulated. Could a common CAI experience be supported as easily by slides of the laboratory apparatus being manipulated as by requiring the students to operate actual appartus?

Graham (1970) made such a comparison using a modified physics CAI lesson on magnetism and compared achievement between the CAI lesson using actual appartus (manipulated by students during the lesson) and using simulated manipulation (by showing slides under computer control). Graham concluded that neither produced criterion performance by the students, and that the instructional efficiency was the same for each. Only the time required to set up the laboratory apparatus prior to student use was saved by the simulated version of the CAI lesson.

Hollen, Bunderson and Dunham (1971) found that, while mean achievement scores for CSE were twice as high as for traditional instruction, the differences were not significant; although significant differences were observed in the time saved using CSE ($p<0.005$). The addition of slides to the CSE presentation made no significant difference in the effectiveness of CSE over traditional instruction, although the trend supported the use of the slides to provide a vicarious experience.

Ridney and Lutz (1975), however, report significantly higher recall of chemistry concepts for students using animated computer graphics over those given a computer generated verbal explanation. Students viewing graphics were higher on the recall of knowledge ($p<0.02$), comprehension ($p<0.1$), and application ($p<0.02$).

Lang (1975) investigated the effects of computer graphic simulations in high school physics laboratory instruction. Selecting random samples of thirty experimental and thirty control subjects from a population of 383 physics students in Westside High School in Omaha, Nebraska, Lang employed eight FORTRAN computer programs principally duplicating the laboratory experiments and problems contained in the second unit, called "Motion in the Heavens," of the Harvard Project Physics (HPP) course (Rutherford, et al., 1970). The semi-conversational programs used one-on-one drove a hard-copy graphics terminal on which appeared output such as cometary and planetary orbits. Lang found no statistically significant differences ($p<0.05$) between the two groups' mean posttest scores on the HPP unit two tests, although a statistically significant difference ($p<0.05$) in favor of the experimental group appeared upon retesting ninety days later. Lang found the experimental groups higher ($p<0.01$) on an attitudinal scale. No sex-related differences were observed ($p>0.O5$).

Computer-Assisted Lectures

Computer Assisted Lecturing (CAL) appears to be little-used and has been evaluated in only one study (Dunkum, 1979) regarding student short-term learning despite some calls in the literature for its employment (Bell and Moon, 1969; Meiser, 1976). There are few recorded uses of

CAL (Corrin, 1966, Muller, et al., 1973) and only two large scale installations for such use are known to this researcher (University of Texas, Austin, TX; Dartmouth College, Hanover, NH).

It has been suggested that CAI may be more effective with groups than with individuals (Gerell, 1972) or, where equally effective, more efficient (Okey and Majer, 1975, 1976). It is also suggested that whenever the programming is sufficiently flexible to respond to students in an adaptive manner rather than forcing them through a single sequence of content presentations, superior learning can result (Lahey, et al., 1973). Thus, an interactive lecture using a feedback loop that adapts the subsequent presentation of a computer simulated experiment may produce increases in learning efficiency and effectiveness. The one study which attempted to do this (Dunkum, 1979) found no statistically significant differences in student short-term achievement.

In that study, three Advanced Placement (AP) physics B classes (N=45) taught by instructor A, along with four general physics classes (N=78) and one AP physics C class (N=10) both taught by instructor B were selected from one Northern Virginia suburban high school.

The students were randomly assigned within their classes to experimental (CAL) and control groups. Following assignment and attrition, the experimental (CAL) and control groups were found to be statistically equivalent (α=0.05) in terms of sex, mean Otis-Lennon IQ, entry-level algebra skills, and entry-level physics knowledge. The groups contained similar numbers of blacks and orientals. No attempt was made to determine whether the groups were similar in socio-economic status.

Students in general physics and AP physics B classes were found to significantly differ statistically (α=0.05) in terms of mean Otis- Lennon IQ, entry-level algebra skills, and entry-level physics knowledge. Accordingly, the classes were studied separately. The AP physics C class was not studied separately due to its small size.

A pretest-posttest control group design was employed in which a treatment consisted of the experimental (CAL) subjects participating in a computer assisted lecture (given to control subjects on the following day without the computer but by the same teacher) with an associated pretest given approximately ten school days before and an identical posttest the day after the control group lecture. The achievement tests (with a mean KR reliability coefficient of 0.76) each contained two subtests, one concept-oriented and one experiment-oriented, with questions from behavioral objectives where the teachers based the lecture on.

Four lectures were presented to each group during the second semester of the 1977-78 school year — one of the Millikan experiment, another on Young's double slit experiment, the others, on the motion of charged particles in uniform B-fields experiment, and on the photoelectric effort experiment.

Computer simulated experiments for projection by classroom TV monitor were written in BASIC for use with a Wang 2200 mini-computer under instructor control during the experimental (CAL) group lectures.

Three null hypotheses concerning student achievement were tested to determine whether statistically significant differences ($\alpha=0.05$) existed between experimental (CAL) and control groups regarding (1) whole test and subtests, pretest and posttest group mean scores within groups, (2) whole test and subtests group mean pretests-posttest difference scores between groups, and (3) proportions of correct responses on any test item. These null hypotheses and their associated statistical tests are presented in full at the end of chapter three and discussed in detail in chapter five.

Comparison of the pretest and posttest scores and the item responses on the tests between the experimental (CAL) and control groupings of all subjects, of general physics subjects, and of AP physics B subjects suggested that:

1. Experimental (CAL) and control groups had equivalent entry-level knowledge of the content of the four lectures, as measured by their associated pretests.

2. Experimental (CAL) and control groups learned additional content associated with the four physics lectures, such learning may reasonably have resulted from the groups' attendance at those lectures.

3. On the whole, experimental (CAL) and control groups learned equally.

4. Differences in learning between experimental (CAL) and control groups appear infrequently, and when they do appear, favor the experimental (CAL) group most often with respect to content which may reasonably be assumed as having been more extensively treated in experimental (CAL) group lectures than in control group lectures, namely, material tested usually by the experiment subtest portions of the achievement tests and treating objectives associated with the computer program used.

SUMMARY

With respect to the literature of CSE (and CAL), one might conclude:

1. CSE is least effective when merely generating data or verbal explanations.

2. CSE is most effective when related to some sensory experience in the student and when the programming is conversational.

3. Vicarious experiences may be as effective as actual apparatus manipulation in supporting CSE.

4. CSE is at the least as effective as traditional laboratory instruction, is more efficient, and, in some circumstances, may be more effective.

5. CSE may be at the least as effective in large group presentations as in one-on-one situations.

6. CAL is no more effective than regular lecture demonstrations, as measured by student short-term learning.

REFERENCES

Alderman, D. L. *Evaluation of the TICCIT Computer-assisted Instructional System.* Princeton Educational Testing Service, 1971.

Alderman D. L., Appel, L. R., and Murphy, R. T. "PLATO and TICCET: An Evaluation of CAI in the Community College." *Educational Technology* 18 (April 1978): 40-45.

Alpert, D., and Bitzer, D. L. "Advances in Computer-based Education." *Science* 167 (20 March 1970): 1582-90.

Anastacio, E. J., and Alderman, D. L. *Evaluation of the Educational Effectiveness of PLATO and TICCIT.* Princeton: Educational Testing Service, 1973; Bethesda, Md.: ERIC Document Reproduction Service, ED 088 934, 1974.

Anastacio, E. J., and Morgan, J. S. *Factors Inhibiting the Use of Computers in Instruction.* Princeton: EDUCOM, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 069 219, 1973.

Anger, C. D., and Prescott, J. R. "A Monte Carlo Simulation of Brownian Motion in the Freshman Laboratory." *American Journal of Physics* 38 (June 1970): 716-19.

Baltz, A. J., and Machlup, S. "Instructional Uses of the Computer: Orbiting Satellites for the Elementary Laboratory". *American Journal of Physics* 39 (March 1971): 333.

Barrett, R. S. "The Computer Mentality". *Phi Delta Kappan* 49 (April 1968): 430-34.

Bates, G. C. "The Role of the Laboratory in Secondary School Science Programs." *In What Research Says to the Science Teacher: Volume 1,* edited by M. B. Rowe. Washington: National Science Teachers Association, 1978.

Bell, N. T., and Moon, R. D. *Teacher Controlled Computer Assisted Instruction.* East Lansing: Michigan State University, 1969; Bethesda, Md.: ERIC Document Reproduction Service, ED 044 028, 1971.

Bennett, W. R. *Scientific and Engineering Problem-Solving with the Computer.* Englewood Cliffs, N.J.: Prentice-Hall, 1976.

Bitzer, D. L. "Computer Assisted Education". *TIP* 12 (June 1973): 173-78.

Bitzer, D. L., Blomme, R. W., Sherwood, B. A., and Tenczar, J. *The PLATO System and Science Education.* CERL (Computer-based Education Research Laboratory) Report X-17. Urbana: University of Illinois, 1970; Bethesda, Md.: ERIC Document Reproduction Service, ED 042 624, 1970.

Blackwell, F. W. "Probable State of Computer Technology by 1980". *Journal of Educational Data Processing* 9 (1972): 12-17.

Blum, R., ed. *Computer Based Physics: An Anthology.* College Park, Md.: Commission on College Physics, 1969.

————. *Computers in Undegraduate Science Education.* College Park, Md.: Commission on College Physics, 1971; Bethesda, Md.: ERIC Document Reproduction Service, ED 072 648, 1973.

Blum, R., and Bork, A. M. *Computers in the Science Curriculum.* College Park, Md.: Commission on College Physics, 1969; Bethesda, Md.: ERIC Document Reproduction Service, ED 058 032, 1972.

————. "Computers in the Physics Curriculum". *American Journal of Physics* 38 (August 1970): 959-70.

Boblick, J. M. "The Use of Computer Simulation in the Teaching of High School Physics". *Science Education* 54 (January 1970): 77-82.

————. "Writing Chemical Formulas: A Comparison of Computer Assisted Instruction with Traditional Teaching Techniques". *Science* 56 (April 1972): 221-25.

————. "Discovering the Conversation of Momentum Through the Use of a Computer Simulation of a One-Dimensional Elastic Collision". *Science Education* 56 (July 1972): 337-44.

Bork, A. M. "Computers in High School Physics". *The Physics Teacher* 6 (September 1968): 295-305.

————. *Physics Dialogs for Student Use.* Irvine: University of California, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 060 618, 1972.

————. "Effective Computer Use in Physics Education". *American Journal of Physics* 43 (January 1975: 81-88.

————. *Current Status of the Physics Computer Development Project.* Irvine: University of California, 1975; Bethesda, Md.: ERIC Document Reproduction Service, ED 107 201, 1975.

————. *Student Computer Dialogs without Special Purpose Languages.* Irvine: University of California, 1975; Bethesda, Md.: ERIC Document Reproduction Service, ED 102 947, 1975.

————. "New Computers for Education". *Journal of College Science Teaching* 5 (September 1976): 59.

Bork, A. M., and Ballard, R. *Computer Graphics and Physics Teaching.* Irvine: University of California, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 060 616, 1972.

Bork, A. M. and Luehrmann, A. *Introductory Computer-Based Mechanics.* College Park, Md.: Commission on College Physics, 1968.

Bork, A. M., and Marasco, J. "Modes of Computer Usage in Science". *The Journal 4* (February 1977): 13-19.

Bork, A. M., and Peckham, H. *Computer Needs for Teaching Physics.* Irvine: University of California, 1971; Bethesda, Md.: ERIC Document Reproduction Service, ED 060 623, 1972.

Bork, A. M., and Sherman, N. *A Computer-Based Dialogue for Deriving Energy Conservation for Motion in One-Dimension: A Computer Simulation for the Study of Waves.* Irvine: University of California, 1971; Bethesda, Md.: ERIC Document Reproduction Service, ED 058 033, 1972.

Braun, L. "The Digital Computer as a General Purpose Simulator". *Journal of Educational Data Processing* 7 (1970): 151-80.

————. Huntington Computer Project. Maynard, Mass.: Digital Equipment Corporation, 1971.

————. *Huntington Two Project.* Maynard, Mass.: Digital Equipment Corporation, 1972.

Bright, R. L. "The Time is Now". *American Education* 3 (October 1967): 12-14.

Bron, W. E. "Computer Aided Physics Laboratory Instruction: Project CAPLIN". *American Journal of Physics* 40 (March 1972): 380-86.

Bukoski, W. J., and Korotkin, A. L. "Computing Activities in Secondary Education". *Educational Technology* 16 (January 1976): 9-23.

Bundy, R. F. "Computer-Assisted Instruction — Where Are We?" *Phi Delta Kappan* 49 (April 1968): 424-29.

Butman, R. C. "CAI: There Is a Way To Make It Pay, But Not In Conventional Schooling". *Educational Technology* 13 (December 1973): 5-9.

Campbell, G. M., and Jansson, L. C. "Computer Costs and Capabilities for Instruction and Administration". *NASSP Bulletin* 58 (March 1974): 54-63.

Castleberry, S. J. and Lagowski, J. J. "Individual Instruction Using Computer Techniques". *Journal of Chemical Education* 47 (January 1970): 91.

Castleberry, S. J., Montague, E. J., and Lagowski, J. J. "Computer Based Teaching Techniques in General Chemistry". *Journal of Research in Science Teaching* 7 (1970): 197-208.

Chesley, R. E. "Using Computers in High School Physics". *The Physics Teacher* 9 (May 1971): 272-75.

Clivieri, P. "Computer Usage Trends: A Survey of the Impact of Computers at the Secondary Level on Higher Education." *ACM SIGCUE Bulletin* 10 (April 1976): 14-16.

Corrin, M. L. "Lecture Demonstration with an Analog Computer." *Journal of Chemical Education* 43 (November 1966): 579-81.

Cox, M. J. *Computers in Undegraduate Physics Teaching.* Guildford: Institute for Educational Technology, University of Surrey, 1975.

Craig, N. C., Sherertz, D. D., Carlton, T. S., and Ackerman, M. N. "Computer Experiments." *Journal of Chemical Education* 48 (May 1971): 310-14.

Culp, G. *Computer-Assisted Instruction in Undergraduate Organic Chemistry: Design, Application, and Evaluation — Technical Report* 10. Austin: University of Texas, 1971; Bethesda, Md.: ERIC Document Reproduction Service, ED 072 630, 1973.

____________. *The Use of Computer-based Instruction in Undergraduate Organic Chemistry.* Austin: University of Texas, 1975; Bethesda, Md.: ERIC Document Reproduction Service, ED 110 015, 1975.

Darnowski, V. S. "Computer-Aided Instruction: A Tool for Science Teaching in the Seventies." *The Science Teacher* 35 (January 1968): 22-26.

Dean, P. "Simulation of Experiments." *The Physics Teacher* 10 (April 1972): 204-05.

Douglas, J. H. "Learning Technology Comes of Age". *Science News* 110 (11 September 1976): 170-74.

Dowling, J. "A 'Canned' Computer Lab". *American Journal of Physics* 40 (January 1972): 76.

____________. "Canning — An Approach to the Physics Laboratory." *American Journal of Physics* 43 (March 1975): 237.

Dowling, J., and Rice, P. "A 'Canned' Computer Lab for Measurement of RC Time Constants." *American Journal of Physics* 40 (December 1972): 1346.

Dunkum, W. W. *Achievement and Student-Teacher Verbal Interactions in High School Physics Lectures With and Without Computer Simulated Demonstration Experiments.* American University, Washington, D.C., May, 1979.

Dunnagan, T. "Technical Transport Problems." *Creative Computing* (November-December 1975): 26-27.

————, ed. *Documentation Guidelines — Project CONDUIT.* Hanover: Dartmouth College, 1976.

Dunnagan, T. *Technical Transfer Guidelines — Project CONDUIT.* Hanover: Dartmouth College, 1976.

Edwards, J., Norton, S., Taylor, S., Dunseldorp, R. and Weiss, M. "Is CAI Effective?" AEDS Journal 7 (Summer 1974): 122-26.

————. "How Effective is CAI? A Review of the Research." *Educational Leadership* 33 (November 1975): 147-49.

Ehrlich, R. *Physics and Computers.* Boston: Houghton, Mifflin Company, 1973.

Evans, A. *Physics of Energy and Environment — Project COMPUTE.* Hanover: Dartmouth College, 1976.

Finn, E. J. "An Interactive Instruction Session in Ray Tracing." *American Journal of Physics* 41 (June 1973): 818-21.

Fletcher, J. D., Suppes, P., and Jamison, D. T. *A Note on the Effectiveness of Computer-Assisted Instruction.* Stanford: Institute for Mathematical Studies in the Social Sciences, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 071 450, 1973.

Fox, W. T. "Computer-Oriented Laboratory Exercises for Geology and Oceanography." *Journal of Geological Education* 17 (1969): 125-34.

Fromer, R. "Author Support Requirements of a Computer Based Instructional System." *Education Technology* 13 (April 1973): 18-19.

Fulton, J. P., and Hazeltine, B. *Instruction Using Experiments in a Computer.* Washington: National Center for Educational Research and Development, 1973; Bethesda, Md.: ERIC Document Reproduction Service, ED 096 104, 1975.

Gerard, R. W. "The New Computerized Shape of Education." In *Inventing Education for the Future.* New York: Chandler, 1967.

Gerrell, G. E. *Computer-Assisted Instruction of College Physics Students in Small Groups.* Washington: National Center for Educational Research and Development, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 064 952, 1972.

Graham, D., Schwarz, G., and Hansen, D. *Multimedia Simulation of Laboratory Experiments in a Basic Physics Lesson on Magnetism.* Tallahassee: Computer-Assisted Instruction Center, Florida State University, 1970; Bethesda, Md.: ERIC Document Reproduction Service, ED 551, 1971.

Greenslade, T. B. "Two Computer Physics Games." *American Journal of Physics* 41 (January 1973): 134-35.

Greenspan, D. "Arithmetic Applied Mathematics." *Computers and Mathematics with Applications* 1 (October 1977): 1-24.

Griswold, R., and Haugh, J. F. Analog Computer Simulation." *Journal of Chemical Education* 45 (September 1968): 576-80.

Grossberg, A. B. "An Improved Version of the Prism Spectrometer Experiment." *American Journal of Physics* 37 (May 1969): 599.

Haddad, D. J. "Simple Pendulum Experiment." *American Journal of Physics* 36 (March 1968): 273.

Hall, K. A. "Computer-Assisted Instruction: Problems and Performance." *Phi Delta Kappan* 52 (June 1971): 628-31.

Hammond, K. R. "Computer Graphics as an Aid to Learning." *Science* 172 (28 May 1971): 903-08.

Hansen, D. N. *The Role of Computers in Education During the 70's.* Tallahassee: CAI Center, Florida State University, 1970; Bethesda, Md.: ERIC Document Reproduction Service, ED 043 238, 1971.

Hansen, D. N., Dick, W., and Lippert, H. *Research and Implementation of Physics Via Computer-Assisted Instruction.* Tallahassee: CAI Center, Florida State University, 1968; Bethesda, Md.: ERIC Document Reproduction Service, ED 059 610, ED 059 611, 1972.

Hearn, D. D., and Reid, A. "Classroom Use of Interactive Computer Graphics." *American Journal of Physics* 38 (July 1970): 846.

Hedges, W. D. "Computer-Assisted Instruction and the Schools." *Education Leadership* 30 (January 1973): 361-65.

Hickey, F. R. "Technique for Producing Computer-Animated Films." *The Physics Teacher* 13 (October 1975): 414-16.

Hollen, T. T., Bunderson, C. V., and Dunham, J. L. "Computer-Based Simulation of Laboratory Problems in Qualitative Analysis." *Science Education* 55 (April 1971): 131-36.

Hughes, W. R. "A Study of the Use of Computer Simulated Experiments in the Physics Classroom." Ph.D. dissertation, Ohio State University, 1973; Ann Arbor, Mich.: University Microfilms, 74-3205, 1973.

Inman, D.J., Reaves, L. J., and Vaugh, G. C. "Rediscovery of Shell's Law Via the Computer." *The Physics Teacher* 13 (October 1975): 416-17.

Isaacs, G. L. *Interdialect Translatability of the BASIC Programming Language.* ACT Technical Bulletin No. 11. Iowa City: CONDUIT/CENTRAL, 1973.

Jamison, D. "Estimated Costs of Computer-Assisted Instruction for Compensatory Education in Urban Areas." *Educational Technology* 10 (September 1970): 49-57.

Jamison, D. Suppes, P., and Wells, S. "Effectiveness of Alternative Instructional Media: A Survey." *Review of Educational Research* 44 (Winter 1974): 1-67.

Jirgal, G.H. "A Computer-Assisted Course in Intermediate Mechanics." *American Journal of Physics* 40 (March 1972): 437-40.

Jones, A. *Multimedia Computer-Assisted and Computer-Managed Instruction.* Paris: Centre for Educational Research and Innovation, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 066 023, 1972.

Jones, J.E. "Computer-Simulated Experiments in High School Physics and Chemistry." Ph.D. Dissertation, Iowa State University, 1972; Ann Arbor, Mich.: University Microfilms, 73-3897, 1972.

Jones, J.L. *Physics Tutorial Problem Workbook — Project CONDUIT.* Hanover: Dartmouth College, 1973.

Koch, W.J. *The Use of Computers in Instruction in Secondary Schools.* Washington: National Association of Secondary School Principals, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 070 289, 1973.

Kromhout, O.M. *Effect of Computer Tutorial Review Lessons on Exam Performance in Introductory College Physics.* Tallahassee: CAI Center, Florida State University, 1972; Bethesda, Md.: ERIC Document Reproduction Service, ED 072 654, 1973.

————. "Effectiveness of Computer Review Lessons in a General-Education Physics Course." Ph.D. dissertation, The Florida State University, 1975; Ann Arbor, Mich.: University Microfilms, 76-2659, 1975.

Kromhout, O.M., Edwards, S., and Schwarz, G. "A Computer Guided General Education Physics Course." *American Journal of Physics* 37 (October 1969): 995-1007.

Lahey, G.F., Hurlock, R.E., and McCann, P.H. *Post Lesson Remediation and Student Control of Branching in Computer Based Training.* San Diego: Naval Personnel and Training Research Laboratory, 1973: Bethesda, Md.: ERIC Document Reproduction Service, ED 083 797, 1974.

Lang, C.R. "Computer Graphic Simulations in High School Physics." Ph.D. dissertation, Kansas State University, 1975; Ann Arbor, Mich.: University Microfilms, 76-17116, 1976.

Lankton, R.S. Lankton First Year Algebra Test Manual. Rev. ed. New York: Harcourt, Brace and World, Inc., 1965.

Liao, T. "Analog Computer Simulations in High School Science Courses." *The Physics Teacher* 10 (May 1972): 245-48.

Lindsay, R.E. *CAI Physics Experiments.* Yorktown Heights, N.Y.: International Business Machines, 1969.

Lower, S.K. *Making the Computer Make a Difference in College Chemistry.* Burnaby, B.C.: Simon Fraser University, 1973; Bethesda, Md.: ERIC Reproduction Service, ED 079 994, 1973.

Lunetta, V.N. "The Design and Evaluation of a Series of Computer Simulated Experiments for Use in High School Physics." Ph.D. dissertation, The University of Connecticut, 1972; Ann Arbor, Mich.: University Microfilms, 72-32153, 1972.

————. "Computer-Based Dialogs: A Supplement ot the Physics Curriculum." *The Physics Teacher* 12 (September 1974): 355-56.

————. Newton's Law: *A Computer-Based Simulation for Introductory Physics.* Technical Report No. 1 Iowa City: University of Iowa, 1974; Bethesda, Md.: ERIC Document Reproduction Service, ED 095 017, 1974.

Lunetta, V.N., and Blick, D. "Evaluation of a Series of Computer-Based Dialogs in Introductory Physics." *AEDS Journal* 7 (Winter 1973): 33-42.

Luskin, B. "An Identification and Examination of Obstacles to the Development of Computer-Aided Instruction." Ph.D. dissertation, University of California, 1970.

Martin, D. "Analog and Hybrid Simulation in Science Education." *Educational Technology* 12 (April 1972): 62-63.

Meiners, H.F., ed. *Physics Demonstration Experiments.* New York: The Ronald Press, 1972.

Meiser, C.W. "Electronic Blackboard — The Use of a Computer Terminal in the Classroom." ON-LINE 5 (January 1976): 2-6.

Merrill, J.R. "Simple Computer Programs in Introductory Geometrical Optics." *Ameican Journal of Physics* 39 (April 1971): 442-46.

————. *Use of Computers in Introductory Physics Teaching.* Bethesda, Md.: ERIC Document Reproduction Service, ED 05 034, 1971.

————. *Quantum Mechanics.* Cupertino, Cal.: Hewlett-Packard, 1973.

————. *Using Computers in Physics.* Boston: Houghton-Mifflin, 1976.

Messina, R.J. "Instructional Uses of the Computer: Laboratory Exercises on Eclipsing Binaries." *American Journal of Physics* 40 (May 1972): 760.

Mitre Corporation. *An Overview of the TICCIT Program.* McLean, Va.: The Mitre Corporation, 1974; Bethesda, Md.: ERIC Document Reproduction Service, ED 089 663, 1974.

Muller, M.T., Allan, J.J., and Lagowski, J.J. *The Use of On Line Video Projection Techniques in Computer-Augmented Lectures.* Austin: University of Texas, 1973; Bethesda, Md.: ERIC Document Reproduction Service, ED 081 204, 1973.

Nevison, J.M., and Hoogendyk, C.G. *Moving the Program: The Final Report of Project CONDUIT at Dartmouth College.* Hanover: Dartmouth College, 1974: Bethesda, Md.: ERIC Document Reproduction Service, ED 093 340, 1974.

Niblock, J.S. "Computer Use in the Public Schools: A Survey." *AEDS Journal* 4 (September 1970): 1-16.

Norberg, A.M. "Individualizing Instruction in Large Undergraduate Biology Laboratories." *American Biology Teacher* 37 (November 1975): 470-72.

Oettinger, A.G. *Run, Computer, Run.* Cambridge: Harvard University Press, 1969.

Okey, J.R., and Majer, K. "Individual and Small Group Instruction with Computer-Assisted Instruction." Paper presented at the American Educational Research Association Annual Meeting, Washington, D.C., April 1975; Bethesda, Md.: ERIC Document Reproduction Service, ED 107 239, 1975.

————. "Indivdual and Small-Group Learning with Computer-Assisted Instruction." *Audio Visual Communications Review* 24 (Spring 1976): 79-86.

Ostrander, P. "Instructional Uses of the Computer: Program FORCE." *American Journal of Physics* 43 (January 1975): 89-90.

Peckham, H. *Geometrical Optics.* Cupertino, Cal.: Hewlett-Packard, 1972.

————. *Mechanics.* Cupertino, Cal.: Hewlett-Packard, 1972.

————. *Statistical Mechanics.* Cupertino, Cal.: Hewlett-Packard, 1972.

————. *Waves.* Cupertino, Cal.: Hewlett-Packard, 1972.

————. *Computers, BASIC, and Physics.* Reading: Addison-Wesley Publishing Company, 1975.

Rigney, J.W., and Lutz, K.A. *The Effects of Interactive Graphic Analogies on Recall of Concepts in Chemistry.* Technical Report No. 75, Los Angeles: University of Southern California, 1975; Bethesda, Md.: ERIC Document Reproduction Service, ED 109 639, 1975.

Robson, J.W. *Computer Orineted Physics Problems.* College Park, Md.: Commission on College Physics, 1971.

Rodewald, L.B., and Lagowski, J.J. "Use of Computers in Organic Chemistry Instruction." *Journal of Chemical Education* 47 (February 1970): 134-36.

"Schoolmen Like CAI but Worry about the Cost: School Administrators Opinion Poll." *Nations Schools* 82 (October 1968): 66-67.

Schwarz, G., Kromhout, O.M., and Edwards, S. "Computers in Physics Instruction." *Physics Today* 22 (September 1969): 40-49.

Schwendeman, R.H. "Computer Simulation of Experimental Data." *Journal of Chemical Education* 45 (October 1968): 665-68.

Shirer, D.L. "Computers and Physics Teaching, Part I: Digital Computers. *American Journal of Physics* 33 (July 1965): 575-83.

Showalter, V.M. "Conducting Science Investigations Using Computer-Simulated Experiments." *The Science Teacher* 37 (October 1970): 2-24.

Smith, S.G. "Use of Computers in the Teaching of Organic Chemistry: PLATO System." *Journal of Chemical Education* 47 (September 1970): 608-11.

Smith, S.G., and Sherwood, B.A. "Educational Uses of the PLATO Computer System." *Science* 192 (23 April 1976): 344-50.

Statz, J. "Interview with Don Bitzer: PLATO." *ACM SIGUE Bulletin* 9 (April 1975): 4-6.

Suppes, P. "Arithmetic Drills and Review on a Computer-Based Teletype." *The Arithmetic Teacher* 13 (April 1966): 303-09.

————. "Computers in the Classroom: Handling Student Differences." *Ohio Schools* 45 (November 1967): 18-21; *Wisconsin Journal of Education* 100 (January 1968): 8-11; *Education Digest* 33 (October 1967): 8-10.

————————. "Computer Technology and the Future of Education." *Phi Delta Kappan* 49 (April 1968): 420-23.

————————. *Progress Report: Stanford Program in Computer-Assisted Instruction.* Stanford: Institute for Mathematical Studies in the Social Sciences, 1968.

————————. "How Far Have We Come? What's Just Ahead." *Education Digest* 34 (February 1969): 6-8.

Suppes, P., and Morningstar, M. *Evaluation of Three Computer-Assisted Instructional Progams.* Stanford: Institute for Mathematical Studies in the Social Sciences, 1968; Bethesda, Md.: ERIC Document Reproduction Service, ED 031 408, 1968.

————————. "Computer-Assisted Instruction." *Science* 166 (1969): 343-50.

Taylor, S., Edwards, J., Norton, S., Dusseldorp, R.V., and Weiss, M. "The Effectiveness of CAI." Paper presented at the Annual Convention of the Association for Educational Data Systems, New York, 8 May 1974; Bethesda, Md.: ERIC Document Reproduction Service, ED 092 074, 1974.

Thomsen, D.E. "Physics Without Limits." *Science News* 12 (17 September 1977): 186-87.

Vinsonhaler, J.F., and Bass, R.K. "Summary of Ten Major Studies on CAI Drill and Practice." *Educational Technology* 12 (July 1972): 29-32.

Visich, M., and Braun, L. *The Use of Computer Simulations in High School Curricula.* Stony Brook: State University of New York, 1974; Bethesda, Md.; ERIC Document Reproduction Service, ED 098 740, 1974.

Wang, A.C. *Index to Computer-Based Instruction.* Milwaukee: Instructional Media Laboratory, University of Wisconsin, 1976.

Wang Laboratories. *Wang BASIC Language Reference Manual.* Tewksbury, Mass.: Wang Laboratories, 1976.

Weinstock, H.R. "Critique of Criticisms of CAI." *Educational Forum* 37 (May 1973): 427-33.

Weinstock, H.R., and Wiley, S. "A Cooperative Computer-Curriculum Development Project." *Journal of College Science Teaching* 6 (January 1977): 190-91.

Wiley, S. "Student Exercises in Statistical Physics." *American Journal of Physics* 43 (March 1975): 270.

Wilkins, C.L., and Klopfenstein, C.E. "Simulation of NMR Spectra: Computers as Teaching Devices." *Journal of Chemical Education* 43 (January 1966): 10-13.

Yu, D.U.L. *The Use of a PDP-11/20 Computer in a Non-Calculus General Physics Course.* Bethesda, Md.: ERIC Document Reproduction Service, ED 082 503, 1974.