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THE COMPUTER AND EXCELLENCE

By PATRICK SUPPES

PROBABLY no one doubts the proposition that children are capable of learning more than they actually do in school. Probably no one doubts, either, that the structure of courses and the curriculum can be improved. The hard problem is to become clear about how we can reorganize our schools and the curriculum in order to provide our children an opportunity to learn more. Perhaps the most important point to emphasize about this search for improvement is that we should not anticipate that it will come to an end.

The problem of adjusting the pace of curriculum in any subject area to the background knowledge and motivation of students is a deep and complicated one. I don't pretend to be able to offer a general solution. But some of our experiences at Stanford in elementary-school mathematics, I think, represent a feasible approach to the problem.

Let me begin with two examples from my own experience. The first concerns the teaching of geometrical constructions in the first grade. Starting in 1958, Newton Hawley and I taught a first-grade class daily, two weeks at a time, in the special subject of geometry. We tried to go through as many of the constructions in Book 1 of Euclid's *Elements* as we could. The students we were teaching were bright and able, but we were working with an entire class, not with some specially selected subgroup. Rather than try to summarize what we did, I will quote from my diary entry for May 2, 1958:

> The entire session was spent on review of the things we have done during the past two weeks. The main part of the review was to elicit from the students a list of the eight constructions we have considered which are, namely,
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> 1) draw a circle with given radius;
> 2) draw a circle with given center and one point on the circle;
> 3) construct an equilateral triangle with given base;
> 4) find the midpoint of a line segment;
> 5) draw an acute angle;
> 6) draw an obtuse angle;
> 7) bisect a given angle;
> 8) given three line segments, construct a triangle.
>
> We then had some discussion of which of these eight constructions was the most difficult. We took a vote and the class results were: No. 8 was the hardest, and No. 4 followed. The students enjoyed this procedure of voting on the most difficult very much.

Almost ten years later, talk about these constructions in the primary grades is not as surprising as it was then. But at the time there was scarcely an elementary school in the country in which such matters were being taught.

The second example concerns the teaching of mathematical logic to bright fifth and sixth graders. We have done this for ten years, with the important practical result that we have found that the elements of logic, as ordinarily taught in introductory college courses, can be mastered without great difficulty by able elementary-school students. Indeed, in the summer of 1964 we even taught a substantial body of material to some very bright children who were about to enter the second grade. These examples suggest that if we can train teachers and provide the appropriate circumstances, it is a relatively simple matter to teach a good deal more of mathematics and also of other subjects to the abler students in our schools.

There are at least two major obstacles to this straightforward approach. One is a complicated matter of policy, illustrated by the remark of a mother of one of the students I was teaching several years ago: "I don't see any reason for teaching so much mathematics to our children. What they need is a great deal more poetry." Practical decisions must be made about the amount of time devoted to poetry and the amount of time devoted to mathematics, or to social studies, or to English, but it is absolutely essential for all of us to realize that as yet we have scarcely the beginings of a serious, rational method for making these relative determinations.

A kind of feudal-fiefdom concept dominates the organization of curriculum. Each subject area is allocated a certain percentage of time; for example, elementary-school mathematics ordinarily amounts to about 15 to 16 per cent of the curriculum. It is relatively easy within this 15 or 16 per cent to discuss the advantages and disadvantages of increasing the amount of geometry or giving some exposure to logic. It is quite

—*Leigh Wiener.*

Preschool reading comprehension test—"In the next ten years the impact of computer-assisted instruction will be felt in a very large number of school systems."

another thing to discuss whether or not another 1 per cent should be added to the mathematics portion of the curriculum at the expense of literature, elementary science, or social studies, or whether the mathematics curriculum should be reduced in order to provide more time for poetry and belles-lettres. I can't begin here to discuss the complexities of the issues. We are far from having a clear approach to them, let alone a way to resolve them.

THE second difficulty results from one of the best substantiated facts in psychology and education: the existence of significant individual differences in learning ability. In 1963 at Stanford we began an accelerated program in mathematics with a group of bright children selected from the first grades in four culturally advantaged schools. Their IQ range is from 122 to 160, with a mean of about 137. Strikingly large individual differences exist even within this relatively homogeneous group of children.

During the first year, for example, the fastest student did 400 per cent more work than the slowest student, as measured by the number of problems completed, which is indicative of the relative speed with which they progressed through the curriculum. To take a slightly different measure for comparison, during the second grade the top four students in the group did about 170 per cent more work than the bottom four students, again as measured by the number of problems completed during the year. We are just completing the analysis of the data for their third-grade work, and the results appear to be comparable to the second grade, although the difference between the top four students and the bottom four students is greater. These differences in learning rate, it is important to emphasize, were not well correlated with IQ, but are due to factors we cannot at present identify.

Examples of significant individual differences in learning ability, even among relatively homogeneous students, are in no sense restricted to mathematics. In experiments with Stanford undergraduates over several years on various aspects of learning Russian, we have been struck by the highly significant differences in ability to learn a second language. In a controlled experiment on the learning of a spoken vocabulary of 300 Russian words, the difference in learning rate, as measured by the number of items successfully mastered in ten sessions, was more than 300 per cent between the slowest and the fastest student in the group. In this case we did not have IQ measures, but we may assume that all the students were highly motivated since they volunteered for the experiment. The data on the slowest and fastest student were not unusual; the other students in the experiment spread out between the two bounds in a relatively uniform fashion.

What can we do to accelerate learning in the schools, especially in a way that is sensitive to the large individual differences in learning rate? Previously, I have discussed in these pages the proposal that for the foreseeable future computer-assisted instruction provides the only practical and economically feasible solution to these problems [see "Plug-In Instruction," *SR*, July 23, 1966]. Here I would like to describe further how content is handled in computer-assisted instruction—the character of the curriculum and, in particular, the impact of individualization.

Research showing the desirability of regular drill-and-practice in basic mathematical skills, particularly those in arithmetic, goes back for over forty years and is well documented in the literature on mathematics education. Clearly, the computer can offer a regular and standardized program on an individualized basis in this area. During the academic year 1965-66 we wrote and tested such a program of individualized instruction. We divided curriculum for each of the grades three to six into concept blocks and each of these concept blocks was presented for between four and ten days. All students began each concept block at the middle level of difficulty. On subsequent days they moved up or down, depending upon their performance levels. Drills on five different levels of difficulty were available. The student found his own level of difficulty, which could vary over the course of the concept block, depending upon his performance. A very considerable advantage of such an approach is that students are not put in tracks at the beginning of the school year and thereby fixed once and for all at the level at which they should work. We know far too little about evaluation of ability and achievement to make such decisions on a permanent basis.

CONSIDER what would be required of a classroom teacher to conduct such a program of individualized review and practice in arithmetic. At the beginning or end of each day, she would need to assign each student to a level of difficulty based upon his past performance. Upon completion of the exercises she would have to grade and evaluate the student almost immediately to avoid a lag in assignment to the next level.

During the current academic year we are striving for a still deeper level of individualization. In addition to the five levels of difficulty on a concept block, approximately 30 per cent of the work is devoted to review of past concept blocks. We keep a running score of the student's work for the entire year and continually review his weakest areas of competence. The same five levels of difficulty are used in the review of the concept block on which the student's past performance was the worst. For example, if the student exited from a concept block with a score corresponding to a level-two performance, he enters review work on this block at the same level. The student is branched upward or downward in levels of difficulty, depending upon his daily per-

The Computer and Costs

WITH CURRENT TECHNOLOGY and without involving large numbers of students, individualized work in arithmetic and in spelling could probably be brought to school districts at a cost of $40 to $50 per student per year, if it were installed in reasonable numbers. [Therefore] to give students a continual experience of the kind I have described in arithmetic in the elementary school would lead right now to about an 8 per cent increase in the cost of instruction per student. These figures, I would like to emphasize, can certainly be improved upon with mass production.

Beyond the cost of installation, it is estimated that ordinary classroom instruction with the kind of systems available in the near future will cost perhaps 30 cents per student per hour. On the other hand, tutorial instruction for special, remedial, or vocational education, or for handicapped children, is very, very much more expensive . . . $3 or $4 an hour. . . .

If you look at education as an industry over the last sixty years and compare it with the steel industry, the automobile industry, any other major industry in this country, the percentage of the investment in capital equipment as compared to salaries is reversed in education [in comparison] to the national trend in all other major industries. I think we can anticipate that with [changing] technology there will be a trend comparable to that in other major industries; namely, a significantly bigger percentage of total expenditures will be devoted to capital equipment and to the implementation of technology.

—P.S.

formance. With a score of 80 per cent or better he branches upward, unless he is already at the top level; with a score running between 60 and 79 per cent, he remains at the same level; and with a score below 59 per cent, he is branched downward.

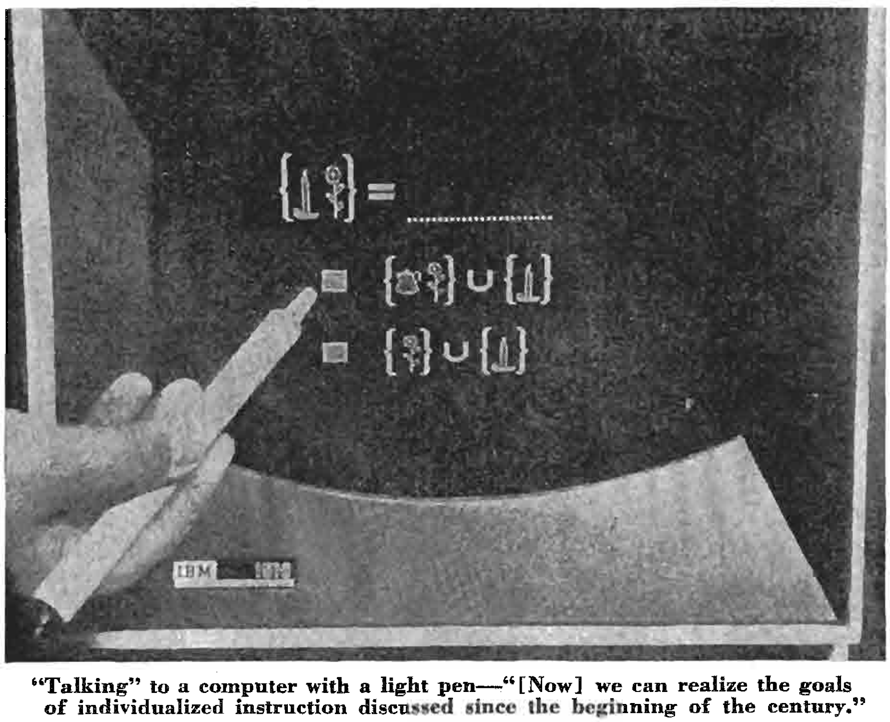
The preliminary evidence from 1965-66 is that such a program leads to specific improvements in performance on arithmetic-achievement tests as compared to the performance of control groups. This is no surprise. It only confirms research, running back many years, that regular exercises to provide practice on basic skills and concepts will improve long-term performance in arithmetic. The computer provides a standardized and regular way of doing this on an individual basis, tailored to the needs of each student. In principle, such a program could be put into practice by a teacher. But in fact, the elementary-school teacher already has too many responsibilities in too many areas to provide such a daily individualized program.

A common criticism of programed instruction is that the answers required of students are too simple and too stereotyped, and that not enough individual freedom and diversity is permitted. These criticisms do not necessarily apply to properly organized computer-assisted instruction, as shown by the subject of logic, which we have been teaching at computer consoles for several years.

We initially give children work with "sentential inferences" of the following sort: *If John is here, then Mary is at school. If John is here, where is Mary?* We move on to examples in simple mathematical contexts of the rules of inference that most readers have encountered in secondary-school geometry. We want to provide an environment in which they may make conceptual progress as rapidly as possible. We want to avoid giving the children restricted multiple choices; on the other hand, we do not want to ask them to write out constructed answers, which is tedious for children, particularly at the elementary-school age level. In such a case, we can simply ask the child to input the rule of inference he wishes to apply to the given premises or to the given lines in the proof. Usually, the child needs only three or four characters on the keyboard of the console, which in almost all circumstances is like a standard typewriter keyboard. We use two letters to abbreviate the rule, and in most cases, the rule applies to two previous lines of premises or proof.

In the example about John and Mary given above, the student would use what we call the IF rule. He would input on the keyboard, "IF 1 2," which indicates that the IF rule is to be applied to the lines 1 and 2. The program then would automatically type out the result of applying this rule to those two lines. This is a very simple example. Actually, the student has a large number of opportunities for different types of responses, even essentially different proofs, as he learns an ever larger body of rules of inference and is exposed to larger bodies of laws and facts to be used as premises in inference.

During the current academic year elementary algebra also is being included in this program. We are recording all the different proofs that students give in order to collect objective data on how much genuine diversity students exhibit in coming to grips with a subject—a question that has been of continual concern in discussions of new mathematics and social science curricula. (One of the most positive aspects of computer-assisted instruction is the possibility of gathering complex objective data on student reactions to a given curriculum.)


"Talking" to a computer with a light pen—"[Now] we can realize the goals of individualized instruction discussed since the beginning of the century."

The presentation of special topics to able students, the provision for selected topics in smaller rural schools, and patient and intensive work with some of the very slow students—all can be handled by computer-assisted instruction, and at present there is no feasible alternative method in sight. Soon, for example, it will be possible to offer an essentially self-contained computer-assisted instruction course in elementary Russian in many high schools throughout the country, without supervisory personnel who are trained in Russian or themselves are prepared to teach Russian. Soon it also will be practical to offer a calculus course in rural high schools by use of computer-assisted terminals connected by telephone lines to a central computer located several hundred miles away.

TODAY, to equip every elementary-school classroom with a console connected by telephone lines to a computer located at the school district office or some nearby central point would cost approximately $2,000 per terminal, but mass production probably could reduce the cost to not more than $1,000 per terminal, including the cost of curriculum development and preparation. There are approximately 1,000,000 elementary-school classrooms in the country. Thus over a ten-year period the total investment to install a minimum of one terminal per classroom would be approximately $1 billion. This is a great deal of money, but during this same ten-year period the country will spend approximately $500 billion on education, and this $500 billion dollars will itself represent only approximately 5 per cent of the gross national product.

We are all aware of how rapid the spread of television has been in the twenty years from 1946 to 1966. It would be foolish to predict that the spread of computer-assisted instruction will follow the same rapid course, but it is fair to forecast that in the next ten years the impact of computer-assisted instruction will be felt in a very large number of school systems in this country. The technology alone is not important. What is important is that by the use of computers we can realize the goals of individualized instruction that have been discussed in American education since the beginning of this century. And we can take another significant step toward realizing the full learning potential of our children.