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by

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INSTITUTE FOR MATHEMATICAL STUDIES IN THE SOCIAL SCIENCES

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STANFORD, CALIFORNIA

COMPUTER-ASSISTED INSTRUCTION IN THE SCHOOLS:

POTENTIALITIES, PROBLEMS, PROSPECTS*

Patrick Suppes

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.

*The work reported here has been supported by the Carnegie Corporation of New York, the National Science Foundation, and, in part, by the U.S. Office of Education. A first draft of this paper was given on May 3, 1965, at a Scientific Computing Symposium in Westchester, New York on Man-Machine Communication sponsored by IBM.

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 curriculum 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 introduce 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 mathematics 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 difficult 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 talking 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 sentential 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 abbreviations 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. Programming 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 geometric 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 construction 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 environment 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 exercises 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

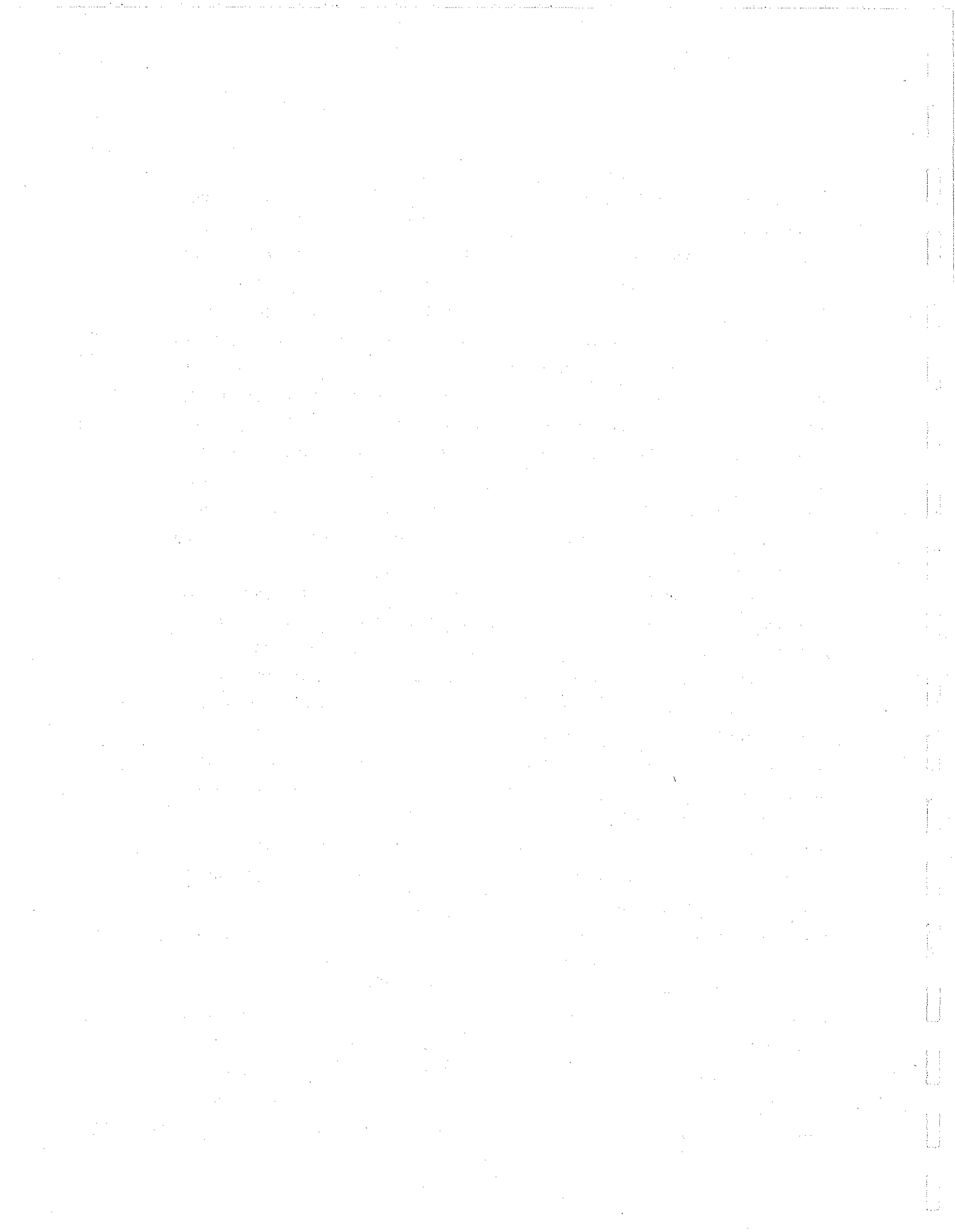


TABLE 1. SET OF 20 EXERCISES
PRESENTED ON TELETYPE UNDER COMPUTER CONTROL
TO 36 FOURTH-GRADE STUDENTS

EXERCISES

- | | |
|---|-------------------------------|
| 1. $5 \times 20 = 20 \times$ _____ | 11. $7 + 8 = 7 + (3 +$ _____) |
| 2. $6 \times 6 = 4 \times$ _____ | 12. $99 \div 11 =$ _____ |
| 3. $(2 + 6) \times 5 = 5 \times$ _____ | 13. $84 \div 7 =$ _____ |
| 4. $(11 - 3) \times 2 = 4 \times$ _____ | 14. $49 \div 7 =$ _____ |
| 5. $21 \div 7 =$ _____ | 15. $4 \times 7 =$ _____ |
| 6. $4 \times 6 = 2 \times$ _____ | 16. $5 \times 9 =$ _____ |
| 7. $3 \times 9 = (7 \times 3) +$ _____ | 17. $8 \times 6 =$ _____ |
| 8. $25 + 9 =$ _____ | 18. $6 \times 9 =$ _____ |
| 9. $43 - 7 =$ _____ | 19. $27 + 8 =$ _____ |
| 10. $58 + 5 =$ _____ | 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 relative difficulty of performing two operations quickly, even though the individual computations are simple. Analysis of individual student performance 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 instruction 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 generalization, 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 successful; 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 previous 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 mistakes. 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 pessimistic. 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 understand 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 computerized 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 controlled 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.

