

New Cultures from New Technologies

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When I was asked to write this Education Forum for BYTE, I was in the process of correcting the proofs of my book, *Mindstorms: Children, Computers and Powerful Ideas*. (See reference 1.) There I struggled to present in two hundred pages a vision of a few ways in which computers might affect how children learn; it is challenging now to find the right 3000 words to convey something of the same vision. What images, what metaphors best capture for me the essence of the computer as it might enter the lives of children?

I start with an image, more general than the computer, that has helped me to think about how the world takes up any new technology. The first movies were made by setting the newly invented motion-picture camera in front of a stage where a play was performed just as plays always had been. Only after some time did cinema become more than theatre plus camera. When it did, what emerged was

something original and unique, a whole new culture with new modes of thinking and new breeds of people—stars, directors, scriptwriters, cameramen, critics, and audiences whose sensitivities, expectations, and ways of seeing were quite different from those of the theatre-goers of the past.

So too with the computer. The first instinct of educators is to couple the new technology to their old methods of instruction. My vision is of something much grander. So I dream of using this powerful new technology not to "improve" the schools we have always known (and, to be honest, hated) but to replace them with something better. I do not believe that this something will look anything like what is now known as "computer-aided instruction" (CAI). I think it will be more like the growth of a new culture, a "computer culture" in which the presence of computers will have been so integrated into new ways to think about ourselves and about the subject matters we learn that the nature of learning itself will be transformed.

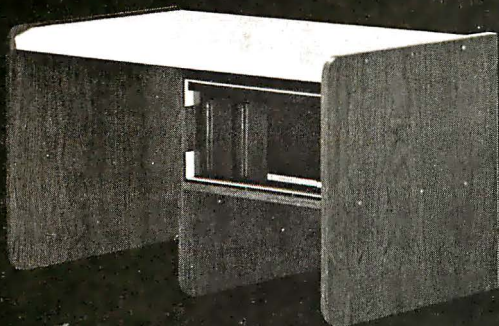
In thinking about the nature of such potential transformation, the LOGO group of the Massachusetts Institute of Technology (MIT) Artificial Intelligence Laboratory has been guided by the idea of creating computer-based environments in which mathematics and other areas of "formal" learning can be learned in a natural fashion, much as a child learns to speak; and applying concepts from artificial intelligence to children's learning, to help children become articulate about, and thus gain control over, the learning process. Before developing these ideas, I would like readers to clear their minds of a misleading but common image. People generally think about computers in schools as a scarce resource to which students have occasional access. It is time we learned to think in terms of a computer for every child, and we should think about children having access to computers from infancy. If we think in these terms, we begin to recognize that there is a clear discontinuity between the current ideas about using computers in schools and the situation of the future. I really believe that almost everything being done today is only relevant to the future in that it sets a bad example so that people become accustomed to primitive models.

A natural place to begin a search for "something new in education" is to look for examples of highly successful learning. For me the most dramatic image of successful learning is the way children learn to talk. This learning contrasts with school learning in many ways, of which I think two are most important. First, it is highly successful: all children learn to speak the colloquial dialect in which they grow up. Second, it has none of the technical paraphernalia of schooling—no curriculum, no set lesson times, no quizzes, no grades, no professional teachers. It is part of living. I call it learning-without-teaching or

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Piagetian learning (after the Swiss philosopher-scientist Jean Piaget who has done more than anyone else to show us how very much children learn in this way).

Much of the work done to date in the whole area of computers and education—eg: CAI—has promoted a style of learning that gives the impression of a child being “programmed” by the computer. Our approach has been diametrically opposed to that. By striving to make the computer’s processes as transparent as possible and creating activities in which children “teach” (ie: program) computers in a well-structured, procedural language like LOGO, we have aimed toward putting children in control of their own learning. Obviously, I cannot hope to explore these ideas in much depth in a short space. What I shall try to do is to describe a couple of learning environments we have created which I believe challenge the fundamental assumptions our society makes about children and learning.

Mathland

The belief that only a few people are mathematically minded is a truism in our culture and a cornerstone of our educational system. It is therefore sobering to reflect on the flimsiness of our reasons for believing it. In fact, the only evidence is crass empiricism: look around and you will see that most people are very poor at mathematics. But look around and see how poor most Americans are at speaking French. Does anyone draw the conclusion that most Americans are “not French-minded?”, that they are not capable of learning French? Of course not! We all know that these same people would have learned to speak French perfectly well had they grown up in France. If there is any question of lack of aptitude, the aptitude they lack is not for French as such but for learning French in schools.

Could the same be true of mathematics? Could there be a place, a “mathland,” which is to mathematics as France is to French, where children would learn to speak mathematics as easily and as successfully as they learn to speak their native dialect?

I believe that the answer is *Yes*. In *Mindstorms* I suggest that the world we live in contains pockets of mathland, which explains why all children learn some mathematics spontaneously (eg: one-to-one correspondences, conservation of number, reversibility of logical operations) and some children become very good at it. Here I have space only to talk about some ways in which the world could become much more of a mathland for everyone.

Computers are the Proteus of machines: they take on many different forms. One of their manifestations is as mathematics-speaking beings. If children grew up surrounded by such beings, the learning of mathematics might very well be much like the learning of spoken language. Developing and testing this image has become a central research question for us at MIT: under what conditions will children talk in mathematical languages to mathematics-speaking computers? The results have already convinced us that the idea of mathland is fundamentally sound and that, indeed, what the mathematics schools fail to teach can be learned successfully on the model of picking up living languages.

But computers do not automatically create that result. For example, instructing computers in FORTRAN to



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manage inventories is of no interest to the average child. Babies brought up in IBM computer centers will be no better at mathematics than any others. They may even be worse (and their other lapses of culture might be more disturbing). In order for computers to play the role of mathland for a child, two conditions are necessary: the computer must understand a language a child can learn (and love to learn), and the computer must be able to do something for the child.

Euclidean Geometry → Cartesian Geometry → Computational Geometry

Turtle graphics is this kind of mathland. It was first developed in our laboratory as part of the programming language LOGO and then taken over by several other languages including Smalltalk and UCSD-Apple Pascal.

A lot of experience has taught us that computer graphics can be a great turn-on. People of all ages enjoy putting images on the screen, and when these images can be made to move and change color, they acquire a dimension completely lacking in conventional pencil-and-paper drawing. At the heart of the work on turtle graphics is the idea of developing a new kind of geometry—"turtle geometry"—which provides powerful and yet easily accessible means to manipulate shapes and motions. To put this in perspective, recall that you probably encountered at school at least two styles of doing geometry: Euclid's style (primarily logical in structure) and Descartes' style (primarily algebraic). Turtle geometry is a new style matched to the computer: it is a computational style of thinking about geometry. The difference in spirit is illustrated by how one thinks about a familiar geometric object in Cartesian and in turtle geometry. Descartes taught us to think of the circle as an equation such as:

$$x^2 + y^2 = R^2$$

In turtle geometry it is possible to use such equations, but the natural way to think about a circle is as a process. To do this, turtle geometry adopts as its fundamental concept an entity called a *turtle* whose properties include its *position* (as does the point in Euclidean and Cartesian geometry) and also its *heading*. At any particular time, it is at a position and is facing in a particular heading. The position and the heading are changed by commands that are built into a programming language. Among these are FORWARD <some number> which causes the turtle to move in the direction of its heading without changing the heading, and RIGHT <some number> which causes the turtle to change the heading while keeping the position fixed; ie: to pivot in place. Given these commands, a program in LOGO to draw a square of a certain fixed size takes the simple form:

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TO SQUARE
FORWARD 100
RIGHT 90
FORWARD 100... etc
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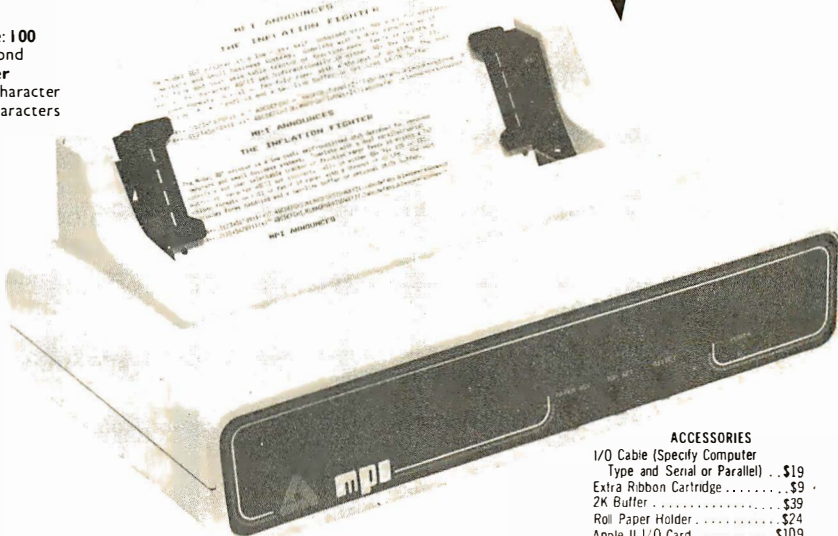
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A slightly more sophisticated program to draw squares of varying size takes the form:

TO SQUARE SIZE
REPEAT 4 [FORWARD :SIZE RIGHT 90]

Now we can think of a circle as generated by:

TO CIRCLE
REPEAT 360 [FORWARD 1 RIGHT 1]

More sophisticated programming leads to circles of variable diameter and even to letting the number of steps go to the limit, but the simple example will illustrate the main point I want to make here. Children can solve the problem of drawing a circle by using a very powerful heuristic principle: play turtle, walk out yourself what you want the turtle to do and describe what you did in turtle language. The children are practicing a lot of powerful ideas. They are exposed to the idea of using heuristic knowledge, they are learning to think of formal mathematics as rooted in (not opposed to) intuitive body-mathematics, and they are using mathematics as a language; moreover, they are learning to think about mathematics not as a ritual to be learned by rote but as an instrument to be used for personal ends.

Computer as Pencil

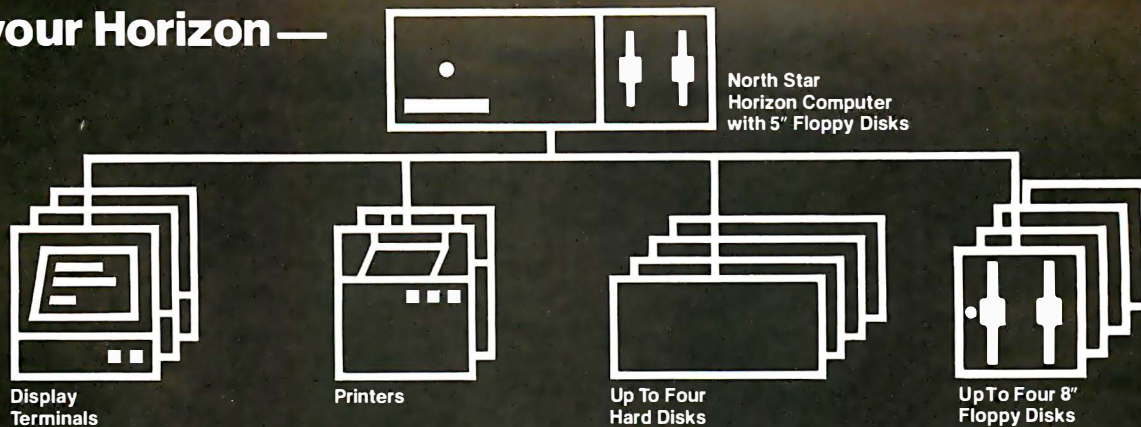
This image refers to the many uses of the pencil: it is used to scribble, to doodle, to draw, to write, to work sums, or to chew on. It is used for illicit notes as well as for official assignments. I see the computer in the life of the child as equally ubiquitous and equally versatile. I also see it as equally personal. Children own pencils, they are not intimidated by them. This should be equally true of the child's personal computer.

The metaphor of the pencil is a good way to summarize some of the ways the image of the computer I am building up here differs from the one that is becoming established in schools.

Suppose that the only access children had to pencils (which I take in a generic sense including pens, crayons, and the like) was at school, and even there "pencil time" had to be scheduled on the one or two pencils available to each classroom. This might (or might not) be better than having no pencils at all, but clearly under those conditions the pencil would not play the important role it now does in the intellectual development of children from infancy onwards. In my vision the computer will become as free a resource as the pencil now is.

Second, there is the question of the power of the computer to be used flexibly for many purposes. The microcomputers in schools today can barely be used flexibly by those few who have the inclination to become virtuoso programmers in BASIC. This is very different from the model of the pencil that can be picked up by everyone—even the one-year-old infant—and also used by the most sophisticated writer or artist. LOGO and Smalltalk are only first steps toward programming languages that will truly satisfy our slogan: "No threshold and no ceiling." A child of five or less should be able to write a program in the first few minutes of contact with the computer and a computer scientist should find the system congenial and rich.

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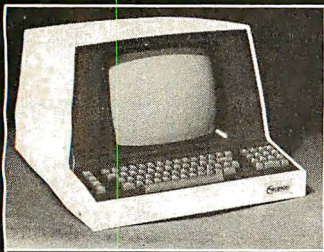
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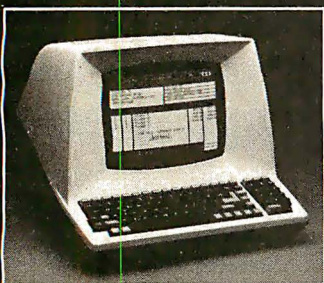
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Third, I mention the use of the pencil and of the computer as writing instruments. The computer is rapidly becoming the standard writing instrument. Most journalists use word processors, as do increasingly many offices. I am using one as I compose this article. But the schools are not offering children this facility, although one could argue that it is children who are in most need of writing aids. The reason is clearly linked to the ratio of computers to students. One or two computers per class simply does not give enough access for the computer to become the primary writing instrument. On the other hand, one computer per child, which is how I think we should be thinking about the future, could lead to massive changes in the way children develop writing skills. A well-designed text editor makes editing—substitution and deletion of words, shifting of sentences or paragraphs, and so on—an easy and aesthetically acceptable process. Compare the situation of a child attempting such a task with paper and pencil: the mess of multiple erasures and labor of rewriting means that the first draft is almost always the final copy. I have seen children who hated writing become avid writers when they have a text editor at their disposal. Wide availability of computers with text-editing capabilities might lead to even more fundamental changes in children's relation to alphabetic representation of language. Consider the implications of the following story:

Recently I observed the first group of nursery-school children working with a computer called the Lamplighter Computer (a Texas Instruments 99/4 personal computer with additional memory to support an extended version of LOGO and a real-time text-editing system) developed over the past few years through a collaboration between our research group at MIT and Texas Instruments. A four-year-old girl (I shall call her Robin) was working with some dynamic graphics programs that allowed her to make shapes appear on the screen, move, change color, and stick together by pushing one or another of some fourteen keys on the keyboard. The plan was that when Robin was tired of using a program she would ask the teacher to set up a new program. And this is in fact what she did for the first few times. But then Robin took charge of the whole process and began typing the control characters necessary to interrupt a program she no longer wanted and typing the names of the programs she did want, even though this was at a measured rate of about two characters per minute. In breaking out of the role of dependence on adults, Robin symbolized the fact that computers will enable children to break out of many of the roles into which technological primitivity and social custom have cast them.

We should not pass too quickly over the significance of the simple fact that Robin could make things happen by typing words. It might well be the first time in her life that alphabetic language actually served a real and personal purpose. The spoken language and its precursors enter from the first year of life into a significant process of interaction with the world. Learning to speak empowers the child. But for most children the act of writing serves at most to gain the approval of adults. Could this be the reason children learn to talk so easily and so young

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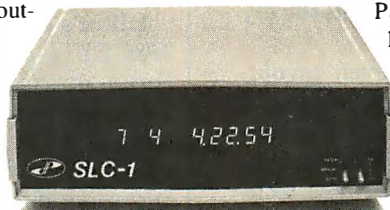
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while they learn to write with so much difficulty so many years later? Watching Robin left me more firmly convinced than ever of a conjecture I have pursued for quite a few years. Children could learn to write as early and as easily as they learn to speak if the environment in which they lived gave as much support to the alphabetic language as ours does to the spoken language. I have no doubt that if Robin had her own computer and could use it whenever she wished, and if this computer gave her access to enough exciting things to do, she would within weeks have mastered the keyboard, the alphabet, and enough of spelling and syntax to put her firmly on the road to the kind of mastery of written language that usually comes, if at all, well into the school years.

Meaning Versus Ritual in Learning

The fundamental question for education is not how to improve schools but how to understand why schools are necessary. Why is some knowledge (like learning to talk) picked up so easily and naturally from the culture, while other kinds of knowledge seem to require deliberate, organized instruction? In *Mindstorms* I explore the many factors that make a difference. Here I have space only for one. Children learn to speak because it is a *meaningful* activity, a meaningful part of their lives. It is not surprising that children do not learn to write when writing serves no real purpose in their lives. I think the computer can change this. For Robin, alphabetic communication was beginning to become purposeful. As computers become increasingly available to children I would expect many children to share Robin's experience of writing as a meaningful activity. This shift—from meaningless ritual imposed from above to purposeful, self-directed activity—is also true of Mathland. No activity in school is experienced as more devoid of meaning than the parody of mathematics known as school math.

The harm done by making children learn ritualistically goes very deep. It develops the worst possible habits of learning. It undermines the individual's self-confidence as an independent intellectual agent: it infantilizes the child. A shift to more meaningful learning of fundamental subjects could have far deeper consequences than improved mastery of these subjects. It could mean that children become more effective learners with greater intellectual self-respect. And if this happens, not only the nature of children's learning but also the role of children in society may have changed.

I have hinted at a vision of profound, even revolutionary, change in how children learn. I think this might happen. We have the technology to make it possible. But there is nothing inevitable about it. Society has a very bad track record in making intelligent use of new technologies, and, in this case, many vested interests are threatened by the changes I envision. The "system" will react by defending its old ways. Already in schools we see computers being used to reinforce instead of displace the most ritualistic teaching methods. I believe that the most profound effects of computers on how children learn could occur outside of schools. In fact, I think that computers would tend to make schools as we know them obsolete. But most of my "official research" is concerned with how to use computers in schools. Research funds are easily available for the reformist goals of improving schools. I believe that the most profound effects of com-

puters could be to develop a new respect for children as independent intellectual agents. But most people in our country like to think of children as intellectually dependent.

How will it all work out? It is futile for me to play prophet, but worthwhile to bear some ideas in mind when thinking about the future. I want to end by mentioning an idea that encouraged me to think positively. I can best introduce it by comparing the education market with markets for other products. Suppose you invent a new kind of kitchen machine. If you can prove that there is a market of a million people, you will easily find the capital to develop the idea and get it out into the world. But if you invent a new approach to learning mathematics, the fact that a million people want it may be of no avail—a million people across the nation may still be a tiny minority with no clout in every school district. But once there are a few million owners of home computers capable of carrying powerful learning methods, you will have access to a market of individuals ready to spend personal dollars for the good of their children. The importance of this fact is not that it will enable good ideas now collecting dust on shelves to get out into the world. It will encourage inventive and ambitious people to enter the field of educational innovation in unprecedented numbers. It will be part of the creation of a new class of professionals and of entrepreneurs and perhaps even of "stars" analogous to what happened in the course of the emergence of cinema as a culture. The history of cinema has been the history of that culture. The future of computers in education will be indissociable from the story of the people who will make the computer culture. ■

References

For more about Turtle Geometry see S Papert, *Mindstorms: Children, Computers and Powerful Ideas*. New York, Basic Books, 1980 (ISBN 0-465-04627-4, \$12.95). Also see H Abelson and A diSessa, *Turtle Geometry*, MIT Press, Cambridge MA (to appear 1981). For a bibliography of the LOGO group's internal publications, write to LOGO, c/o MIT Artificial Intelligence Laboratory, 545 Technology Sq, Cambridge MA 02139. (Please include \$1 for handling.)

Editor's note: A note in the introduction to the July 1980 BYTE editorial incorrectly states that Education Forum articles by Seymour Papert and James Garson were to appear in the August and September BYTES, respectively. However, because of unavoidable scheduling considerations, Seymour Papert's article is appearing this month, and James Garson's article will appear in a future issue. We apologize for any inconvenience this change might have caused....CM

Education Forum is an occasional feature in BYTE intended to foster debate about the uses of personal computers in the schools and colleges. We encourage reader participation. Contributors should supply their full names and addresses for publication, along with their telephone numbers, which will not be published.