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This technical report is concerned with the evaluation of three Computer-Assisted Instruction (CAI) Programs - The Drill-and practice Program in Elementary School Mathematics, The Brentwood Tutorial Mathematics Program, and the Russian Program. Among the results reported were (1) the drill-and-practice mathematics program used in Mississippi and California showed positive results for grades 1 through 6 in Mississippi and for some other grades in California in comparison with matched control groups, (2) the tutorial mathematics program used with first and second graders in a deprived area in California had a statistically significant positive effect for slow learners in grade 1 in comparison with traditional classroom instruction, and (3) in the Russian course for college students, CAI students performed significantly better than control students on final examinations for two of the three academic quarters for the first-year course and on a quarter examination used in the second-year course. (RP)

# EVALUATION OF THREE COMPUTER-ASSISTED INSTRUCTION PROGRAMS

BY

PATRICK SUPPES AND MONA MORNINGSTAR

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(Continued on inside back cover)

# EVALUATION OF THREE COMPUTER-ASSISTED INSTRUCTION PROGRAMS

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Evaluation of Three Computer-assisted Instruction Programs[1]

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Abstract

The drill-and-practice mathematics program run in Mississippi and California showed positive results for grades 1 through 6 in Mississippi and for some grades in California in comparison with matched control groups. The tutorial mathematics program run with first and second graders in a deprived area in California had a statistically significant positive effect only for slow learners in grade 1 in comparison with traditional classroom instruction. In a Russian course for college students, CAI students performed significantly better than control students on final examinations for two of the three academic quarters for the first-year course and on the only quarter examination evaluated thus far in the second-year course.

# Evaluation of Three Computer-assisted Instruction Programs[1]

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Although computer-assisted instruction has reached the operational stage in various parts of the curriculums in a number of places in the United States, very few "hard data" evaluations of student achievement in these programs have yet been published. The purpose of this paper is to report the results of the evaluative testing of students in three programs that have been running at Stanford over the past several years. The first is the drill-and-practice program in elementary mathematics. Results are reported for schools in California for the 1966-67 and 1967-68 academic years and for schools in McComb, Mississippi for the 1967-68 academic year. The second program is a first- and second-grade tutorial mathematics curriculum conducted at the Brentwood School in East Palo Alto, California. Results of evaluative testing for 1966-67 and 1967-68 are given. The third program is the tutorial curriculum in elementary Russian at Stanford University, which is in its second year of operation at the time of writing this paper.

We shall not attempt a wide-ranging evaluation of computer-assisted instruction in terms of reporting observations of student behavior; the results of student, parent or teacher questionnaires; or detailed analyses of curriculum performance. Some results of this kind have already been published in Suppes, Jerman, and Brian (1968). We also shall not report evaluation of the Stanford tutorial programs in reading. For this the reader is referred to Atkinson (1968). The purpose of the present paper is to concentrate on the classical comparison of experimental groups with control groups and to compare their relative rates of achievement. In the case of the two mathematics programs, the primary instruments of evaluation were Stanford Achievement Tests (Kelley, Madden, Gardner, & Rudman, 1963), which are not a product of Stanford University but are commercial tests. In the tutorial mathematics program, individualized Stanford-Binet intelligence tests were used. In the Russian program, which was under the direct supervision of Professor Joseph Van Campen at Stanford University, the evaluation consisted of comparative performance on midterm and final examinations in the course.

It should be emphasized that the primary purpose of this paper is to present without extensive interpretation the evaluative results. We do conclude with some discussion of the results, but the main function of the paper is to present in standard data form the results of the testing.

## 1. Drill-and-practice Program in Elementary-school Mathematics

The drill-and-practice program began in the spring of 1965 with 41 fourth-grade children who were given daily arithmetic drills on a teletype machine in their classroom. By the end of the 1965-66 school year, 270 students in grades 3 through 6 in three California elementary schools were participating in the program. For a detailed account of 1965-66, see Suppes, Jerman, and Brian (1968). During the 1966-67 school year, the program was further expanded to include grades 1 through 6 with more than 1,500 students involved. Student participation increased again during 1967-68 with approximately 1,000 students in California, 600 students in Mississippi, and 1,100 students in Kentucky.

Because changes occurred in the curriculum and the computer system as the program developed during the first two years, statistical evaluation was not begun until the 1966-67 academic year. During 1966-67 and 1967-68, Stanford Achievement Tests were used for evaluation. The primary aim of the program was to provide drill and practice in the skills of arithmetic, especially computation, as an essential supplement to regular classroom instruction. The concepts presented to the students for drill and review at the computer terminal have been previously introduced in the classroom by the teacher.

For the 1966-67 and 1967-68 school years, the curriculum material, for each of grades 1 through 6, was arranged sequentially in blocks to coincide approximately with the development of mathematical concepts introduced in several text series. There were 20 to 27 concept blocks for each grade level. Each concept block included a pretest, five days of drill, a posttest, and sets of review drills and review posttests. A brief description of the material in each concept block is shown in Table 1.

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Insert Table 1 about here

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Parallel forms of a test were prepared for each concept block. The test consisted of an equal number of problems from each of five levels of difficulty. For a given student, different forms of the test were assigned for the pretest and for the posttest in each block. The form assigned for the pretest was counterbalanced among students. The forms of the test not assigned as a pretest or a posttest for a given student were divided into halves and used as review posttests for that student.

TABLE 1

Concept Blocks for Grades 1-6, Drill-and-Practice Program 1966-67

| Grade 1 | | Grade 2 | |
|---|---|---|---|
| Block | Description | Block | Description |
| 1. | Counting, How many, 0-9 | 1. | Addition facts to 10, horizontal |
| 2. | Counting in sequence | 2. | Subtraction facts to 10, horizontal |
| 3. | Sums to 4 | 3. | Addition and subtraction facts to 10, vertical |
| 4. | Sums to 4, vertical, mixed | 4. | Addition facts to 10, mixed horizontal and vertical with variables |
| 5. | Differences to 4, vertical, mixed | 5. | Mixed addition and subtraction to 10, mixed horizontal and vertical |
| 6. | Sums to 6, vertical, mixed | 6. | Counting by 1's and 2's; finding what comes before and after |
| 7. | Sums to 7, vertical, mixed | 7. | Addition, 11, 12, 13, horizontal and vertical |
| 8. | Differences to 7, vertical, mixed | 8. | Subtraction, 11, 12, 13, horizontal and vertical |
| 9. | Sums to 9, vertical, mixed | 9. | Mixed addition and subtraction, horizontal and vertical to 13 |
| 10. | Sums to 10, vertical only | 10. | Units of measure; counting; inequalities |
| 11. | Differences to 10, vertical only | 11. | Addition, 14, 15, 16, horizontal and vertical |
| 12. | Sums to 10 with variables | 12. | Subtraction, 14, 15, 16, horizontal and vertical |
| 13. | Differences to 10 with variables | 13. | Mixed addition and subtraction, horizontal and vertical, 14, 15, 16 |
| 14. | Sums and differences to 10, horizontal | 14. | Word problems; units of measure; counting to 200 |
| 15. | Sums and differences to 10, vertical format | 15. | Fractions, 1/2, 1/3, 1/4 |
| 16. | Sums and differences to 10 with variables | 16. | Addition, 17, 18, 19, horizontal and vertical |
| 17. | Sums to 10, 3-digit numbers | 17. | Subtraction, 17, 18, 19, horizontal and vertical |
| 18. | Column addition, sums with 10's, no regrouping | 18. | Mixed addition and subtraction, horizontal and vertical |
| 19. | Column subtraction, no regrouping | | |
| 20. | Mixed addition and subtraction in columns, facts to 10 | | |
| 21. | Mixed addition and subtraction, inequalities | | |
| 22. | Mixed 1- and 2-digit column addition and subtraction | | |
| 23. | Sums to 10 with form a + b = c + d | | |
| 24. | Sums to 10 with variables, form a + b = c + d | | |
| | (continued) | | (continued) |

Table 1 (continued)

| Grade 1 (continued) | | Grade 2 (continued) | |
|---|---|---|---|
| Block | Description | Block | Description |
| 25. | Special addition and subtraction | 19. | Units of measure; counting; inequalities |
| 27. | Special mixed drills | 20. | Multiplication, 2's and 3's to 9 (i.e., 2 x 0 = ___ ... 2 x 9 = ___ ) |
| | | 21. | C and A Laws for addition, subtraction, and multiplication |
| | | 22. | Achievement Tests |
| | | 23. | Mixed drill: fractions; units of measure; inequalities; multiplication |
| | | 24. | Mixed drill: addition, subtraction, multiplication |
| | | 25. | Special addition and subtraction |
| | | 27. | Special mixed drills |

Table 1 (continued)

| Grade 3 | | Grade 4 | |
|---|---|---|---|
| Block | Description | Block | Description |
| 1. | Mixed addition and subtraction, horizontal format, sums 0-18 | 1. | Addition, 1 and 2 digit, vertical and horizontal |
| 2. | Addition, sums 0-18, horizontal and vertical | 2. | Subtraction, 1 and 2 digit, vertical and horizontal |
| 3. | Subtraction, sums 0-18, horizontal and vertical | 3. | Subtraction, 2 and 3 digit, vertical format |
| 4. | Addition, no carry, vertical (2 addends, 3 digit) and (3 addends, 2 digit) | 4. | Addition, 2 and 3 digit, column addition |
| 5. | Subtraction, no borrow, vertical 2 and 3 digit | 5. | Mixed addition and subtraction, vertical format, limits same as Blocks 3 and 4; word problems |
| 6. | Addition, vertical with carry | 6. | Measure: length, time Weight, money: some word problems |
| 7. | Subtraction, with borrow | 7. | Multiplication, 2's $\rightarrow$ 9's, horizontal format; levels by products |
| 8. | Mixed addition and subtraction, carry and borrow | 8. | Mixed addition, subtraction, and multiplication; word problems; Add. and subt., vertical format; limits same as Blocks 3, 4, and 7 Multiplication, horizontal format |
| 9. | Measure and word problems and inequalities | 9. | CAD Laws: days 1-4 apply law<br>day 5 identify law |
| 10. | Column addition and subtraction; add; subtract | 10. | Division: ladder form, no remainders, level by products, single-digit divisor, 2's $\rightarrow$ 9's |
| 11. | Measure, inequalities | 11. | Multiplication: 2's through 12's horizontal format, level by products |
| 12. | Multiplication, horizontal, 2's and 3's | 12. | Fractions: identify (to 1/8) simple reducing |
| 13. | Mixed multiplication and division, 2's and 3's | 13. | Mixed drill: mult., div., fract., inequalities, word problems; same limits as Blocks 10, 11, 12 (horizontal and vertical) |
| 14. | Division, ladder form 1 digit into 2 digit | 14. | Long division: ladder form, 1-digit divisor, 2-4 digit dividend, random divisors |
| 15. | CAD Laws, add<br>subt.<br>mult. | | (continued) |
| 16. | Mixed drill: measure, word problems, inequalities | | |
| 17. | Fractions | | |
| 18. | Multiplication, horizontal 2's $\rightarrow$ 9's | | |
| 19. | Mixed drill: multiplication, division, fractions | | |
| 20. | Division, ladder form 1 digit into 3 digit | | |
| | (continued) | | |

Table 1 (continued)

| Grade 3 (continued) | | Grade 4 (continued) | |
|---|---|---|---|
| Block | Description | Block | Description |
| 21. | Multiplication, vertical 1 x 2 digit | 15. | CAD Laws: days 1-3 using law; days 4-5 identify law |
| 22. | Achievement Tests | 16. | Fractions: addition, subtraction, reducing |
| 23. | Mixed drill: column add; subt.; multiply | 17. | Measure: time, money, liquid measure, length, weight; some word problems |
| 24. | CAD Laws | 18. | Multiplication: multiples of 10, inequalities |
| 25. | Special addition and subtraction drills | 19. | Mixed drill: mult., div., frac. CAD Laws; same limits as Blocks 14, 15, 16, 18; some word problems |
| 27. | Special mixed drills | 20. | Long division: ladder form, 1-digit divisor, 2-4 digit dividend, random remainders |
| | | 21. | Fractions |
| | | 22. | Achievement Tests |
| | | 23. | Mixed drill: long division, fractions, negative numbers; same limits as 20, 21, 22 |
| | | 24. | Estimation of quotients in division |
| | | 25. | Special addition and multiplication drills |
| | | 26. | Special subtraction and division drills |
| | | 27. | Special mixed drills |

Table 1 (continued)

| Grade 5 | | Grade 6 | |
|---|---|---|---|
| Block | Description | Block | Description |
| 1. | Addition, vertical and horizontal<br>1, 2, and 3 digit<br>Level 4, carry to 10's<br>Level 5, carry to 10's or 100's | 1. | Mixed drill: 1/2 column, add., subt.; 1/2 multiplication; some involving decimals |
| 2. | Subtraction, vertical and horizontal, 1 and 2 digits | 2. | Multiplication: 2's → 12's, level by products, horizontal format |
| 3. | Mixed addition and subtraction, 3, 4 digit; mixed borrow, carry | 3. | Column multiplication:<br>(1 digit) x (2 digit) through (2 digit) x (3 digit) |
| 4. | Multiplication, 2's → 12's<br>Level by products, horizontal | 4. | Division: ladder form, 1-digit divisor |
| 5. | Multiplication, vertical<br>Up to 1 x 4 digit<br>Carry, no carry | 5. | Fractions: factors, reducing, comparing, simple add., subt. |
| 6. | Mixed drill: multiplication, division, fractions | 6. | Mixed drill: inequalities, decimals, word problems, exponents, add., subt., mult., div. |
| 7. | Division: ladder form<br>Level 3: 1 into 3 digit | 7. | Division: ladder form to 2-digit divisors |
| 8. | Measure | 8. | Fractions: add, subtract |
| 9. | Multiplication, vertical<br>2 digit, 2's → 12's | 9. | Measure: length, time, money, temperature, liquid measure |
| 10. | Mixed drill: column add, subtraction, multiplication, decimals, CAD Laws | 10. | Ratio: per cent |
| 11. | Division: ladder format<br>Level 3: 2 into 3 or 4 digit | 11. | Division: ladder form, 2-digit divisor |
| 12. | Fractions | 12. | Mixed drill: fractions (add., subt., mult.), ratio, per cent, div. decimals (add., subt.) |
| 13. | Measure, decimals | 13. | Fractions: decimal, add., subt., mult. |
| 14. | CAD Laws | 14. | CAD Laws: days 1-4 apply law<br>day 5 identify law |
| 15. | Division: ladder format | 15. | Multiplication: multiples of 10, horizontal format |
| 16. | Fractions | 16. | Division: ladder form, 2-digit divisors, 3-5-digit dividends |
| 17. | Mixed drill: multiplication, division, fractions | 17. | Mixed drill: fractions (+, -, x, ÷), fractions (column add.) CAD Laws, division |
| 18. | Measure | | |
| 19. | Fractions, decimals | | |
| 20. | Mixed drill: multiplication, division, decimals | | |
| | (continued) | | (continued) |

Table 1 (continued)

| Grade 5 (continued) | | Grade 6 (continued) | |
|---|---|---|---|
| Block | Description | Block | Description |
| 21. | Division, ladder format | 18. | Measures: all, including a few metric; area, volume |
| 22. | Achievement Tests | 19. | Ratio, per cent |
| 23. | Mixed Drill: summary | 20. | Mixed drill: all operations, per cent, decimal mult. |
| 24. | Estimation of quotients in division | 21. | Negative numbers: add, subtract, multiply |
| 25. | Special addition and multiplication drills | 22. | Achievement Tests |
| 26. | Special subtraction and division drills | 23. | Mixed drill: summary |
| 27. | Special mixed drills | 24. | Estimation of quotients in division |
| | | 25. | Special addition and multiplication drills |
| | | 26. | Special subtraction and division drills |
| | | 27. | Special mixed drills |

For each day of drill, five drills, one at each of the five levels of difficulty, were prepared; a total of 25 drills per block. Several sets of review drills for each block were also prepared at the five defined levels of difficulty. The drills and the review drills for the most difficult level, level 5, and the level 5 problems on the tests were rewritten for the 1967-68 school year at a higher difficulty level than those presented in the 1966-67 curriculum.

Each student responded to problems presented on a teletype located in the school. The Model-33 teletypes were connected to the PDP-1 computer at Stanford via telephone lines. After the student signed into the program by typing his assigned student number and his first name, the teletype printed his last name and presented the appropriate set of problems. The temporal pace of the problem presentation was determined by the student.

The materials presented to the student for the seven days required for each concept block were:

| | |
|---|---|
| Day 1 | pretest; |
| Days 2-5 | drill and review drill; |
| Day 6 | drill and review posttest; |
| Day 7 | posttest. |

Examples of the format for several types of problems are shown in Figure 1.

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Insert Figure 1 about here

---

The teletype printed each individual problem and then positioned itself to accept the answer in the appropriate place. The student typed in the answer. If his answer was correct, he proceeded to the next problem.

```
GRADE  BLOCK       PROBLEM

  1      1       HOW MANY M S...
                 R M R R M M
                 M R M M R M

                 ---

  1      2       COUNT.
                 10 11 --- 13

  1      4       3 + 1 = ---


  2      4       9 + 1 = 5 + ---

  2      5       7 + N = 9
                     N = ---

  2      9       1 1
                 + 2
                 ---

  2      9       1 0
                 - 3
                 ---

  3      1       --- + 35 = 38

  3      4        2 3
                  1 4
                 +2 1
                 ----

  4      2        3 6
                 -2 3
                 ----

  4      6       3 YD. AND 2 FT. = --- FT.

  4      9       36 X (28 + 34) = (--- X 28) + (--- X 34)

  5      4       --- X 11 = 33

  5      5       2 9 4
                    X4
                 -----

  5      6       1/3 OF 18 = ---

                    -----
  6      4       5 / 9 5

  6      5       TYPE THE MISSING NUMERATOR OR DENOMINATOR.
                 2/3 = ---/9

  6      6       TYPE < OR = OR >
                 3 + 8 --- 9 + 4

  6      7       (17 X ---) + 9 = 28722
```

Fig. 1. Samples of problem formats for grades 1 through 6, drill-and-practice program.

If he input the wrong answer, the teletype printed NO, TRY AGAIN and presented the problem again. If he made a second error, the teletype printed NO, THE ANSWER IS ... and presented the problem once more. If the student input the wrong answer for the third time, he was given the correct answer and the teletype automatically proceeded to the next problem. The student was allowed from 10 to 40 seconds to respond, depending upon the type of problem presented. If a student took more than the allotted time to input his answer, the procedure just described was followed, but the teletype printed TIME IS UP, TRY AGAIN in place of NO, TRY AGAIN.

The level of difficulty of the first day of drill was determined by the student's performance on the pretest according to the criteria presented in Table 2. The level of difficulty of each successive drill in the same concept block was determined by the student's performance level on the preceding day's drill. Thus, if the student's performance on a drill was 80 per cent or greater his next drill was one difficulty level higher. A score of less than 60 per cent branched him down a level for the next drill. Otherwise, the student remained at the same difficulty level for the next drill.

Whereas the drill content was the same for all students in a class with only the difficulty level changing as a function of the preceding day's performance, the content of the review drills differed among students as a function of the total past performance history of each student. The computer individually selected the review drills to correspond to the content of the past block that had the lowest posttest score for that student, with the restriction that he was not reviewed for two seven-day blocks in a row on the same past block. The level of difficulty of the review drills was determined by the posttest according to the criteria presented in Table 2;

Insert Table 2 about here

the difficulty level remained constant for all four days of review. Once a student had received a set of review drills on a given concept block, the score on the review posttest, given on the sixth day, replaced the previous posttest on that concept block for determining the concept block and difficulty level for future review drills.

The branching structure for a seven-day sequence of problems is shown in Figure 2. Each darkened circle represents a drill; each open circle

Insert Figure 2 about here

represents a review drill. To make up for absences, a student could take more than one drill per day, branching accordingly after each drill.

## Evaluation

To evaluate the effectiveness of the drill-and-practice program, the arithmetic portion of the Stanford Achievement Test (SAT) was administered to both experimental and control classes. Four different levels of the SAT were used. Each level had one, two, or three arithmetic sections which are described briefly in Table 3. Unless otherwise noted,

Insert Table 3 about here

the tests were administered in October and again in May by either the classroom teacher or a member of the staff at the Institute.

TABLE 2

Branching Criteria

| From Pretest to Drill[a] | | From Drill to Drill | |
|---|---|---|---|
| Per cent correct | Level assigned for drill | Per cent correct on drill $D_i$ | Level assigned for drill $D_{i+1}$ |
| 0 - 19 | 1 | 0 - 59 | next lower level |
| 20 - 39 | 2 | 60 - 79 | same level as $D_i$ |
| 40 - 59 | 3 | 80 - 100 | next higher level |
| 60 - 79 | 4 | | |
| 80 - 100 | 5 | | |

[a] Also from Posttest to Review

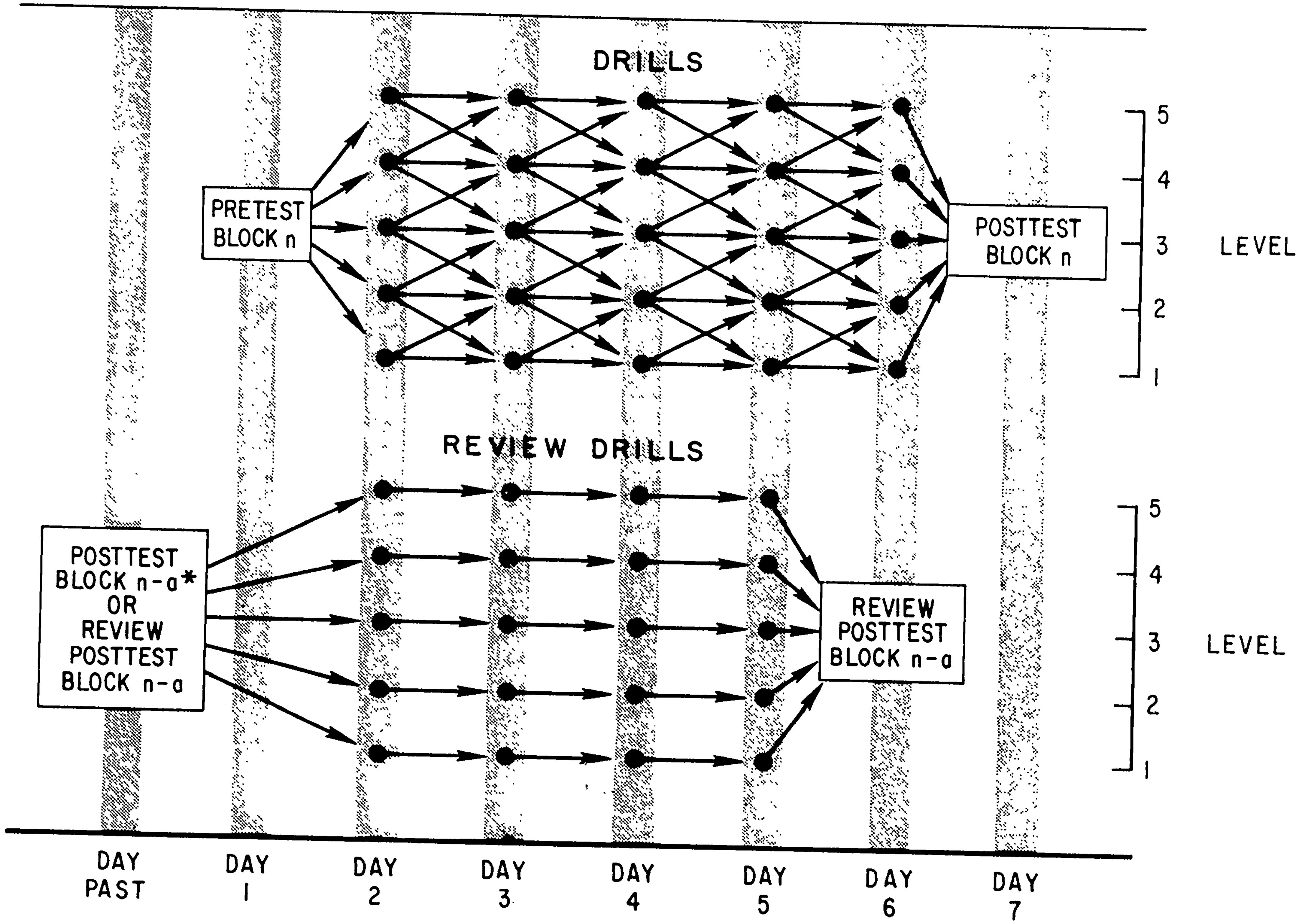


Fig. 2. Branching structure for a seven-day concept block.

*n-a Block with lowest posttest performance.

TABLE 3

Description of Stanford Achievement Test Batteries - Arithmetic Portion

| |
|---|
| Primary I: Middle of grade 1 to middle of grade 2<br>A. Arithmetic, 63 items<br>(Measures, problem solving, number concepts) |
| Primary II: Middle of grade 2 to end of grade 3<br>A. Arithmetic Computation, 60 items<br>(Addition, subtraction, multiplication, division)<br>B. Arithmetic Concepts, 46 items<br>(Numbers, measures, problem solving) |
| Intermediate I: Beginning of grade 4 to middle of grade 5<br>A. Arithmetic Computation, 39 items<br>(Addition, subtraction, multiplication, division)<br>B. Arithmetic Concepts, 32 items<br>(Place value, meanings and interrelationships of operations, average, per cent, etc.)<br>C. Arithmetic Applications, 33 items<br>(Reasoning and problem solving in area, ratio, volume, averages, graphs, etc.) |
| Intermediate II: Middle of grade 5 to end of grade 6<br>A. Arithmetic Computation, 39 items<br>(Addition, subtraction, multiplication, division)<br>B. Arithmetic Concepts, 32 items<br>(Place value, meanings and interrelationships of operations, average, per cent, etc.)<br>C. Arithmetic Applications, 39 items<br>(Reasoning and problem solving in area, ratio, volume, graphs, averages, etc.) |

Although the publishers of SAT recommend that the test in May for grades 2 and 5 be one level higher than the test given in October (Table 3), whenever possible we administered different forms of the same test within a given grade; i.e., Primary II in grade 2 and Intermediate II in grade 5. However, when the administration of the SAT was an integral part of a testing program within a school system requiring adherence to the SAT manual, we were unable to dictate which tests or forms were administered. This fact must be kept in mind when deviations from standard experimental design occur.

California 1966-67

Tests were administered to four schools for the 1966-67 evaluation. Grades 3 through 6 were tested in Experimental School A and Control School B; grades 4 through 6 were tested in Experimental School C and Control School D. In each case, the control school was located in the same district as the experimental school. The pretest and posttest administered was Primary II for grade 3, Intermediate I for grade 4, and Intermediate II for grade 6 in all four schools. For the fifth grade, Schools A and B administered the Intermediate II test for both the pretest and posttest; Schools C and D administered the Intermediate I as a pretest and Intermediate II as a posttest.

The difference between the posttest and pretest grade placement on the SAT Computation Section for each grade for School A versus School B and for School C versus School D was examined. The statistical results of t-tests and the average pretest and posttest grade placement are shown in Table 4.

Insert Table 4 about here

TABLE 4

Grade-Placement Scores on the SAT: California, 1966-67

| | Grade | Pretest | | | | Posttest | | Posttest-Pretest | | t | df |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Experimental | N | Control | N | Experimental | Control | Experimental | Control | | |
| School A vs. B | 3 | 2.9 | 51 | 3.0 | 63 | 3.9 | 3.6 | 1.0 | .6 | 2.50** | 112 |
| | 4 | 3.9 | 60 | 3.9 | 75 | 4.7 | 5.3 | .9 | 1.4 | -2.93** | 133 |
| | 5 | 4.6 | 66 | 4.6 | 81 | 5.2 | 6.3 | .7 | 1.7 | -4.74** | 145 |
| | 6 | 4.9 | 50 | 5.2 | 70 | 7.1 | 7.1 | 2.1 | 1.9 | .95 | 118 |
| School C vs. D | 4 | 3.7 | 61 | 3.8 | 63 | 5.4 | 4.8 | 1.7 | 1.0 | 4.50** | 122 |
| | 5 | 5.4 | 63 | 4.9 | 77 | 6.2 | 5.4 | .8 | .6 | 1.32 | 138 |
| | 6 | 5.8 | 58 | 6.0 | 56 | 7.4 | 7.1 | 1.6 | 1.1 | 2.19* | 112 |

* $p < .05$
** $p < .01$

The increase in performance level for students in the experimental school was significantly greater than in the control schools for grade 3 in School A and for grades 4 and 6 in School C.

At the end of the school year we learned that after examining the results of the pretesting at their school the teachers and administrators at School B, a control school, instituted an additional 25 minutes per day of classroom instruction and practice in arithmetic for grades 4 and 5. Since the performance increase of the students in Control School B in grades 4 and 5 was significantly greater than in Experimental School A, we would conclude that 25 extra minutes of classroom drill can be more beneficial than 5 to 8 minutes per day of computer-based drill. The greater gains for Control School B compared with Control School D supports the conclusion that the performance of the students in School B was a function of the extra drill in the classroom. The effect of classroom drill, however, does not detract from the effectiveness of the drill-and-practice program. Whereas the classroom approach required 25 more minutes of the teacher's time devoted to arithmetic and 25 minutes less of the student's time devoted to nonmathematical topics, the drill-and-practice program required no extra time from the teacher and the student lost only 5 to 8 minutes from non-mathematical subjects.

Since the SAT Concepts and Applications Sections do not include many items contained in the drill-and-practice curriculum, they are not as appropriate as the Computation Section for testing the effectiveness of the program. However, the increase in performance level for the students in the experimental schools was significantly greater than in the control schools on the Concepts Section for grade 6, $t(118) = 2.18$, $p < .01$, in

School A; and for grade 4, $t(122) = 2.37$, $p < .01$, and grade 5, $t(138) = 4.21$, $p < .01$, in School C. On the Applications Section of the SAT the experimental classes performed significantly better than the control classes in grade 4, $t(122) = 1.96$, $p < .05$, and in grade 5, $t(138) = 2.50$, $p < .01$, in School C.

California 1967-68

The administration of the SAT for evaluation of the 1967-68 program included grades 1 through 6 in seven different schools. Two of these schools included both experimental and control students, two included only experimental students, and three included only control students. Within the experimental group from 5 to 9 classes were tested at each grade level; within the control group, from 6 to 14 classes were tested at each grade level. Although the testing program for 1967-68 was more advantageous than that for 1966-67, in terms of number of students tested, the distribution of students among schools and classes made it impossible to conduct matched comparisons as was done in the 1966-67 evaluation. The test level administered as the pretest in October and as the posttest in May was Primary I for grade 1, Primary II for grades 2 and 3, Intermediate I for grade 4, and Intermediate II for grades 5 and 6.

Again a t-test was used to determine the difference between the experimental and control students in terms of change in performance from October to May within each grade. The results of this comparison and the average pretest and posttest grade placement are shown in Table 5. The

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Insert Table 5 about here

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TABLE 5

Grade-Placement Scores on the SAT: California, 1967-68

| Grade | Pretest | | | | Posttest | | Posttest-Pretest | | t | df |
|---|---|---|---|---|---|---|---|---|---|---|
| | Experimental | N | Control | N | Experimental | Control | Experimental | Control | | |
| 1 | 1.39 | 58 | 1.30 | 267 | 2.64 | 2.51 | 1.24 | 1.21 | .33 | 323 |
| 2 | 2.06 | 65 | 2.16 | 238 | 3.21 | 2.90 | 1.15 | .74 | 5.19** | 301 |
| 3 | 3.00 | 136 | 2.85 | 210 | 4.60 | 3.89 | 1.59 | 1.05 | 6.28** | 344 |
| 4 | 3.40 | 103 | 3.49 | 185 | 4.86 | 5.00 | 1.46 | 1.50 | -.38 | 286 |
| 5 | 4.98 | 149 | 4.44 | 90 | 6.40 | 5.32 | 1.42 | .88 | 4.03** | 237 |
| 6 | 5.42 | 154 | 5.70 | 247 | 7.44 | 7.61 | 2.02 | 1.91 | .93 | 399 |

** $p < .01$

students receiving computer-based drill and practice had a significantly greater increase in performance level than the control students on the SAT Computation Section in grades 2, 3, and 5.

The performance of students in the experimental group was significantly better than that for students in the control group on the Concepts Section for grade 3, $t(344) = 4.13$, $p < .01$, and on the Applications Section for grade 6, $t(399) = 2.14$, $p < .05$.

Mississippi 1967-68

The administration of the SAT for evaluation of the first year of drill and practice in Mississippi included grades 1 through 6 in 12 different schools. Eight of these schools included both experimental and control students, three included only experimental students, and one included only control students. Within the experimental group from 1 to 10 classes were tested at each grade level; within the control group, from 2 to 6 classes were tested at each grade level.

The testing of the students in Mississippi was not as consistent, in terms of experimental design, as the testing in California. On the other hand, the computer-assisted instruction program itself operated in an environment that was far removed from the Stanford group responsible for the program, so that the lack of detailed control of the testing by the Stanford research group was somewhat compensated for by the independent environment in which the program was tested. The Primary I level of the SAT was administered as a pretest to students in the first grade in February rather than October. The posttest was given in May. For the remaining grades, the pretest was given in October and the posttest in May. For the second grade, the Primary I level was given as a pretest and the Primary II as the posttest. For grades 3 and 4 the pretest and posttest were the same with Primary II for grade 3 and Intermediate I for grade 4. For grade 5 all of the control students and two classes of experimental students received the Intermediate I level for a pretest and the Intermediate II level for a posttest; one experimental class was administered the Intermediate I test for both pre- and posttest. Although both the pretest and the posttest for grade 6 were at the Intermediate II level, two of the ten classes in the experimental group and one of the six classes in the control group received the same, rather than different, form for the two testing sessions.

The t-value and the average pretest and posttest grade placement for each grade are shown in Table 6. The performance of the experimental

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Insert Table 6 about here

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students improved significantly more than that of the control students in all six grades. The difference between the experimental group and the control group was largest in grade 1 where, in only three months, the average increase in grade placement for experimental students was 1.14 as compared with .26 for control students.

The performance of students in the experimental group was significantly better than that of the students in the control group on the Concepts Section for grade 3, $t(76) = 3.01$, $p < .01$, and grade 6, $t(433) = 3.74$, $p < .01$, and on the Applications Section for grade 6, $t(433) = 4.09$, $p < .01$. In grade 4, the control group improved more than the experimental group on the Concepts Section, $t(131) = -2.25$, $p < .05$.

TABLE 6

Grade-Placement Scores on the SAT: Mississippi 1967-68

| Grade | Pretest | | | | Posttest | | Posttest-Pretest | | t | df |
|---|---|---|---|---|---|---|---|---|---|---|
| | Experimental | N | Control | N | Experimental | Control | Experimental | Control | | |
| 1 | 1.41 | 52 | 1.19 | 62 | 2.55 | 1.46 | 1.14 | .26 | 3.69** | 112 |
| 2 | 1.99 | 25 | 1.96 | 54 | 3.37 | 2.80 | 1.42 | .84 | 5.23** | 77 |
| 3 | 2.82 | 22 | 2.76 | 56 | 4.85 | 4.04 | 2.03 | 1.26 | 4.64** | 76 |
| 4 | 2.26 | 58 | 2.45 | 77 | 3.36 | 3.17 | 1.10 | .69 | 2.63** | 131 |
| 5 | 3.09 | 83 | 3.71 | 134 | 4.46 | 4.60 | 1.37 | .90 | 3.43** | 215 |
| 6 | 4.82 | 275 | 4.36 | 160 | 6.54 | 5.48 | 1.72 | 1.13 | 5.18** | 433 |

** $p < .01$

Comparison between California and Mississippi

The average grade placement on the pretest for grades 1 through 3 was similar for the California and Mississippi experimental groups (Tables 5 and 6). The difference between the two groups increased in grades 4 through 6 with the Mississippi students performing at a lower level than the California students. In spite of the significant gains by the experimental groups compared with the control groups in Mississippi, the discrepancy in grade placement between the California and Mississippi experimental groups for grades 4 through 6 was larger on the posttest than on the pretest. Thus, the overall superiority of the experimental program in Mississippi was related more to a lesser increase in performance level for the control schools in Mississippi than to a greater change in performance level for the Mississippi experimental groups compared with the California experimental groups. In this connection it is important to emphasize that the California schools were all located in relatively affluent middle-class neighborhoods, and the average family income and educational level was undoubtedly higher, although we did not collect systematic data on economic and social variables.

2. Brentwood Tutorial Mathematics Program

This project was designed to explore the feasiblility of using tutorial computer-assisted instruction in mathematics as an integral part of the elementary-school program. During the 1966-67 school year, 45 students in the first grade participated in the program; during the 1967-68 school year, 75 students in the second grade participated; of the 75 second graders, 21 had been in the first-grade program. For the 1966-67 group, Stanford-Binet tests were given in the fall and the SAT was given in the spring to the 45 first graders active in the mathematics program and to the 48 remaining first graders in the same school who were participating in the CAI reading program. For the 1967-68 evaluation, the SAT was administered in the fall and in the spring to 66 of the second graders at Brentwood and to 81 second graders at a control school in the same district. (For a detailed analysis of individual student performance in the curriculum itself, see Suppes and Morningstar, 1969.)

The Brentwood system was tutorial with the computerized aspect of the learning of elementary mathematics completely integrated with classroom work. A member of our staff taught all mathematics not presented in the computer program. Curriculum material was presented by audio and visual displays; the student responded on a standard keyboard or used a light pen to touch one of the answer choices displayed on the cathode-ray tube (CRT). (The computer system at Brentwood was an IBM 1500.)

The curriculum for the first graders contained 400 lessons covering the topics of counting, numerals, addition, subtraction, linear measure, sets and set notation, and geometry. The content and scope of the curriculum were drawn largely from Sets and Numbers, Book 1 (Suppes, 1965), with the addition of some topics such as oral story problems that cannot, by their nature, be adapted to a textbook format. An outline of the programmed curriculum is shown in Table 7.

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Insert Table 7 about here

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Since the programmed lessons were tutorial, many of the lessons relied on oral explanations synchronized with changing visual displays. The

TABLE 7

Curriculum Outline for Grade 1 - Brentwood Tutorial Mathematics Program

| Number of Lessons | | | | Description |
|---|---|---|---|---|
| Book | Core curriculum | Remedial branches | Drills | |
| 1 | 8 | 1 | 0 | Using the machine |
| 2A | 7 | 5 | 0 | Introduction to sets |
| 2B | 3 | 3 | 0 | Matching equal sets |
| 3A | 5 | 4 | 0 | Union of two sets with one member |
| 3B | 3 | 1 | 2 | Union of empty sets |
| 4 | 11 | 4 | 1 | Geometry - learning to identify squares, circles, triangles, and line segments |
| 5 | 7 | 6 | 0 | Balancing set equations |
| 6A | 8 | 7 | 0 | Introducing the numerals 0, 1, and 2 |
| 6B | 9 | 8 | 1 | Introducing N notation with equivalent numerals Introducing the numerals 3 and 4 |
| 7A | 5 | 5 | 1 | Sums with N notation (0-4) |
| 7B | 5 | 0 | 0 | Sums with numerals. Keyboard responses. (0-4) |
| 8 | 8 | 2 | 0 | Review |
| 9 | 8 | 7 | 1 | Addition |
| 10 | 9 | 2 | 1 | Geometry |
| 14A | 4 | 0 | 1 | Measuring line segments |
| 14B | 4 | 0 | 1 | Concave figures, meaning of "half" |
| 15 | 6 | 7 | 1 | Balancing addition equations 0-9 |
| 16 | 7 | 5 | 1 | Number words, one-six |
| 17A | 6 | 5 | 2 | Number words, zero-ten; sums to nine with three addends |
| 17B | 9 | 1 | 1 | Subtraction |
| 18A | 11 | 6 | 0 | Subtraction combinations through six |
| 18B | 6 | 2 | 2 | Relating addition and subtraction |
| 19A | 12 | 1 | 2 | Geometry, matching similar figures |
| 19B | 11 | 3 | 1 | Subsets |
| 20A | 4 | 3 | 2 | Review |
| 20B | 6 | 3 | 2 | Subtraction $c - a = b$, $7 < c < 9$ |
| 21A | 11 | 0 | 0 | Counting and typing to 19 |
| 21B | 6 | 2 | 0 | Place value |
| 22 | 17 | 6 | 1 | Addition on the number line |
| 23 | 14 | 1 | 1 | Counting by tens |
| 24 | 19 | 2 | 2 | Counting by fives |
| 25 | 14 | 2 | 1 | Addition combinations, 10-15 |

lessons were short (the average length was less than 10 problems), and explanations were simple and direct. Generally the problems within one lesson were all of the same type; the first few were accompanied by explanatory audio messages; the remainder were practice problems.

The students received their programmed instruction in a room which contained 17 student stations and a proctor station for use by the teachers on duty. The student stations were separated by four-foot partitions that extended far enough from the walls to provide a degree of privacy for the students. When the children arrived in the student station room, they looked for their names on the CRT screen at their assigned stations, put on their headsets, and started their program by touching the light pen to a smiling face displayed on the CRT. After the allotted time for the class, approximately 20 minutes, the students were signed off automatically as they completed their current lesson and the message YOU HAVE BEEN SIGNED OFF appeared on the CRT. The children entered an adjacent classroom and joined a teacher who escorted them back to their homeroom.

Both explanatory and practice problems contained provisional audio messages that were heard only by the students who responded incorrectly or who failed to respond within a reasonable time. For example, for one problem, a drawing of a car and a drawing of a truck surrounded by set braces and followed by an equal sign was presented on the CRT; this problem was accompanied by the audio message "There are two members in this set." After this message, two more sets, one empty and one containing a train and a steamshovel, each preceded by a box, were displayed below the initial set; the choices were accompanied by the audio instructions, "Find another set with two members." At this point a small "p" (for pen) was displayed in the corner of the CRT as a signal to the student to respond. If the student touched his light pen to the box in front of the correct choice, a smiling face was displayed and he heard, "Yes, the sets have the same number of members," and presentation of the next problem began.

If the student did not respond within 20 seconds he heard, "Which set below has two members?" If the student responded incorrectly, he heard the audio message "Point to the box next to the set with two members," and saw a sad face. For most problems in the curriculum, students were allowed three chances to produce the correct answer. After three incorrect responses, a brief audio message accompanied the display of the correct answer or an arrow pointing to the correct choice.

For most lessons the number of initial correct responses to the practice problems was accumulated and compared with a criterion. As soon as a student made the required number of correct responses, he was allowed to skip the remaining problems and to begin the next lesson. As soon as a student failed criterion, for instance, three incorrect responses if the criterion was seven out of nine problems, he was branched immediately to a remedial lesson containing the same kinds of problems, but with a slower development of ideas using simpler vocabulary and sentence structure. If a student failed criterion on a remedial lesson, his program stopped, and an automatic call for assistance from a proctor was typed at the proctor station.

This mode of branching permitted students to progress through the curriculum at a rate consonant with their ability to master the concepts. Thus, all students in the class were not required to work on the same concept at the same time as in the drill-and-practice program. In fact, the faster students were separated considerably from the slower students in terms of curriculum material covered during the year.

The classroom activity, completely coordinated with the programmed instruction, included (a) use of physical objects to introduce concepts presupposed by the programmed lessons; (b) work originally planned as programmed lessons; (c) remedial work for individual children; and (d) enrichment material for individual or group use.

The curriculum presented during 1967-68 to the second graders contained lessons covering the topics of sets, numbers, relations, fractions, addition, subtraction, multiplication, division, connections between operations, geometry, measure, and problem solving. An outline of the programmed curriculum is shown in Table 8.

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Insert Table 8 about here

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Observation of student behavior during the first year of the program (1966-67) indicated the advisability of several changes in the structure of the programmed lessons. Children in the first year who failed to respond to a problem within 20 seconds heard an additional audio message giving more detailed instructions and were then allowed additional time for a response. In the second-grade lessons (1967-68) an audio message, sometimes accompanied by visual clues, was presented to the student who requested help by touching the "help" button. This routine decreased the number and length of mandatory audio messages in the program.

The remedial-lesson sequences were also changed. In the first-grade curriculum, remedial material was presented as a block of problems directly

TABLE 8

Curriculum Outline for Grade 2 - Brentwood Tutorial Mathematics Program

| Book | Topic | Book | Topic |
|---|---|---|---|
| 1 | Numerals 0-4. Introduction to sets. | 18 | Review. |
| 2 | Sums 0-4, more and less, subtraction 0-4, circles and line segments, pennies and dimes, empty set, congruence. | 19 | Geometry puzzles, oral drill sums 0-12. |
| | | 20 | Subtraction to 15, "memory" geometry. |
| 3 | Reflexivity of equality, numerals 5-10, sums 4-10, equal sets, number line. | 21 | Subtraction to 16, add multiples of ten. |
| | | 22 | Review. |
| 4 | Column addition 0-5, numerals 11-19, subtraction 5-10, counting from n. | 23 | Rectangles. |
| | | 24 | One-third. |
| 5 | Before, commutativity of addition. | 25 | Ordinals to tenth. |
| 6 | Value of dimes and pennies, sums 10-20, ordinals first-third. | 26 | "1/2" and "1/3", subtraction to 19. |
| 7 | Union of sets. | 27 | Subtracting multiples of 10. |
| 8 | Similarity, addition and subtraction as inverses, type addition equations. | 28 | Review. |
| | | 29 | Number words to "ten". |
| 9 | Open and closed, one-half. | 30 | Review. |
| 10 | Typing subtraction equations, column subtraction. | 31 | Numerals to 100. |
| | | 32 | Missing addends. |
| 11 | Subtraction 10-13, count by twos, solve set equations, numerals (20, 30, ... 90). | 33 | Labeling points, inside and outside, subsets. |
| 12 | Unequal symbol. | 34 | Oral drill for sums to 15. |
| 13 | Review. | 35 | " < " and " >." |
| 14 | Triangles, "tens". | 36 | One-fourth, oral drill for sums and differences to 20, "1/4". |
| 15 | Counting by tens, difference of sets. | | |
| 16 | Regions. | 37 | Review. |
| 17 | Nickels, squares. | 38 | Counting by fives. |

(continued)

Table 8 (continued)

| Book | Topic | Book | Topic |
|---|---|---|---|
| 39 | Review. | 45 | Construction of rectangles. |
| 40 | More and less to 100. | 46 | Puzzle rearrangements, more and less for fractions. |
| 41 | Number line to 100. | 47 | Concavity of plane figures. |
| 42 | Review. | 48 | Addition and subtraction of 2-digit and 1-digit number. |
| 43 | Review. | 49 | Missing subtrahend. |
| 44 | Review. | 50 | Column addition of 2-digit numbers without carrying. |

linked to each lesson in the core curriculum. Thus, students who failed to meet criterion received immediate and detailed remedial instruction. In the second-grade curriculum, a pretest on every concept was given to each child. A child who met criterion on the pretest continued to other core material or to enrichment material, while a child who failed criterion did six to eight remedial lessons spaced over several days.

## Evaluation

During the 1966-67 school year, 93 students were enrolled in the first grade at Brentwood. On the basis of reading scores achieved on an SAT administered in the fall, the students were grouped into four classes by the principal of the school. Two classes were at a low level on reading readiness and two classes were at a medium level on reading readiness. Forty-five of these children, one low-level class and one medium-level class, participated in the tutorial mathematics program. The other two classes, 48 children, participated in a computerized reading program and served as a control group for evaluation of the mathematics program.

The Stanford-Binet I.Q., short form, was administered individually to 40 children in the experimental group and to 45 children in the control group during September 1966. The SAT Primary I Battery was administered to all of the first graders in May 1967. The average I.Q. and the average grade placement on the SAT for the experimental and control groups and for the low- and medium-level classes within each group are shown in Table 9.

Insert Table 9 about here

Since the groups were equivalent in terms of I.Q., the SAT grade-placement scores were appropriate for evaluation of differences between groups.

TABLE 9

Average I.Q. and Stanford Achievement Test Grade Placement

Brentwood First Grade

| | Experimental Group | | | Control Group | | |
|---|---|---|---|---|---|---|
| | Low-level | Medium-level | Total | Low-level | Medium-level | Total |
| I.Q. (Fall 1966) | 82.8 | 99.3 | 91.4 | 81.9 | 100.3 | 92.9 |
| Number of students | 19 | 21 | 40 | 18 | 27 | 45 |
| SAT (Spring 1967) | 1.32 | 1.72 | 1.53 | 1.15 | 1.68 | 1.46 |
| Number of students | 21 | 24 | 45 | 20 | 28 | 48 |

There was no significant difference between the total experimental group and the total control group, $t(91) = 1.10$, $p > .05$, or between the medium-level experimental group and the medium-level control group, $t(50) = .56$, $p > .05$. The students in the low experimental group, however, performed significantly better than the students in the low control group, $t(39) = 3.38$, $p < .01$.

For the 1967-68 school year, all the second graders at Brentwood participated in the tutorial mathematics program. The second graders were divided into five classes--two high-level, two medium-level, and one low-level in terms of reading readiness. There were three classes in the control school--one high, one medium, and one low level. For evaluation, 66 second graders at Brentwood and 81 second graders at the control school, a school in the same district as Brentwood, were given the Primary I Battery of the SAT in the fall and the Primary II Battery in the spring. The average pretest and posttest grade placement for the experimental and control groups and for the low-, medium-, and high-level classes within each group are shown in Table 10. There was a significant difference between the two

Insert Table 10 about here

groups in terms of the change in the SAT score from fall to spring with the control students increasing their grade placement more than the experimental students, $t(145) = -2.83$, $p < .01$. In the analysis of the three subgroups, a significant difference was found for the high-level group, $t(45) = -5.03$, $p < .01$, but not for the medium-level group, $t(65) = -.55$, $p > .05$, or the low-level group, $t(31) = .60$, $p > .05$.

Before these results can be interpreted, several facts should be

TABLE 10

Average Stanford Achievement Test Grade Placement

Brentwood Second Grade

| | Experimental Group | | | | Control Group | | | |
|---|---|---|---|---|---|---|---|---|
| | High-level | Medium-level | Low-level | Total | High-level | Medium-level | Low-level | Total |
| Pretest (Fall 1967) | 1.87 | 1.59 | 1.44 | 1.66 | 1.73 | 1.64 | 1.54 | 1.64 |
| Posttest (Spring 1968) | 2.48 | 2.38 | 1.84 | 2.36 | 2.96 | 2.50 | 1.86 | 2.51 |
| Posttest - Pretest | .61 | .79 | .40 | .64 | 1.23 | .86 | .32 | .87 |
| Number of students | 25 | 24 | 17 | 66 | 22 | 43 | 16 | 81 |

noted about the systems within which the testing and experimentation occurred. In both the first and second grades, the programmed curriculum differed from the curriculum taught in a first- or second-grade classroom, the difference being greater in the second grade. The differences between the two types of curriculum also might have been further decreased in the first grade since both the control and experimental subjects were from the same school. Thus, communication among teachers could have resulted in a change in curriculum for the control classes if the teachers of these classes had discussed their teaching plans with the teachers involved in the experimental program. This interaction between the two types of curriculums would be less likely to occur during the second year, since the two groups of subjects were from different schools.

The differences in the two curriculums were such that the appropriateness of the SAT as an evaluatory test is questionable. The problems in the Computational Section of the Primary II Battery administered to the second grade were more similar to the material taught in the control school than to the material in the CAI curriculum, while much of the material included in the CAI curriculum did not appear on the SAT. A test based on the material taught in the computer-based classroom would not be a satisfactory alternative for evaluating the two teaching methods, unless the control school were presenting the same curriculum. The SAT results, however, proved useful for comparing the students at Brentwood with the students involved in the drill-and-practice program.

Although the low-level class in the experimental first grade at Brentwood performed better on the posttest than the low-level class in the control school, the posttest scores on the SAT for both low-level classes were below the performance level of the first-grade students tested in the spring of 1968 in the Mississippi and California experimental and control schools. (See Tables 5 and 6). Thus, the Brentwood program when compared with a control school program was successful for low-level students, but was not more successful than the drill-and-practice program when SAT scores were used as a performance measure.

The second-grade program at Brentwood was not more effective than the control-school program for teaching the types of computations necessary to perform well on the SAT. In the high ability classes, the control students performed significantly better than the experimental students in terms of their fall to spring change in grade placement and in terms of the final posttest scores. Although the high-level control class was the only class to perform significantly better than the experimental classes, the posttest grade placement (2.96) was similar to the posttest grade placement of the second-grade control groups in California (2.90) and Mississippi (2.80), where the experimental groups were significantly better than the control groups. Unlike the situation reported for the drill-and-practice evaluation for 1966-67 where the superiority of the control group could be attributed to increased attention to mathematics in the control school (grades 4 and 5, Table 4), the superiority of the high-level control students in the Brentwood program, given their similarity to control students in the 1967-68 program, may well be attributed to a failure in the experimental program. Other problems experienced in the program are discussed in the final section of this paper.

3. The Russian Program

The computer-based Russian program was instituted at Stanford in September 1967 under the direction of Professor Joseph Van Campen who designed a program to teach first- and second-year courses at the college level. This program included comprehension of written Russian, comprehension of spoken Russian, and mastery of grammar and syntax. Of the three main components of a college-level language course, i.e., classroom sessions on a daily basis, time in the language laboratory, and regular homework assignments, only the functions of the classroom sessions were assumed by the computer program. In addition to their time at the computer console, the students spent time in the language laboratory and did home assignments. The language-laboratory tapes with drill sheets and homework assignments are prepared by the staff at the Institute.

First-year course, 1967-68

Thirty students began the first-year Russian course in the fall of 1967. Two of the four sections of beginning Russian served as a control group; the other two sections were asked to volunteer for the CAI course. None of the students refused to remain in their assigned sections. The CAI students were required to spend about 50 minutes a day, five days a week at the computer console. A total of 135 lessons were presented to the students in a combined audio and teletype format. The students responded on a Model-35 teletype with a special keyboard using the Cyrillic alphabet.

Although the basic curriculum was the same for all students, there were several remedial branches. At given points in the curriculum, students were tested on several items of a given type and were given remedial instruction on the material covered if their performance on the test block failed to meet a satisfactory standard. Later in the year (1967-68) routines were provided which produced more specific remedial work based on the type of error the student made.

During the period prior to the final examination, lesson summaries for each new lesson and a final summary covering the material for the entire quarter were given to the students. The computer then assessed the student's performance and told him the rules on which he should concentrate his efforts. At subsequent sessions the student was again tested on the material he had missed and was informed where more study was needed. In addition, the student could repeat any lesson or portion of a lesson at the computer console.

Language-laboratory tapes provided material for pronunciation practice and also for testing a student's ability to comprehend spoken Russian. A test at the end of the tape either required the student to transcribe into English a number of Russian sentences, or required the student to respond in writing to oral questions on a paragraph which he had just heard.

In order to evaluate pronunciation, each student made two recordings during each quarter. After each recording session the student was counseled immediately and was told what pronunciation errors he had made and how to correct them.

Second-year course, 1968-69

Instruction began in September 1968 for 19 students enrolled in the second-year Russian course. Thirty-nine lessons, including review lessons, were available for the quarter. The students were at the console for about 45 minutes, five days a week. Homework and study sheets for Lessons 1 through 39 were distributed to the students as they progressed through the lessons. The homework involved translating English sentences into Russian, while the study sheets dealt with new grammar and new vocabulary pertinent to the day's lesson. To develop speech and the ability to write correctly what was heard, the students occasionally were given an option at the conclusion of a teletype lesson to take dictation or to practice pronunciation. These exercises were recorded at the end of the tape used as the audio portion of the regular teletype lessons. Once every two weeks students took written quizzes or read from handwritten or typed scripts. Their pronunciation was corrected and suggestions were made for improvement.

## Evaluation

Of the 30 students starting the first-year computer-based course, 1 left during the first quarter, 3 left between the first and second quarters, 1 left during the second quarter, and 3 left between the second and third quarters. Two new students entered the computer-based section at the beginning of the second quarter. Of the 38 students enrolled for the autumn quarter in the regular Russian section, 10 left the course during the first quarter, 13 left between the first and second quarters, and 3 left between the second and third quarters. Four new students entered the regular section at the beginning of the third quarter, one of these transferred from the computer-based class. Of the 30 students originally enrolled in the computer-based program, 22 (73 per cent) finished all three quarters, whereas of the 38 students in the regular class, only 12 (32 per cent) finished the year's curriculum. This finding suggests that the computer-based course held the interests of the students much better than did the regular course. Probably because Russian is more difficult than French, Spanish, or German for American students, the dropout rate in Russian at Stanford and other universities is traditionally quite high.

Approximately 66 per cent of the content of the final examinations for the autumn and winter quarters was identical for the computer-based and for the regular Russian sections; the complete final examination for the spring quarter was identical for the two groups. The error distribution and the mean number of errors per student for the two groups on the final examination for the autumn, winter, and spring quarters are shown in Tables 11, 12, and 13, respectively. Although the average number of

Insert Tables 11, 12, and 13 about here

errors was lower for the computer-based students in all three quarters, the difference was actually statistically significant for the fall quarter (Mann-Whitney U Test, $p < .001$) and the spring quarter ($p < .05$), but not for the winter quarter. Since the selection process resulting from the poorer students leaving the regular course biases the results on the examination against the computer-based group, the superiority of the computer-based group on the spring examination is more impressive than the difference indicated by the average number of errors.

Of the 19 students enrolled in the second-year Russian course, 12 had participated in the first-year computer course, 7 took the Stanford placement test to qualify for the second-year course and were new to computer-based instruction. Eleven students were enrolled in the second-year Russian course in the regular classroom.

The distribution of errors for the computer-based class and the regular class on the final examination for the fall quarter is shown in Table 14.

Insert Table 14 about here

TABLE 11

Error Distribution for the Common Portion of the Autumn Quarter Final Examination, Russian Program

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 3.5 | 1 | |
| 5 | 2 | 1 |
| 6 | 3 | |
| 7 | 1 | |
| 8 | 2 | |
| 9 | 3 | |
| 11 | 3 | |
| 13 | | 1 |
| 15 | 1 | |
| 16 | 1 | 1 |
| 17 | 2 | |
| 19 | | 1 |
| 21 | 2 | 1 |
| 22 | 1 | 1 |
| 23 | | 2 |
| 25 | 1 | 1 |
| 27 | 3 | |
| 29 | | 1 |
| 30 | | 1 |
| 31 | | 2 |
| 33 | 1 | |
| 34 | | 1 |
| 37 | 1 | |
| 38 | 1 | |
| 41 | | 1 |
| 43 | | 1 |
| 45 | | 1 |
| 53 | | 1 |
| 61 | | 1 |

(continued)

Table 11 (continued)

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 64 | | 1 |
| 65 | | 1 |
| 72 | | 1 |
| 76 | | 1 |
| 79 | | 1 |
| 93 | | 1 |
| 97 | | 1 |
| 120 | | 1 |
| 141 | | 1 |
| Total number of students | 29* | 28** |
| Average number of errors | 15.8 | 49.0 |

* Of the 30 students enrolled, one left during the quarter.

** Of the 38 students enrolled, ten left during the quarter.

TABLE 12

Error Distribution for the Common Portion of the Winter Quarter Final Examination, Russian Program

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 2 | 1 | 1 |
| 6 | 1 | |
| 6.5 | 1 | |
| 8 | 1 | |
| 9.5 | | 1 |
| 10 | 1 | |
| 11 | | 1 |
| 12 | 2 | |
| 13 | | 1 |
| 14.5 | | 1 |
| 16 | 1 | |
| 16.5 | 1 | |
| 18 | 1 | |
| 18.5 | 1 | |
| 19 | 1 | |
| 19.5 | | 1 |
| 21 | 2 | |
| 22.5 | 1 | 1 |
| 23 | 1 | 1 |
| 23.5 | 1 | |
| 24 | 1 | |
| 24.5 | | 1 |
| 25 | 1 | |
| 26.5 | | 1 |
| 27 | 1 | |
| 29.5 | 1 | |
| 30 | | 1 |
| 30.5 | | 1 |
| 32.5 | | 1 |

(continued)

Table 12 (continued)

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 33 | 1 | |
| 37.5 | 2 | |
| 38 | 1 | |
| 39.5 | 1 | |
| 41 | 1 | 2 |
| 47.5 | | 1 |
| Total number of students | 27* | 15** |
| Average number of errors | 21.8 | 25.8 |

* Three of the original students did not enroll, two new students were added, one student did not finish the quarter.

** Thirteen of the original students did not enroll.

TABLE 13

Error Distribution for the Spring Quarter Final Examination, Russian Program

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 21.5 | 1 | |
| 24.5 | 1 | |
| 26 | 1 | |
| 27 | 1 | |
| 31.5 | 1 | |
| 32 | 1 | |
| 34 | | 1 |
| 35 | 1 | |
| 37 | 1 | 1 |
| 39 | | 1 |
| 40 | 1 | |
| 41 | | 1 |
| 42 | 1 | |
| 45 | 1 | |
| 46 | | 1 |
| 47.5 | 1 | |
| 50.5 | | 1 |
| 51.5 | 1 | |
| 60 | 1 | 1 |
| 61 | 1 | |
| 63.5 | | 1 |
| 67 | | 1 |
| 69 | 1 | |
| 69.5 | 1 | |
| 73 | 1 | |
| 74.5 | 2 | 1 |
| 76.5 | 1 | |
| 80.5 | | 1 |
| 81 | 1 | |

(continued)

Table 13 (continued)

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 82 | 1 | |
| 89 | | 1 |
| 91 | | 1 |
| 92 | | 1 |
| 93 | 1 | |
| 106 | | 1 |
| 166 | | 1 |
| Total number of students | 24* | 16** |
| Average number of errors | 53.0 | 71.1 |

* Three students did not enroll.

** Three students did not enroll, three students enrolled for the first time, and one student transferred from the computer-based section to the regular section.

TABLE 14

Error Distribution for the Common Portion of the Fall Quarter Final Examination, Second-year Russian Program

| Number of errors | Number of students | |
|---|---|---|
| | Computer-based | Regular |
| 2 | 1 | |
| 3 | 2 | |
| 4 | 4 | |
| 5.5 | 2 | |
| 6 | 1 | |
| 7 | 1 | |
| 7.5 | 2 | |
| 8.5 | 1 | |
| 11 | 1 | 1 |
| 11.5 | 1 | |
| 12 | | 1 |
| 13 | | 1 |
| 15 | | 2 |
| 15.5 | 1 | |
| 16 | 1 | |
| 16.5 | 1 | |
| 17 | | 1 |
| 17.5 | | 1 |
| 19 | | 1 |
| 21.5 | | 1 |
| 22 | | 1 |
| 24.5 | | 1 |
| Total number of students | 19 | 11 |
| Average number of errors | 6.0 | 15.7 |

Seventy-four per cent of the computer-based students performed better than the best student in the conventional class. The error distributions were significantly different (Mann-Whitney U Test, $p < .001$); the computer-based students performed better on the examination than the conventional classroom students.

## Discussion of the Three Programs

As is the case of any new technology being applied to an area where many existing skills and much existing knowledge is already present, the results of computer-assisted instruction in the early years will necessarily be mixed. From an operational standpoint, the Stanford efforts reflected in the three programs reported here began only in 1965, and so the evaluation reported here covers the first three years of effort. On balance, we feel that the results are positive, but it is also important to note that all the results have not been positive. We feel, however, that we have some explanation for some of the negative results. More importantly, we have learned a great deal since 1965, and we believe that the programs we are now developing and beginning to place in schools on an experimental basis will benefit from the work reported here. The technology is complicated, and our understanding of the underlying psychological principles of learning in any major area of curriculum is still rather tenuous. In our own judgment, while there is nothing definitive about any of the evaluation results reported in this paper, it did seem desirable to report as early as possible in systematic form and in objective fashion the evaluation results obtained.

We turn now to some specific remarks about the three programs.

1. The most negative results, especially when evaluated with respect to the effort expended, were the relative achievement gains of the second-grade students at Brentwood in the tutorial mathematics program. Without being able to give a real causal explanation of these results, we feel that the central problem with the second-grade tutorial program in mathematics at Brentwood centered around operational difficulties. The curriculum material was more complex than that offered in the first year, and there were difficulties in debugging and operating the system satisfactorily. Perhaps the most important single variable was the unsatisfactory systems-response time, which was discouraging for the students. During the latter half of the second year, the response times on the system were often in excess of 10 seconds. The technical reasons for these difficulties are now fairly well understood, but it is a warning to all computer-assisted instruction programs in elementary schools, and at other levels as well, that slow systems-response times are not tolerable.

2. On the other hand, the concept of the tutorial approach at Brentwood is supported by the positive results with the slow learners in the first year. The problems of beginning learning with students who test in the I.Q. range of 65 to 90 upon entering school are difficult and extensive. Teachers must have an infinite degree of patience to work with these students, to sense when progress is being made, and to repeat those things that need repeating. Tutorial programs that are computer-based provide one way of assisting teachers who are working with such classes. We should also like to say in connection with the tutorial program at Brentwood that this was the most radical program from the standpoint of

designing a full curriculum and the one whose parameters we as yet least understand. The Russian program also was tutorial and required a completeness of approach in the sense that almost the entire curriculum was handled at the computer. It is a simpler matter, however, to work with bright and mature college students than with younger relatively slow learners.

3. Turning to the drill-and-practice program, we observe first that as the evidence comparing School A with School B in 1966-67 in California indicates, teachers can do as well with a good regime of drill and practice in the fundamentals of arithmetic as can computers. We do not think that this conclusion is at all surprising. We have known for a long time from studies dating back to the 20's that a daily regime of drill and practice, carried out with faithfulness and regularity by the teacher, does improve the performance of students (see, for example, Wilson, 1925). What seems to be evident already is that the use of terminals to bring a drill-and-practice program to schools can bring a kind of quality control that is difficult to achieve in large numbers of schools with large numbers of teachers. Concentrated efforts in single schools with a dedicated staff can certainly do as well as anything that we can currently offer, but it is especially true of the elementary-school mathematics curriculum that many teachers in the upper three grades, that is, grades 4, 5, and 6, are not really interested in mathematics and would much prefer to turn the problem of providing a regime of review and maintenance of arithmetic skills over to a computer-based instructional program.

4. The results of the data reported here indicate that an individualized drill-and-practice program in elementary mathematics will produce its most impressive results in school environments not educationally and

economically affluent. This is evident from the comparison of experimental and control groups in Mississippi and California. This remark is closely connected with the preceding one, for it is in the less affluent areas of the country that, in general, teacher preparation and teacher training are least satisfactory. One way to meet some of these problems of teacher training, as in mathematics, is to bring work to the student directly on computer-based terminals. Because there was no control school to match the change in achievement data that occurred in the spring of 1967, the evaluation data cited above did not include Elliotsville School in rural Kentucky. Striking effects can be achieved in deprived areas; for example, the average grade-placement increase for a fourth-grade class of 27 students was seven months after only one-and-a-half month's work at teletype terminals.

5. It would be a mistake, however, to conclude that it is only with deprived or slower students that computer-assisted instruction will show really effective results. The program in Russian at Stanford University provides clear evidence to the contrary. There is much about the teaching of foreign language that is particularly well suited to computer-assisted instruction. To keep pace with the programmed exercises, the student must concentrate more directly on the language and not return to an internal monologue in English as he listens to other students respond in a class of 20 or 30. The concentration required of the student at computer-based terminals in the Russian program precludes his attention from wandering; thus, he achieves a degree of efficiency, it seems to us, that would be difficult to match, even in the best organized classroom. This is not to say that our Russian program is without defects. Professor Van Campen plans a large number of improvements for the program that will further deepen the

degree of individualization. We do feel that at both the secondary and college levels computer-based instruction can take over a good deal of the teaching of a foreign language, especially in those languages for which staff is inadequate. From the standpoint of national interest, we need increasing instruction in Russian, Japanese, and Chinese, and yet the staff for teaching these three languages is not generally sufficient, particularly in secondary schools.

6. Another example not discussed here, but that provides clear evidence that computer-assisted instruction is not restricted in its benefits to the deprived or slower learners, is some of our work in logic and algebra at the elementary and beginning secondary-school levels. We have not provided a classical evaluation of this program, which was one of our first curriculum efforts and began with demonstrations in December 1963. There is no good direct comparative evaluation of control-group performance, since the body of curriculum material is not offered in ordinary classes. There is no doubt, however, that this program, which is primarily aimed at bright students in grades 4 to 8, has been effective, because a great many mathematical ideas and skills have been learned by students who would not otherwise have been exposed to the material. Although the evidence is anecdotal, one of our finest examples is the rapid progress made in the logic program by students in Mississippi in comparison with students from upper middleclass environments in Palo Alto. We are especially proud of two Mississippi Negro boys in the eighth grade who stood at the top of the first-year logic program during 1967-68. This possibility of bringing enriched programs to students in a variety of environments where such courses cannot reasonably be offered by the teaching staff, either because

of lack of time or lack of training, is probably one of the most immediately practical aspects of computer-assisted instruction. We want to conclude this evaluation paper by emphasizing the important role of such enrichment programs, and to emphasize their importance in spite of the fact that it is not easy to provide a classical, "hard data" evaluation of such programs.

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## Footnote

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(Continued from inside front cover)

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