COMPUTER-ASSISTED INSTRUCTION IN THE SCHOOLS:

POTENTIALITIES, PROBLEMS, PROSPECTS

by

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INTRODUCTION

I'd like to tell you this evening about some work we've been doing
in the past couple of years, work that has been agonizing at times and
great fun at others. The sense of agony can be conveyed by a joke
you probably all know -- the one about the passenger who got on the
airplane. After a conventional takeoff, the passenger hears over the
intercom, "You will be pleased to know this is one of the first flights
completely on automatic pilot. There is no pilot up front. Everything
is in good order, nothing can go wrong; nothing can go wrong...nothing
can go wrong..." And the analog of that in our environment is that we
get into a cycle of $2 + 2 = 5$, $3 \times 8 = 23$, $4 \times 6 = 25$ and children
run from the terminals. Whenever I have a captive audience I can't
help preaching reliability. It's the sermon in computer-assisted
instruction. I will have more to say about this later.

In November of 1962, Professors Richard C. Atkinson, William K.
Estes and I, all at Stanford, submitted to the Carnegie Corporation
of New York a proposal for a computer-based laboratory for research
in instruction and learning. We were funded early in 1963 and since
then we have been pushing to be operational as much of the time as
possible. The executive committee of this laboratory consists of
Atkinson, Estes and myself, and we have had a lot of assistance from
John McCarthy, of the Department of Computer Science at Stanford.

I don't want to spend a great deal of time describing the hardware or the software, but to describe to you what we are trying to do, what we have done, and what the problems are in computer-assisted instruction. First, I would like to give you a brief sense of the kind of setup we now have. It's limited, but it has possibilities. It is beginning to work and we are hopeful about the future. Immediately adjacent to the IBM 7090 at Stanford, we have a PDP-1 that we share with the Computation Center. We have six stations for teaching purposes.

At each station we have the following assemblage of terminal equipment. The station itself consists of a booth about eight-feet long and seven-feet wide. In each booth, there is an IBM chip system that will access in about one second a microfilm that is optically displayed at about the size of a standard page. On that display the student can respond with a light pen. This IBM device is on the left of the student as he is at the station. To the right of the student is a cathode-ray tube (CRT) supplied by Philco, which has the standard properties of a CRT and a standard keyboard that the student uses for responses. We also have a light pen available for the CRT. The IBM chip system and the Philco CRT are the two visual devices at each station.

The problem that has caused the most headaches is the problem of getting reasonable access to audio messages -- reasonably fast access with fairly good fidelity to audio messages whose lengths run from 2 to 20 seconds. We finally have a solution to this problem in a battery of equipment that is produced by Westinghouse. You can see what kind of combination we have -- a PDP-1 computer that has a direct address to the IBM 7090, an IBM chip system, Philco scopes, Westinghouse audio. When someone asked recently, "How can you expect all the interfaces to work?", I replied that we have had pretty good luck.

THE ELEMENTARY-SCHOOL MATHEMATICS CURRICULUM

Initially we are working on two curriculum areas -- reading and mathematics in the elementary school. I won't say much about the reading curriculum. Professor Richard Atkinson and Dr. Duncan Hansen

are primarily responsible for this curriculum. They are developing
reading materials for first and second graders in the environment that
I have described, and they plan a fairly extensive experimental program
for 1965-66.

My own efforts are particularly associated with the mathematics
work; it is an extension of work in the mathematics curriculum I have
been engaged in for almost ten years. At present the work in mathematics
is ahead of the work in reading. Currently we are running on an operational
basis. I shall sketch the daily schedule in the laboratory in force
this spring (1965). Two kindergarten children came in from 9:00 to 9:30
a.m. to run on the program previously tested with some first graders to
evaluate it for revision. At 10:15 a.m. two very bright second graders
came in and were run on a program in mathematical logic. I'll say more
about it in a bit. At 1:00 p.m. six first graders came in who completed
about 60 per cent of the first-grade curriculum. Six more were run
from 1:30 to 2:00 p.m. on the same schedule. These are the children
we are now bringing into the laboratory. From the standpoint of the
number of children in schools near to us, or any other relevant statistic,
it is a small number; but, compared to what we were running a year ago,
it is a very big increase. In addition, we are running a teletype in a
fourth-grade classroom for purposes of giving drill and practice in
arithmetic. I shall also have more to say later about this teletype
operation.

In the laboratory itself, we are attempting to produce and test
a complete mathematics curriculum for the grades with which we are
concerned. In other words, we program in appropriate form what we
like to call a total curriculum for each grade. Like any ordinary
piece of curriculum writing, a total curriculum contains a good deal
of visual material arranged in an appropriate sequence. But a total
curriculum also has two important ingredients that the ordinary curric-
ulum does not. The first additional ingredient that is time-consuming
and on occasion soul-searching is the preparation of appropriate audio
messages to the child, the sort of thing that is ordinarily left to the

teacher to say. It is absolutely essential in teaching young children
that we communicate with them by talking to them, and not simply by
giving them visual presentations. The second additional ingredient is
making all the decisions that the teacher ordinarily makes regarding
pacing, problem sequence, what topic to take up next, when to intro-
duce a concept, when to review a concept, etc. The details of this
also turn out to be fairly hair-raising. For all the grades in the
elementary school we are attempting to produce this kind of total
curriculum in mathematics. Some of the children mentioned above are
currently working their way through the first-grade curriculum that is
now finished. The curriculum for the second and fourth grades is in
each case about 50 per cent completed.

For the fourth grade we are presently concentrating on division,
using a CRT. If I had more time I would tell you in some detail about
how we plan to use a CRT to teach the division algorithm. Those of
you who are not familiar with the problems of elementary-school mathe-
matics have still heard talk of new concepts and new mathematics at
all school levels. In my own judgment no one has yet introduced into
the elementary-school curriculum a new topic that is nearly as diffi-
cult as that of the long-division algorithm, and the runner-up is the
problem of manipulating fractions. Both of these topics are very
difficult for fourth, fifth and sixth graders. Test results also
show they are difficult for their teachers and for most of the adults
in the population; that is, these skills have traditionally been very
badly mastered. I think that in the kind of environment we are talk-
ing about here we have one of the first opportunities historically to
get an iron grip on the mastery of these skills. The topics that I
like to talk about in elementary-school mathematics -- intuitive geometry,
perhaps a little bit of algebra -- are interesting and fairly trivial
at the elementary level compared to the long-division algorithm.

A more radical program on which we have accomplished a great deal
is the program in mathematical logic, which is historically a strong
interest of my own. Here we are able to take advantage of the computerized

environment in a way that we have just begun to exploit. I would like
to say a few things about this program because in many ways it permits
a greater freedom of response than other parts of the curriculum we have
yet developed. We initially give the children standard work with sen-
tential inferences of the following sort: If John is here, then Mary
is at home. John is here. Where is Mary? We move on to examples
in simple mathematical contexts of the rules of inference that are
familiar to everyone from work in secondary-school geometry. The thing
we can avoid is the eternal writing out of answers, which is tedious
for children, particularly at this age level. On the one hand, we
want to avoid giving them restricted multiple choices, and, on the other
hand, we want to avoid asking them to write out constructed answers.
We don't want fourth graders to be required to type out the response
that N is equal to 2 or Mary is at school. This would slow down the
learning and be relatively demanding, at least during early stages of
learning. What we can do in this case is simply ask the child to input
on the keyboard what rule of inference he wishes to apply to what given
premises or to what given lines in the proof, so, all he has to input
is the reason and the lines to which that reason, or rule, is applied.
This is ordinarily done with four or five characters. We use two
letters to abbreviate the rule, and in most cases the rule applies to
two lines of proof already given. In the example I gave above, we use
modus ponendo ponens, or what we call in context the IF rule. So the
student would input IF 1 2, indicating the IF rule is to be applied to
lines 1 and 2. Then, the program automatically types out the result
of applying that rule to those two lines. This is a very simple example.
But the point is that the child can have a large number of opportunities
for different types of responses, even essentially different proofs,
as we develop a body of rules that he understands.

These rules are built up as generalizations from ordinary language
and gradually applied to mathematical examples. We want to extend this
kind of approach as far as we can in the beginning stages of mathematics
for children at this level. Here are some early examples of the program.

The first two emphasize working with ordinary language rather than mathematical sentences.

Example 1. Derive: We need good shoes.

Premise 1. If we buy sleeping bags, then we are warm at night.

Premise 2. If we are warm at night, then we feel good in the morning.

Premise 3. If we feel good in the morning, then we take a long walk.

Premise 4. If we take a long walk, then we need good shoes.

Premise 5. We buy sleeping bags.

In Example 1, the student would input "IF 1 5" to obtain as line (6):

6. We are warm at night.

He would next input "IF 2 6" to obtain:

7. We feel good in the morning.

After this would follow "IF 3 7" to obtain:

8. We take a long walk.

and finally "IF 4 8" to obtain the derived conclusion:

9. We need good shoes.

Example 2. Derive: Jack and Bill are not the same height.

Premise 1. If Jack is taller than Bob, then Sally is shorter than Mavis.

Premise 2. Sally is not shorter than Mavis.

Premise 3. If Jack and Bill are the same height, then Jack is taller than Bob.

In this example, the student must use modus tollendo tollens, which we call the IFN rule -- the "N" stands for the fact that here we deny the consequence of the conditional premise. Thus in Example 2, the student who is responding correctly would input first "IFN 1 2" to obtain:

4. Jack is not taller than Bob.

and then "IFN 3 4" to obtain the derived conclusion:

5. Jack and Bill are not the same height.

Example 3. Derive: $y + 8$

Premise 1. $x + 8 = 12$ or $x \neq 4$

Premise 2. $x = 4$ and $y < x$

Premise 3. If $x + 8 = 12$ and $y < x$ then $y + 8 < 12$

In this example, the student must use modus tollendo ponens, which
we call the OR rule, as well as two rules dealing with conjunctions --
the rule of Adjunction (A) for putting two sentences together to form
a conjunction, and rule of Simplification (S) for deriving one member
of a conjunction. We show the steps in the derivation in one block,
but it is to be emphasized that the student only inputs the rule ab-
breviations and the numbers at the left of each line.

S 2	4.	$x = 4$
OR 1 4	5.	$x + 8 = 12$
S 2	6.	$y < x$
A 5 6	7.	$x + 8 = 12$ and $y < x$
IF 3 7	8.	$y + 8 < 12$

In these simple examples the possibilities for different proofs
by different students are restricted, but already in this last example,
the order of the lines can be changed, and the possibilities of variation
increase rapidly as the complexity of the problems increases. Pro-
gramming for the evaluation by the computer of any valid step is not a
trivial affair, but it is manageable within the hardware and software
capacities of our present laboratory.

One of the prettier extensions we are beginning to think we see how
to manage is an application of the same logic of responding to geo-
metric constructions, so that the child inputs on the keyboard the
construction to be performed. In the program we are planning, the
child enters an abbreviation for the construction and for the points
to which it is applied. For example, we can fairly quickly reach the
stage of his saying he wants the midpoint of the line segment AB. The
program would then find that midpoint for him. After a good deal of
experience in teaching geometric constructions to elementary-school
children, it is clear to me that there are two kinds of problems
that need to be separated. One kind is the problem of the child's
conceptualizing what is to be done, in particular, of his conceptualizing
the sequence in which he should make responses. The other kind of

problem is the psychomotor problem of execution. Executing with
reasonable accuracy the desired construction can be a difficult task
in terms of the motor skills possessed by these children. It is often
easier for them to give a correct analysis of the problem than it is for
them to execute a construction requiring five or six steps that end up
at the right terminal point. If the construction gets sloppy along the
way they will not come out with the kind of result one is after. And
an important point here is that in working with intuitive constructions
with young children, one doesn't want to add any proof-apparatus of a
verbal sort which will pull the student out of trouble when the con-
struction goes awry. Therefore, we view with particular interest the
development of the program in geometric constructions modeled on the
program in logic.

The final piece of mathematics curriculum that I want to mention
is the work we have recently done with a teletype in an elementary
school some miles south of Stanford. The kind of rich environment
I described for the laboratory itself is in my own judgment necessary
for a complete or total instructional program, but a teletype or IBM
1050 is quite satisfactory by itself for review, drill and practice in
the algorithms and skills that are so important in arithmetic. In
the case of the teletype operation, it has been a very interesting
experience for us to have the following sort of operation going daily.
We are "on the air" for about 2-1/2 to 3 hours with a class of 40
students and we attempt to process all 40 students during that period.
Each student is at the teletype terminal from 2 to 5 minutes. It is
instructive to watch these students slide in and out of position.
They are very efficient about it, not losing more than 20 or 30 seconds
in arriving at the terminal or leaving it. We ask them to begin by
typing in their names and hitting the return key. Timing on the rest
of the drill and practice work is controlled by the program. What we
are finding is that when detailed and objective control of the environ-
ment is possible, we can hope to train a student to a level of accuracy
and perfection of response that is very difficult to achieve in a classroom

environment. Since January, 1965, we had been giving daily drills and
review practice to this class and some others, on a regular classroom
basis. In the teacher's opinion, the students had been doing very well.
However, her estimation of performance could not be precise, since
she did not have time to mark all the exercises. You can appreciate
the problem. She is devoting in the fourth grade a maximum of 50 minutes
each day to the arithmetic program. She has 40 students. If she gives
20 to 30 review problems in arithmetic a day in addition to the other
parts of the arithmetic curriculum, there are a thousand items to look
at and mark, which is pretty demanding. So she did not have time to
mark these exercises, but it was her impression that the students had
been achieving a rather good level of performance. We found that in
the environment we have now set up, we have a much clearer idea of what
they do and don't know.

One of the aspects of the teletype routine that we are particularly
anxious to study over a long period is the time-out routine. In most
of the exercises, if the student has not answered in ten seconds he
is "timed out" and the teletype clicks back and repeats the problem.
He is given a second opportunity of 10 seconds; if he does not respond
within 10 seconds or if he is wrong, the correct answer is typed.
He is given a third opportunity to copy and write the correct answer
and then automatically shifted to the next problem. The ten seconds
is not fixed, of course, but is a parameter of the program. Ten
seconds seem to be about right at present for most of the exercises
we are considering. To acquire arithmetic skills with proper accuracy
and proper fluency, just as in the acquisition of certain kinds of
skills in foreign languages, a timing criterion seems to be a very
useful and important constraint.

The summary data for one day are shown in Table 1. The 20 exer-
cises are shown as they were typed out on the teletype for each student.
Following them in the table is the data analysis for the 36 students
present. From a teaching standpoint, the most important aspects of
this data summary is the item analysis showing the number of correct
responses, wrong responses, and time-outs. From this analysis, for example, it is
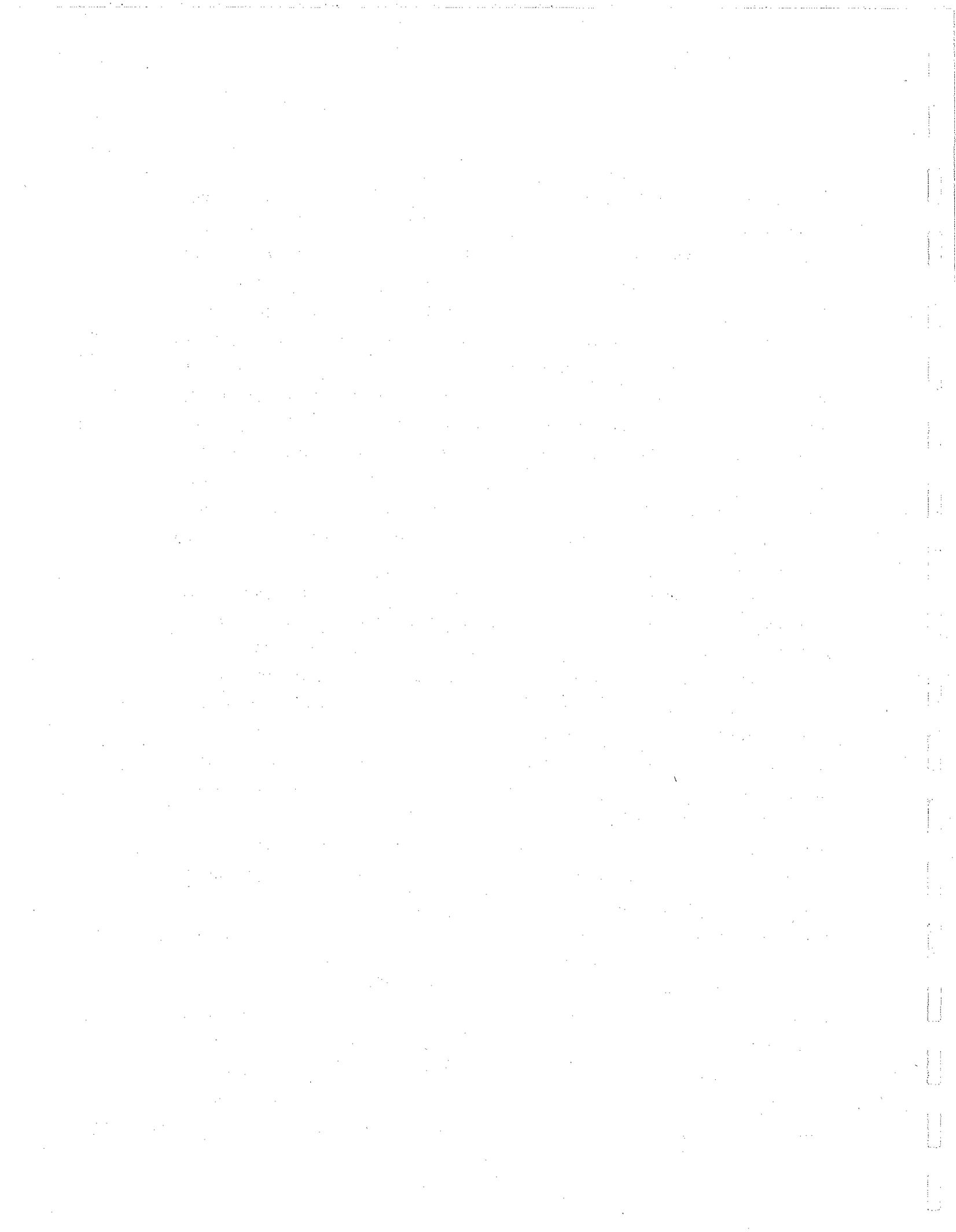
TABLE 1. SET OF 20 EXERCISES
PRESENTED ON TELETYPE UNDER COMPUTER CONTROL
TO 36 FOURTH-GRADE STUDENTS

EXERCISES

1. $5 \times 20 = 20 \times$ _____
2. $6 \times 6 = 4 \times$ _____
3. $(2 + 6) \times 5 = 5 \times$ _____
4. $(11 - 3) \times 2 = 4 \times$ _____
5. $21 \div 7 =$ _____
6. $4 \times 6 = 2 \times$ _____
7. $3 \times 9 = (7 \times 3) +$ _____
8. $25 + 9 =$ _____
9. $43 - 7 =$ _____
10. $58 + 5 =$ _____

11. $7 + 8 = 7 + (3 +$ _____ $)$
12. $99 \div 11 =$ _____
13. $84 \div 7 =$ _____
14. $49 \div 7 =$ _____
15. $4 \times 7 =$ _____
16. $5 \times 9 =$ _____
17. $8 \times 6 =$ _____
18. $6 \times 9 =$ _____
19. $27 + 8 =$ _____
20. $43 + 9 =$ _____

SUMMARY RESULTS
TIME ALLOWED PER EXERCISE 10.00 SEC
AVE RIGHT/PUPIL 13.8
AVE WRONG/PUPIL 2.3
AVE TIME OUTS/PUPIL 3.9
MEAN TOTAL TIME TO FINISH EXERCISES 289.96 SECS

EXERCISE	CORR	WRONG	T/O
1	32	1	3
2	21	9	6
3	27	4	5
4	12	7	17
5	33	0	3
6	24	4	8
7	10	5	21
8	30	3	3
9	7	8	21
10	30	2	4
11	13	3	20
12	33	2	1
13	16	9	11
14	27	3	6
15	35	0	1
16	32	3	1
17	26	6	4
18	29	4	3
19	29	5	2
20	30	4	2

AVE RIGHT/EXERCISE 24.8
AVE WRONG/EXERCISE 4.1
AVE TIME OUTS/EXERCISE 7.1

clear to the teacher that the class understands commutativity of addition
(Exercise 1) much better than application of the subtraction algorithm
when some sort of regrouping of tens and ones is required (Exercise 9).
The low percentage of correct responses on Exercise 7 indicates the rela-
tive difficulty of performing two operations quickly, even though the
individual computations are simple. Analysis of individual student per-
formance is also printed out for use by the teacher. In the case of the
set of exercises shown in Table 1, the record of the best student was
as follows:

Pupil 15

Number right 19 Number wrong 0 Time outs 1 Total time 149.9 secs.

Time out was on Exercise 11.

And of the worst student:

Pupil 29

Number right 5 Number wrong 4 Time outs 11 Total time 480.1 secs.

Exercises wrong 2, 6, 11, 17

Time outs 1, 3, 4, 5, 7, 8, 9, 10, 13, 19, 20

I would like now to review in a more general setting some of the
potentialities of computer-assisted instruction, some of the problems
and what seem to be the prospects. Necessarily I shall not enter into much
detail.

POTENTIALITIES

There are at least four major aspects of computer-assisted instruc-
tion that seem to offer great potentiality for education at all levels,
particularly at the elementary-school level, where we have been working.
The first and most important is concerned with the psychological variable
that is often claimed to represent the best-known psychological general-
ization, namely, the definite and clearly significant existence of
individual differences. The fact is that children enter school with
remarkably different abilities to work at different rates and with
different levels of accuracy and understanding. It is common cant in
education to modify the Marxist slogan and to say, to each child according
to his need, but for reasons of economic necessity, we are not actually

able to offer a curriculum program to each child according to his needs.
The economic reasons are obvious. We simply cannot afford that many
teachers. In the elementary school, the teacher is running a three-ring
circus. She is not only teaching mathematics, she is teaching reading,
related language-art skills, writing, social studies, and elementary
science. She certainly cannot attempt in these various subject matters
to give very much attention and accommodation to individual student
differences, no matter how willing or, really, no matter how able she
may be. In practice, in the first two grades, because of the primary
importance of reading, some attempt is made in the first two grades to
diversify reading into three or four groups. Often it is quite success-
ful; yet even within these small groups it is not really possible to
accommodate individual differences in any deep and serious way.

For the past year and a half we have been working with a very
homogeneously selected group of what are now second graders. They are
a group of very able children, selected from four different elementary
schools. The IQ range is from 122 to 167, with a mean of 137.5 We
hoped that by breaking them into four small groups of from eight to
ten students, we would be able to handle individual differences fairly
satisfactorily. Moreover, they are, as I said, very homogeneous in
initial measures of ability. In actual fact, it has been extremely
difficult even with this very selected and small group of students
to give them appropriate attention as far as individual differences
are concerned. Furthermore, the academic spread of their sequential
positions in the mathematics curriculum is now almost two years. The
ablest children are now (spring, 1965) working up toward the end of the
fourth grade, and the slowest in the group are just past the end of the
second grade. Computer-assisted instruction can be expected to result
in this kind of variation in achievement rates. And I emphasize that
we have not been able to accommodate individual differences to the
extent we would like. For a group of children in a more ordinary
elementary-school environment, the range in ability and achievement
would be much greater. As far as I can see, if we take seriously the

existence of individual differences -- and there is every psychological reason to take it seriously, for the mass of experimental and empirical data on individual differences is really overwhelming --, there is little hope of accommodating this important psychological variable in the usual classroom setting, in spite of pious remarks to the contrary. We need something like computer-assisted instruction in which we can individualize the presentation of the curriculum to each child. If someone asks, why should computers be used in instruction, the single shortest and simplest answer is simply that, computer technology provides the only serious hope for accommodation of individual differences in subject-matter learning.

The other areas in which computer-assisted instruction has valuable potentialities are less important than this overwhelming one of accommodating individual differences, but as we begin to solve the tactical problems before us, they too are significant in the educational setup. One I have already mentioned. It is the important matter of correcting responses, keeping records, relieving the teacher of routine, so that she may teach her class as she would like to do. We made a survey last year of first-grade teachers with whom we were working and asked them, "How long would you need to spend on your students' workbooks in mathematics outside the class if you did an adequate job of marking?" "About an hour and a half a day" turned out to be the average response. This is simply too much to demand of teachers when other parts of the curriculum are considered as well. What happens in practice is that in most cases the teacher has to correct a random sample on an occasional basis. In a computer-assisted environment this can be done automatically, easily and simply, and the teacher is relieved of an enormous chore.

The next thing I would like to mention is closely related to this. It is not simply a matter of record-keeping, but a matter of a systematic and straightforward introduction of many of the standard skills. I have mentioned already the division algorithm, but my remarks apply to other algorithms that we teach in school. As we study in detail how the children are learning and performing we can develop computer routines that the teacher can rely upon and can use for the bulk of the children.

The routine introduction of standard skills can be handled by computer-based terminals. The teacher can then move to the much more challenging and much more important task of trouble-shooting, of helping those children who aren't making the grade with the material we are giving to the bulk of the children; for it is inevitable in these early years that the depth of programming, the depth of the alternatives we can offer, will be insufficient to cover all the children. We have in our programs what we call a teacher-call. When the child has run through all the branches of a concept, and has not yet met a satisfactory performance criterion, there is a teacher-call at the proctor station and the teacher is supposed to come over and help. We anticipate getting teacher-calls on a regular basis, and I am sure that this will be part of the scene for a long time, if not forever. But these teacher-calls are something that require individual attention, individual creative effort on the part of the teacher, and not her routine introduction of how to divide two-digit divisors into three-digit dividends.

The fourth potentiality to note is that for the first time we shall have the opportunity to gather data in adequate quantities, and under sufficiently uniform conditions, to take a serious and deep look at subject-matter learning. My own interests are very much centered around finding out how children learn. This continues to be the case, even though occasionally I think I have gotten swamped in the problems of technology, curriculum-writing and administration of this new computerized environment. What I tell some of my friends in experimental psychology is that from the standpoint of experiments they have been familiar with, we are going to trivialize much of the pervious work, because of our enormous data-gathering capacity, particularly for gathering data under standardized circumstances. Enormous gaps exist in the literature of elementary mathematics learning, even in elementary arithmetic. Almost all the research that has been done has centered around the learning of arithmetic. If you asked for slightly more advanced pieces of mathematics you would have a few romantic tales by some mathematicians

who have become interested in the subject, but as far as real analysis
of how students learn mathematics, we as yet know very little.

PROBLEMS

I turn to what I would list as the foremost pressing problems of
computer-assisted instruction. The first problem is the one that I
mentioned at the beginning -- reliability. The machines have got to
work and they have got to work right. The program has got to be
thoroughly debugged. Chaos is introduced if over a sustained period
children are put in the terminal environment and the program and
machines do not perform as they should. Reliability is as important
here as in the airplane story we began with. There is no other problem
as important in the initial work with computer-assisted instruction
as the problem of reliability.

The second problem I would mention is one that plagues all of us
working in curriculum, not simply those in computer-assisted instruction.
It is the problem of simple-minded curriculum preparation and programming.
Because we have a new environment, because we are struggling to conquer
technological side-effects that we don't ordinarily have in getting
curriculum material into an ordinary classroom, it is sometimes easy to
settle for less than the best in curriculum and programming. It is
far too easy to make the curriculum too simple or to forget important
aspects of interest and complexity. Some of you may have followed the
literature of programmed learning, particularly the critical reviews
that have appeared in the mathematical literature -- I guess The
Mathematical Monthly has been one of the best sources of critical
and perceptive reviews of programmed learning materials in mathematics
instruction. You are undoubtedly aware that one can get caught up in
the surface programming problems and neglect all too readily the
curriculum contents itself.

The third problem is one that, in psychological terms, I would
call the problem of stimulus deprivation. In computer-assisted instruction,

are we going to be able to provide a rich enough stimulus environment
for the student? There is no doubt that we can do so in the short
haul, but I am waiting to see what will be our problem in this respect
as we enter the second or third year. I know that we will make mis-
takes. It is foolish to think we won't. We will do things that will
bore the students; we will do things that will lose their interest.
I just hope that we will be clever enough and wise enough to meet
the problems as they arise. On the other hand, some people are too pessi-
mistic. The problem is not psychologically as complex as many people
would like to make it. There is no doubt that, other things being equal,
the children have an enormous initial interest in using the equipment
that is part of computer-assisted instruction. With proper nurture of
that interest, I think we can overcome problems of stimulus deprivation
and the associated problems of motivation.

The fourth problem is a pressing one in terms of any universal
use of computer-assisted instruction; it faces us not tomorrow, but the
day after tomorrow. The problem is how to make the cost reasonable for
use on a very wide basis in schools throughout the country. I don't
pretend to be an expert on this problem. There are a lot of people
who know a lot more about it than I do. I will simply mention that
obviously costs have got to come down very considerably before every
elementary school or any reasonable percentage will have computer-
controlled terminals available to children in the classroom or close to
the classroom. At the moment our own concern is to find out in more
detail what the problems are in terms of the operational side of this
sort of instruction, and not to concern ourselves directly with the
problem of economic feasibility. For a variety of reasons I do think
the economics of computer-assisted instruction will look much more
feasible in a matter of two or three years.

PROSPECTS

Regarding prospects for the future, let me just finish by mentioning
a few salient points. Concerning subject matter, without any question

it is the skill subjects that we can handle most easily, that we under-
stand how to teach in this environment. We can bring these subjects
under control in a deep and organized way and can present them to the
student in a way that makes a great deal of sense from a psychological
standpoint as well as from a curriculum standpoint. The skill subjects
that would be particularly important are two that I have mentioned,
reading and mathematics, and, as a third major subject of instruction,
the teaching of foreign language. Although we have not worked with
foreign language thus far, it seems evident to me, as it does to many
people, that this is one of the most promising areas in which to apply
computer-assisted instruction. As a matter of fact, we have already
seen a move in that direction in the vast spread of language laboratories
around the country. There are two fundamental psychological criticisms
of language laboratories. First, there is no individualization of
instruction, the important variable I mentioned earlier. Secondly,
the student is not asked to make an overt response that is evaluated.
There is not sufficient check-up on what the student understands or
doesn't understand as he listens to material in the laboratory. Both
of these criticisms may be met by the use of computer-based terminals.

Other subjects will undoubtedly be handled successfully in a computer-
ized environment; but the skill subjects that constitute a rather large
part of elementary teaching at all levels will be the first on which
we can make real headway. Also important to mention is the upgrading
and raising of standards that I think we can expect in those aspects
of elementary subjects that are concerned with drill and practice.
From a psychological standpoint, there is no doubt that the kind of
variables learning theorists have talked about for decades can be con-
trolled in a much deeper and more substantial way, because of the relative
completeness of control of the environment, particularly of timing
variables. I think it is difficult to emphasize enough the impact that
widespread use of computer-assisted instruction can have on the mastery
of skills: elementary skills in mathematics, for example, and in
reading and foreign languages.

Finally, a question is often raised regarding the prospects for teachers in this new environment. Are we trying to eliminate the teachers? There has been no move in the history of education in this country that really led to a reduction of teachers, and I think exactly the same thing is true of computer-assisted instruction. What we shall be able to do is to raise the quality of education, not reduce the cost of instruction or the number of teachers. The prospect that we find exciting is the possibility of providing enough terminals in an elementary school to permit a teacher to send half of her class to have individualized instruction on computer-based terminals during part of the day. During this same period she can make a more individualized, more concentrated effort on the reduced class of 15 or 20.

Nearly all teachers regard textbooks as an indispensable aid to good teaching. It seems to me a reasonable prediction that the same will be true of computer-assisted teaching terminals in the not very distant future.