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ABSTRACT
        The Institute for Mathematical Studies in the Social
Sciences at Stanford University has operated a three-year
computer-assisted instruction (CAI) network for hearing-impaired or
deaf students; the effectiveness of the two main curricula in the
program, elementary mathematics and language arts, was evaluated. The
computer network spans the United States and in its three years has
involved 5,000 deaf students. The curriculum in elementary
mathematics is divided into strands, serie. f related problems, and
the language arts program tries to teach gr.. atical rules by the
inductive approach. Groups of students were systematically selected
for evaluation of the two curricula and received pre- and post-tests.
The results showed that CAI could be used successfully by deaf
students and that gains in mathematical computation two to three
times greater than classroom instruction could be achieved by CAI.
Furthermore, these gains could be precisely predicted from the number
of CAI sessions. (WH)

COMPUTER-ASSISTED INSTRUCTION IN MATHEMATICS AND

LANGUAGE ARTS FOR DEAF STUDENTS

by

Patrick Suppes and John Dexter Fletcher

Computer-assisted instruction in mathematics and language arts for deaf students*

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INTRODUCTION

This paper summarizes a three-year project running from July 1, 1970 to June 30, 1973, which was concerned with research and development in computer-assisted instruction (CAI) for hearing-impaired or deaf students. CAI curriculums developed by the Institute for Mathematical Studies in the Social Sciences (IMSSS) at Stanford University were used by more than 1,000 deaf students during the 1970-71 school year and by more than 2,000 deaf students during the 1971-72 and 1972-73 school years.

THE STANFORD CAI SYSTEM

The central processor for the Institute's computer system is a Digital Equipment Corporation PDP-10. In addition to 256K of core memory, short-term storage of programs and student information was provided by sixteen 180,000,000-bit disk modules; long-term storage of student response data was provided by magnetic tape. Communication with remote student terminals in participating schools was provided by private telephone lines. High-speed data transmission (generally 2400 or 4800 baud) and time-division multiplexing were used to communicate with clusters of 16 or more student terminals. Of the more than 180 terminals connected to the Institute system in 1972-73, about 125 terminals could be used simultaneously with no appreciable detriment to the system's speed of response. Any curriculum could be run at any time on any student terminal.

Figure 1 shows a map of the United States on which superimposed lines indicate the network operating in 1972-73. As can be seen, high-speed data transmission to Austin, Texas and Washington, D.C. was used to distribute programs in the southwest and on the east coast. Also shown is a direct line to New Mexico, which supported a similar installation at Isleta Pueblo, an Indian reservation approximately 20 miles from Albuquerque, New Mexico.

The student terminals were Model 33 teletypewriters, which communicated with the central computer system at a rate of about 10 characters per second. In a typical school,

one room containing 8 to 15 student terminals was assigned for CAI. Ordinarily one person was chosen by the school as the CAI terminal proctor; this same person was in charge of the equipment and the supervision of students in the terminal room.

When a student seated in front of a terminal presses the start key, the program responds by typing

HI
PLEASE TYPE YOUR NUMBER AND NAME.

Each student receives a number, which he inputs together with his first name. He uses the same number for all courses and types a one-letter identifier as a prefix to indicate which course he is requesting.

SUMMARY OF CAI CURRICULUMS

All CAI curriculums developed by the Institute were available to students in the participating schools for the deaf. The curriculums most relevant and most widely used were mathematics strands, arithmetic word problem solving, and a special language arts course developed solely for deaf students. In addition, a basic English course (available from Computer Curriculum Corporation), an algebra course, a computer programming course in AID, a computer programming course in BASIC, and a deductive logic and algebra course were used on various occasions by a number of students. A quantitative summary of usage for 1971-72 is shown in Table I.

We give here a brief description of the elementary mathematics curriculum and the language arts curriculum.

Elementary mathematics strands

The objectives of the curriculum were (a) to provide supplementary individualized instruction in elementary mathematics at a level of difficulty appropriate to each student's level of achievement, (b) to allow acceleration in any concept area in which a student demonstrates proficiency and repeated drill in areas of deficiency, and (c) to provide a daily profile report of each student's progress through the curriculum.
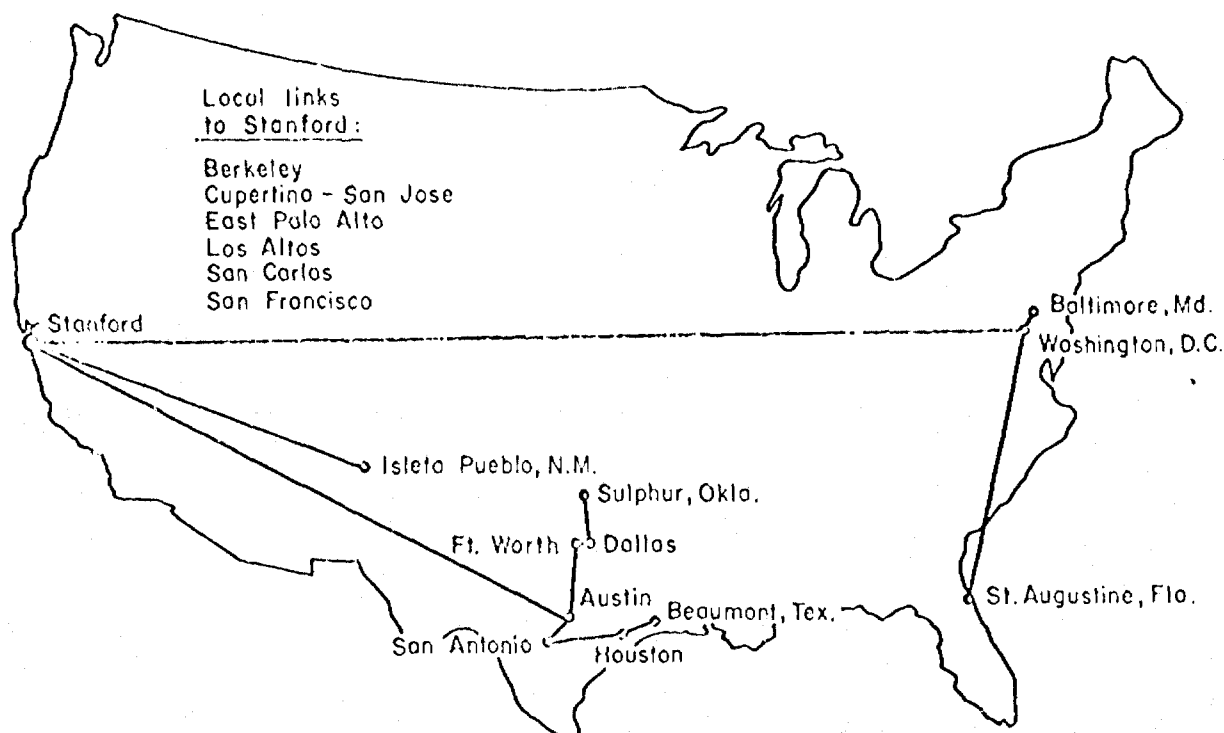
Figure 1—IMSSS national network, 1972-73

A strand is a series of problems of the same operational type (e.g., number concepts, addition, subtraction, fractions) arranged sequentially in equivalence classes according to their relative difficulty. The 14 strands in the program and the grade levels spanned by each strand cover the core elementary-school mathematics curriculum.

A student in the strands program works on fewer than 14 strands; the actual number depends on his grade level and performance. The strands approach provides a high degree of individualization because each student's lesson is prepared for him daily by the computer, the lessons are presented as mixed drills at a level of difficulty in each strand determined by the student's prior performance, and the student moves up each strand at his own pace.

Details of the curriculum are given in Suppes,[1] Suppes, Goldberg, Kanz, Searle, and Stauffer,[2] and in Searle, Lorton, and Suppes.[3]

Language arts

After carefully considering the language difficulties of hearing-impaired students, we designed the language arts curriculum to stress the structure of English, with particular emphasis on the roles of syntax and inflection and on the meaning of function words. An inductive rather than a deductive strategy was used. The course does not explicitly state 'rules' of English usage, rather it presents items illustrating aspects of standard English usage singly and in combination. Incidental learning of basic sentence patterns is enhanced by presenting curriculum items in complete sentences. Fewer than one-tenth of the exercises present the student with single words or isolated phrases. Incidental learning is also enhanced by requiring many constructed rather than multiple-choice responses.

There are four general course objectives. Students are to:

(1) Recognize specified grammatical categories;
(2) Recognize and supply various forms of given grammatical structures;
(3) Select appropriate grammatical units to complete a specified structure; and
(4) Perform specified transformations on grammatical structures.

The curriculum is divided into 218 lessons of 20-30 exer-

TABLE 1—Institute CAI Curriculums Used by Participating Schools for the Deaf, 1971-72

Curriculum	Number of students
Elementary Mathematics (Strands)	2146
Arithmetic Word Problem Solving	107
Language Arts	1071
Algebra	83
Basic English	165
Computer Programming in AID	93
Computer Programming in BASIC	124
Logic and Algebra	216
Total Students 2279	

cises. Separate topics are presented in separate lessons and often there is a sequence of lessons on a single topic. The lessons are ordered to provide a cumulative basis of concepts building upon one another. Several lessons review topics presented in preceding lessons.

The course was described in detail by Fletcher and Beard,[4] Fletcher, Jamison, Searle, and Smith,[5] and Fletcher and Stauffer.[6]

It should be emphasized that the network was primarily developed to bring elementary mathematics and language arts to deaf students. Use of the other courses was on an optional and relatively infrequent basis in relation to the total number of students, but the network was flexible enough to provide additional work for students who wanted it, ranging from a secondary-school course in English to computer programming.

EVALUATION OF ACHIEVEMENT

During the course of the three years of the project a number of detailed studies were undertaken to measure the achievement of students using the CAI courses. We summarize here the two main studies dealing with achievement in the elementary mathematics strands curriculum and in the language arts curriculum.

Mathematics strands experiment

The purpose of the experiment was to measure the effect of varying numbers of mathematics strands sessions on arithmetic computation grade placement (GP) measured by the strands curriculum and by an on-line, computer-administered version of the Stanford Achievement Test (SAT) Arithmetic Computation subscale. This on-line version of the SAT was called the Modified SAT or MSAT. Construction and administration of the MSAT was detailed by Suppes, Fletcher, Zanotti, Lorton, and Searle.[7] Each student was allowed to take only a specified number of mathematics sessions at the terminal. All other sign-ons were spent working language arts lessons.

Three hundred eighty-five students from among those who were taking both CAI mathematics strands and CAI language arts, whose average GP on strands was between 2.4 and 5.9, and who had taken at least 15 mathematics strands sessions, began the experiment. The students selected were assigned at random to five experimental groups that differed in the maximum number of mathematics strands sessions they permitted during the experimental period of approximately 70 school days. Treatment groups 1, 2, 3, 4, and 5 were assigned 10, 30, 70, 100, and 130 sessions, respectively.

Session limits were imposed on a calendar basis so that students with low numbers of sessions received them distributed throughout the experimental period. A participating student had no control over whether he received a mathematics strands or language arts lesson. Whether he signed on for mathematics strands or language arts a student was given a mathematics strands lesson if he was eligible for one. Otherwise, he received a language arts lesson.

Five models were tested to study the relationship between the two independent variables of pretreatment scores and the number of mathematics strands sessions on the one hand and the dependent variable of posttreatment scores on the other. We tested a linear regression model in the two dependent variables, a linear regression model with an interaction term between the two independent variables, a multiplicative Cobb-Douglas model of econometric type, a log-quadratic model in the two independent variables, and an exponential model in the two independent variables. Detailed results are not summarized here.

Parameters for the five models were generated twice, once using mathematics strands average GP as pretreatment and posttreatment achievement measures and once using MSAT GP scores. The linear model with interaction accounted for more of the variance in the dependent variable (posttreatment average GP) than did any of the other models, but despite the inclusion of a term for the interaction of number of sessions with pretreatment GP, it represented only a slight improvement over the simple linear model. Assuming $N_i = 120$ or slightly less than one session per day for a school year and taking $a_2 = .0123$ from the linear model, we can project $T_{i1} - T_{i1} = 1.48$. That is to say, if a student from this population takes about one strands session per day for an entire school year, we can expect his strands average GP to increase by about a year and a half. Data presented later show that strands average GP underestimated both GP measured by paper-and-pencil administrations of the SAT and GP measured by the MSAT. This improvement of 1.48 can be compared with an expected GP increase over a school year of .3 to .4 in the SAT computation subtest for hearing-impaired students receiving ordinary instruction.[8]

Among the models and parameters using MSAT GP as pretreatment and posttreatment measures, the multiplicative model from econometrics that assumed weighted interaction of number of sessions with pretreatment GP accounted for more of the variance in the posttreatment measure than did any other model, but, as with strands average GP, it represented only a slight improvement over Model I, the simple linear model. Again, assuming $N_i = 120$ and taking $a_2 = .0084$ from the linear model, we can project $T_{i1} - T_{i1} = 1.01$. That is to say, if a student from this population takes about one strands session per day for a school year of 120 net days, we can expect his MSAT GP to increase by about one year. Roughly, we can expect an increase of .1 in MSAT GP for every 12 sessions taken.

Suppes, Fletcher, Zanotti, Lorton, and Searle[7] concluded that the mathematics strands CAI curriculum can lead to substantial increases in mathematics computation GP when used by hearing-impaired students. The increases are sufficient to bring the students to GP gains expected of normal-hearing students. Moreover, these gains can be achieved by students working intensely for only a few minutes a day in a supplementary drill-and-practice program. The time spent at a computer terminal by each student ranged from 6 to 10 minutes for each session.

In addition, Suppes, Fletcher, Zanotti, Lorton, and Searle[7] concluded that a simple linear model of student achievement gives a good account of the posttreatment distribution of GP measured either by the MSAT or by the strands GP. The investigation of other models, including models with interaction terms, did not lead to any substantial improvement in accounting for posttreatment GP variance. The results of the analysis, including the application of the linear model, indicate that greater numbers of CAI sessions are beneficial for all students, across all levels of pretreatment achievement.

Language arts experiment

This experiment was analogous to the mathematics strands experiment described by Suppes, Fletcher, Zanotti, Lorton, and Searle.[7] Each student was allowed to take only a specified number of language arts sessions. All other sign-ons were spent working mathematics strands sessions.

Two hundred thirty students from among those who were taking both CAI mathematics strands and CAI language arts in 1972-73 were selected for the experiment, and were assigned at random to one of five experimental groups that differed in the maximum number of 10-minute language arts sessions they permitted. Students assigned to groups 1, 2, 3, 4, and 5 were permitted 20, 45, 70, 95, and 120 sessions, respectively. The subjects were selected from students in the California School for the Deaf, Berkeley, California; the Oklahoma School for the Deaf, Sulphur, Oklahoma; and the Texas School for the Deaf, Austin, Texas. Random assignment of these subjects to the five treatment groups was stratified so that roughly the same number of students from each school could be assigned to each of the treatment groups. When the experiment began, 45 students were assigned to group 1, 46 were assigned to group 2, 46 were assigned to group 3, 47 were assigned to group 4, and 46 were assigned to group 5. One-way, fixed-effects analysis of variance and five models of student progress were used to investigate student performance at the end of the 80-school-day experiment period. The five models of student progress investigated were the same as those used in the mathematics strands experiment.

The assistance of teachers and proctors was sought to help students achieve the number of language arts sessions they were assigned. Teachers were urged not to give compensatory off-line work to those students assigned to low numbers of on-line sessions, and, in general, not to alter the classroom work of any student because of his participation in the experiment.

Fletcher and Beard[4] reported that complete data were obtained for 197 subjects. However, 46 of these subjects had received 100 or more sessions in 1971-72 and these subjects were removed from the experiment prior to any data analyses which were then performed on the 151 remaining subjects. In the analysis of variance there were 33, 27, 26, 33, and 32 subjects in treatment groups 1, 2, 3, 4, and 5, respectively. Students in groups 1, 2, 3, 4, and 5 received an average of 22, 46, 69, 88, and 106 sessions, respectively. These averages were lower than expected for groups 3, 4, and 5, but the treatment groups appeared sufficiently distinct to proceed with analysis of variance. The F-ratio for this analysis was not statistically significant, indicating that the range of sessions considered did not have a significant effect on posttest scores. The paper-and-pencil language arts test developed by the project appeared to be reliable and fairly valid. The correlation between pretest and posttest scores on the test was .910 with an F-ratio for significance of regression beyond $p < .01$, and the correlation between posttest scores and number of lessons completed was .645 with an F-ratio for significance of regression beyond $p < .01$.

Models I, II, III, IV, and V accounted for 83 percent, 83 percent, 66 percent, 83 percent, and 33 percent, respectively, of posttest score variance. The only model to which a term that included a measure of sessions taken contributed significantly was Model V. In all other models the only significant independent variable was the pretest score. An additional model, Model VI, was investigated. This model was of the form

$$E(T_2) = a_0 + a_1 T_1 + a_2 N + a_3 L,$$

where T_2 refers to posttest score,

T_1 refers to pretest score,
N refers to number of sessions taken,
L refers to number of lessons completed,

and a_0, a_1, a_2, and a_3 are parameters of the model. Model VI accounted for 85 percent of the variance in posttest scores. Both sessions and lessons, in addition to pretest scores, contributed significantly $(p < .01)$ to the model. However, the regression coefficient in Model VI for number of sessions taken was negative, indicating an inverse relationship between number of sessions taken and posttest scores when number of lessons completed was taken into account.

Fletcher and Beard[4] concluded that the course is of significant value to students whose ratio of lessons completed to sessions taken is high but of much less value to students whose ratio of lessons completed to sessions taken is low. The relationship between sessions taken and posttest scores was concluded to be more complex than anticipated.

Language arts item analysis

Fletcher and Beard[4] reported several results from their item analysis of the language arts curriculum that are not widely noted in the literature on deafness.

First, the "directions" lessons were far easier than anticipated, given the general impression among deaf educators that deaf students experience difficulty in following directions. Some reasons for this result may be that the directions in these lessons and in the curriculum were easier to follow than those given in classroom instruction, that the directions given in the language arts CAI were more clearly communicated to students than the directions given in classroom

instruction, and that deaf students have less difficulty following directions than generally supposed. More research is required to decide among these alternatives.

Second, although pronouns were generally far easier than anticipated, items on possessive pronouns were extremely difficult for the students. Specifically, possessive pronouns that differ in number (his boxes, their box) and/or gender (his sister, her husband) from the nouns they modify were seldom completed correctly.

Third, copulas joining subjects with predicate complements that differ in number from their subjects were very difficult for the students. Copulas for items such as the following:

> The house (is, are) blue and white.
> The girls (seem, seems) lonely.

were seldom completed correctly.

Fourth, the students had very little trouble with contractions with the exception of "I'm," which was far more difficult than anticipated.

CONCLUSIONS

We began this project with the conviction that we had a powerful instructional tool at our disposal. Our aims were to demonstrate that CAI could be used to advantage by deaf students, that it could support serious research in deaf education, and that a favorable argument could be made for the economics of CAI. Behind these aims was the general intent of initiating large-scale use of CAI in schools for the deaf. To some extent we successfully met each of these aims.

It seems reasonable to conclude that CAI can be used successfully by deaf students. We did not set out to apply CAI to all of deaf education; we attempted only what we could do well. The curriculums concentrated on the skill subjects of mathematics and language arts, and, within these subjects, we emphasized aspects that were most amenable to computer presentation. Under these constraints we achieved favorable results. Certainly, the gains in mathematics computation ability that were two to three times greater than those expected from classroom instruction and the precision with which GP increase could be predicted as a function of CAI sessions are notable.

We also concluded that CAI provides a substantial foundation for research on the problems and processes of deaf education. The range of research undertaken by this project barely represents the diversity of inquiry that can be supported by CAI. The unobtrusive and precise control over experimental conditions made possible by computer presentations, as well as the accuracy and speed of computer arithmetic and data retrieval, permits a wide spectrum of experimental possibilities that we have only begun to explore.

The major drawback of CAI, however, is its cost. Computers require a sizable commitment of funds, both for acquiring capital equipment and for maintaining operations. Fortunately, the steady increase in the quality of available CAI is matched by a steady decrease in its costs. In the mid-1960's, when CAI first became available, it cost about $40 per student contact hour. Currently, CAI offered by the IMSSS system costs $1.50-$2.50 per student contact hour, depending on communication expenses. For the immediate future we can expect continued decreases in the costs and continued increases in the quality of CAI.

The proof of this project is in its impact on deaf education. Specifically, the willingness of the participating schools to support CAI from their own funding sources is the ultimate test of the project's impact. To date 13, of the 15 schools that participated in this project have committed funds to continue their CAI activity in 1973-74. The two remaining schools have not decided what CAI implementation alternative to adopt. Two schools that received no CAI from this project will be added to those supporting CAI in one network that directly resulted from this project. We expect the growth of CAI in schools for the deaf to continue.

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