The Children's Machine

RETHINKING SCHOOL IN THE AGE OF THE COMPUTER

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laboratories and giving it to the children of the world. A first step in the quest was to recognize that one of the sources of the technologists' power was the veil of esoteric mystery woven around the idea of programming. The situation is quite analogous to the way priests of other ages kept power from people by monopolizing the ability to read and write, and by keeping what they considered the most powerful knowledge in languages the common people could not understand. I saw the need to make computer languages that could be "vulgarized"—made available to ordinary people and especially children.

This has turned out to be a long and difficult task. Computer languages, like natural languages, cannot be "made"; they have to evolve. What could be made was a first shot at such a language, named Logo, which would serve as a starting point for a longer evolution that is in fact still continuing.

For the sake of concreteness, the ideas in this book are developed through the story of my own inventions. I make no secret of the fact that I love and value some of them. I believe that some may even have a long-term future. But I repeat that my purpose here is not to tell the reader how to do things right but to provoke and fuel imaginations. In this book my real-life inventions serve the same purpose as the imaginary examples of time travelers and hypothetical nineteenth-century engineers. They are meant to evoke further ideas, to prepare our minds for other, much more exciting inventions still to be made. My purpose could not be further removed from advocating a particular invention as *the* solution to *the* problem of education; rather, each example is meant to serve as a pointer to a vast area of new opportunities for educational invention. My goal in relation to Schoolers—or to anyone who thinks that any form of learning is the right and natural form of learning—is to stir the imagination to invent alternatives. Piaget said that to understand is to invent. He was thinking of children. But the principle applies to all of us.

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School: Change and Resistance to Change

I made a first pass at creating images of educational megachange in *Mindstorms: Children, Computers, and Powerful Ideas,* written in the late 1970s, a time when personal computers were still novelties. IBM had not yet moved into the field, nor had the Japanese. The original Apple was mostly the darling of enthusiastic computer hobbyists.

The subtitle of the book reflects a gap in my experience and knowledge by mentioning children and excluding school. Children's involvement with computers had already begun. The first primitive video games had appeared, and one could mount experiments in which large and expensive machines simulated the still nonexistent personal computer. Children's interest in what they could do with the machines was not distracted by knowing that a million-dollar machine stood behind the terminal used in the experimental setting. No similar experiment could be done on what schools might do in a world in which computers would be everyday objects. Their reaction was so profoundly determined by considerations of price and size that no "simulation" could provide insights into how they would allocate real budget and accept real changes in their organization. It is not surprising, then, that my discussion of schools lacked the texture that real experience gave to the discussion of how computers could mediate between children and ideas. I was not the only one to suffer from this failing; in fact, a persistent tunnel vision continues to deform public discussion of the relationship between technology and schools. My purpose in this chapter is to develop a wider-angled view.

Mindstorms was written at a turning point in the development of educational computing. At that time, there were at most a handful of classrooms in which anything like the classroom incidents mentioned in the previous chapter could possibly have taken place; in fact, the only activities in the field that I know of were two formal research projects, my own and a related one mounted by Alan Kay, a seminal contributor to the idea that the computer could be an instrument for everyone. Yet two years after the book was published, there were hundreds of classrooms in which one could see similar events, and two years later still, there were tens of thousands. This growth of a school computer culture was still far from megachange, but it had reached proportions that made it incomparably richer as a source of insight into educational change than the cramped experiments of the previous decade. In ten years American schools had bought three million computers; tens of thousands of teachers enrolled in classes to learn about computers; new industrial giants moved into the education market; twenty thousand items purporting to be "educational software" were offered for sale.

These dramatic events did not fail to attract media attention. Apart from the sheer numbers, the very idea of a small child using a computer gave people a sense that something new, exciting, and a little disturbing was in the air. Add to this the photogenic quality of children with eyes made brighter by the light of the screen, and it is understandable that computers in schools for a while aroused more enthusiastic coverage in the press than sensible discussion about what it all meant. But what did it mean? What sensible questions would lead to understanding what was happening and

where it might go? A headline in the *Wall Street Journal* reflected the doubts of sensible people interested in the bottom line. SCHOOLS BUY MANY COMPUTERS, it proclaimed, BUT BENEFITS IN CLASSROOMS ARE SMALL. The tone of skepticism is understandable. Talk of crisis in the schools was on the rise. Even in the uncritical climate of Reagan's Washington, the report "A Nation at Risk" had dramatically proclaimed this. It is not surprising that questions were asked: Where are all those computers we have heard so much about? What are they doing? Far from producing improvement, they seemed unable even to stop the deterioration.

I offer two replies to the kind of doubts raised by the *Journal,* one relatively superficial and one more serious. The superficial response concerns the use of the word *many* to describe the number of computers in the schools, which at the time was between one and two million. Was this a lot? Yes, if one thought of a mountain of computers piled up in one's backyard. No, if one divided it by the number of students in all those classrooms. I know what it is like to have had my intellectual life change, and more than once, through using computers. In addition to intellectually deeper changes, my writing habits have changed because I take a computer on a plane, in a car, out on the lawn, or to the bathroom; and my communication habits have changed as a consequence of so many colleagues and friends being in touch through electronic mail. Just two days ago I clarified my thinking about the economic reform in Russia by programming a soft simulation of economic competition. This can happen because I have a computer, in fact several computers, within reach at most times.

The critical level at which computers really make a difference is surely less than what I have, but equally surely more than what schools offer most students. A million computers divided among fifty million students gives each of them one-fiftieth of a computer. I do not think that the significant benefits that computers have brought me would have accrued from a fiftieth of a machine. Simple arithmetic, which is not altered in principle by the fact that some schools may have had three or four times the average number of computers, provides so obvious an explanation of the *Journal*'s puzzle that one wonders whether the journalists who wrote the article were really thinking in any concrete sense about what they were writing. I wonder whether they would be surprised if observation of schools in some country where only one writing instrument could be provided for every fifty students suggested that writing does not significantly help learning.

The argument that a small number of computers is unlikely to produce big change might seem to be contradicted by some of the incidents mentioned earlier, where children enjoyed the experience of sharing two computers with a whole class. There is no doubt that, with or without computers, an isolated event can sometimes precipitate important intellectual growth. But more often, change requires a much longer and more social computer experience than is possible with two machines at the back of a classroom. In chapter 6 we'll meet Debbie, who did have an "aha" experience about the meaning of mathematics, but she was in a school which owned over a hundred computers. Also, such change is often reversible, as in the case of Raymond, whose experience with computers gave him his first taste of enjoyable and successful learning at school. This student who had been classified as "learning disabled" produced a quality of work that astonished his teachers, his parents, and even himself. However, this taste of something better aggravated his dislike of the ways of regular classroom life to such an extent that in the end he rejected school even more deeply than he had before his computer experience.

Another reason for small effect involves deeper problems than that of numbers. In the early 1980s there were few microcomputers in schools, but those few were almost all in the classrooms of visionary teachers, most of whom employed them in a "progressive" spirit, cutting across School's practices of balkanized curriculum and impersonal rote learning. Thereafter, however, the pattern changed sharply. The initiative and the power in the field of computers were moving from teachers to school administrations—most often at the city or even at the state level. When there were few computers in the school, the administration was content to leave them in the classrooms of teachers who showed greatest enthusiasm, and these were generally teachers who were excited about the computer as an instrument of change. But as the numbers grew and computers became something of a status symbol, the administration moved in. From an administrator's point of view, it made more sense to put the computers together in one room—misleadingly named "computer lab"—under the control of a specialized computer teacher. Now all the children could come together and study computers for an hour a week. By an inexorable logic the next step was to introduce a curriculum for the computer. Thus, little by little the subversive features of the computer were eroded away: Instead of cutting across and so challenging the very idea of subject boundaries, the computer now defined a new subject; instead of changing the emphasis from impersonal curriculum to excited live exploration by students, the computer was now used to reinforce School's ways. What had started as a subversive instrument of change was neutralized by the system and converted into an instrument of consolidation.

This analysis directly contradicts the answer most commonly given by researchers when asked why computers have made so little dent in the problems faced by School. They are inclined to say that "schools don't know how to use the computer"; and they propose to remedy this by more research on methods of using computers, by developing more software, especially software that will be easier to use, and by setting up channels of dissemination of knowledge about computers. They are fundamentally wrong. Of course, research will increase the variety and effectiveness of uses of computers, but this is not what will change the nature of computer use in schools. The shift from a radically subversive instrument in the classroom to a blunted conservative instrument in the computer lab came neither from a lack of knowledge nor from a lack of software. I explain it by an innate intelligence of

School, which acted like any living organism in defending itself against a foreign body. It put into motion an immune reaction whose end result would be to digest and assimilate the intruder. Progressive teachers knew very well how to use the computer for their own ends as an instrument of change; School knew very well how to nip this subversion in the bud. No one in the story acted out of ignorance about computers, although they might have been naïve in failing to understand the sociological drama in which they were actors.

This view of the development of computers in schools points to a very different approach to what can be learned from the experience of computers in schools than that of the *Wall Street Journal* article. The question has shifted from "Did it succeed, yes or no?" to "What actually took place below the surface; what can we learn from the experience that will inform future strategies?" The principal "lesson" I learned represents a significant shift from the views I advanced in *Mindstorms,* and what is still customary in the field of educational computing.

The shift is analogous to the emergence of developmental teaching, which eschews molding a mind as if it were a passive medium and instead tries to collaborate with the student's developmental patterns. If the student does not progress in the expected way, the developmental teacher tries to understand what happened, rather than branding the student as a failure. Looking below the surface one can often see an inner coherence in what appeared to be just plain wrong, one sees mental roadblocks that stand in the way of progress, and one sees dynamic elements that can be mobilized to serve it. *Mindstorms'* ideas about children were quite thoroughly developmental, but I now blush at recognizing how my thinking about School contravened basic developmental canons. I characterized much of what School does as "wrong" and preached at it about what was "right." Such procedures are not effective in guiding children and will not be effective either in guiding educational innovation. School will not come to use computers "properly" because researchers tell it how to do so.

It will come to use them well (if it ever does) as an integral part of a coherent developmental process. Like good developmental teachers, researchers can contribute best if they understand change in School as development, and support this by transferring the ideas that were successful for understanding change in children.

Piaget vastly increased understanding of children by means of an idea that seems, as many of the greatest ideas do, ridiculously obvious once one has understood it. All mental operation, he said, has two facets, which he calls *assimilation* (changing your representation of the world to fit your ways of thinking) and *accommodation* (adapting your ways of thinking to fit the world). School's first response to the computer was, quite naturally, one of assimilation. School did not let itself change under the influence of the new device; it saw the computer through the mental lens of its own ways of thinking and doing. It is a characteristic of conservative systems that accommodation will come only when the opportunities of assimilation have been exhausted. In the interim one sees interesting subplots of the developmental story as the system displays its ability to block off incipient accommodations.

In education the acronym CAI (Computer Aided Instruction) is used for the fully assimilated usage of computer technology. CAI refers to programming the computer to administer the kinds of exercise traditionally given by a teacher at a blackboard, a textbook, or a worksheet. This is so far from challenging the assumptions of traditional School that critics frequently ask whether it does anything at all to justify the cost of computers. The most hardened skeptics describe the computer as "a thousand-dollar flash card," and what it does as "drill and kill."

Advocates reply by listing advantages of having a computer ask a student, for example, to calculate 35 percent of $2.00. Those most frequently cited include immediate feedback (one will learn more from a mistake by being told immediately not only that one is wrong but why); individualized instruction (the questions can be matched to the level of competence of the student); and neutrality (the computer is not subject to biased perceptions, by student of teacher and vice versa, related to race, gender, or personal history). Statistical studies show that the introduction of CAI will often modestly raise test scores, especially at the low end of the scale. But it does this without questioning the structure or the educational goals of traditional School.

The first sign of incipient accommodation came, as perhaps it always does, through another assimilation. Large numbers of progressive teachers were able to assimilate the computer to their ideas about teaching (and about getting around School), and this gave rise to a movement that I shall call the Progressive Educational Technology (or PET) Movement.

CAI is older than PET—in fact, it dates back almost as far as the idea of the computer. When I first entered the computer scene it was already in existence and, in fact, held a monopoly on thinking about computers in education. The first formulations of ideas that would become those of PET emerged slowly from the development of Logo and the turtle, mentioned in the last chapter. In the early 1970s this stream of development was joined by another under the leadership of Alan Kay, a computer scientist, musician, and inspiring personality who was, I believe, the first person to use the words *personal computer.* At the end of the 1970s, these ideas filtered slowly into the awareness of progressive teachers who happened also to be in touch with the excitement that accompanied the first microcomputers.

In 1980 three events came together to give a powerful boost to the awareness among teachers that computers could be used in the spirit of progressive education. *Mindstorms* set this out in easily accessible form, inexpensive personal computers reached a level of performance that could support a usable version of Logo, and Logo software became commercially available. The result was a grass-roots movement that generated many thousands of classroom implementations of PET. The character of this movement and the depth of its conflict with School's philosophy cannot be captured by abstract formulas. Instead, some anecdotes will convey the texture of the conflict.

Even now I can close my eyes and see a 1981 scene in a fifth-grade classroom in a New York City public school. Two worlds seemed to coexist in one room: At one end, a teacher, Thelma, was giving a "lesson" at the blackboard; at the other, a cluster of students was working with two computers. The computer group ran into a problem and sent someone to "ask the teacher." Thelma said, "Maybe Bill can help"—and continued her lesson without missing a beat, quite unperturbed by the fact that Bill had now joined the ranks of students who weren't even pretending to listen to her.

The front and the back of the room were separated by much more than a difference between the technology of the computer and the technology of the blackboard. A far greater difference marked the children's relationship with what they were doing. In front, they were following someone else's agenda; in the back, they were following their own. Among them, the ones I remember most vividly were Brian and Henry.

When I came into the room I was captured, as was every visitor, by the spectacular visual effects on the computer screen produced by programs written by the two students. Colored shapes moving in complex intertwining paths spoke immediately to a choreographic talent, a sense of movement and drama. I had to examine the display more closely before I was able to recognize the mathematical sophistication that went into controlling the geometry and dynamics of the movements. These boys were engaged in a mathematical exercise fundamentally different from calculating 35 percent of $2.00 on command. Their activity included such calculations (together with more sophisticated mathematical thinking) but not as set exercises; the calculations came up in the course of doing a larger and personally motivated project. In fact, I chose the percentage problem as my example to illustrate CAI expressly because it is quite like one of the many different kinds of calculational problem Brian and Henry did have to solve: For example, at what speeds do two objects have to move so as to arrive at the same place at the same time if one follows a path whose length is 35 percent of the length of the other?

This latter problem is harder than the usual School kind because its geometric form makes it more complex and because the boys would have to scrounge and scurry to find out how to do it: ask a teacher or fellow student, look in a book, work by analogy with another situation, try to invent a method, resort to trial and error. Children never seem to mind: What makes School math repugnant for the Brians and boring for the Henrys is not that it is "hard" but that it is a senseless ritual dictated by the agenda of a set curriculum that says, "Today, because it is the fifteenth Monday of your fifth-grade year, you have to do this sum irrespective of who you are or what you really want to do; do what you are told and do it the way you are told to do it." The point is not that their teacher was willing, as some advocates of "free school" have proposed, to let her charges do anything they wanted. Far from it: She imposed very high standards and demanded commitment and discipline. But when Brian and Henry wanted to do something that was deeper, more instructive, and more intellectually demanding than the fifth-grade curriculum, her instinct as a teacher told her to encourage them.

The previous relationship between these boys says a great deal about School as an intellectual environment. Although these two boys had been classmates for four years, they hadn't talked to one another much until the computers brought them together. They had already developed strong individual interests in life, and although School threw them into the same room, it provided few opportunities for these interests to meld into real relationship. Thus School squanders its most valuable resource—the interchange between the most intellectually interesting students.

Henry had always been the math whiz and his fantasies were in science fiction; Brian had always cared about music and dance. Watching him, one had no doubt that the sensory and bodily aspects of the world were important to him. Henry was awkward in his movements, one might say out of touch with his body. He cared little about clothes and colors. But although this cut him off from a significant area of experience, up to the arrival of the computers he had not experienced it as a deficiency—certainly not as a deficiency relevant to his schoolwork. Science and mathematics, the areas he enjoyed and excelled in most, seemed to have no relationship with sensory enjoyment and physical action. Indeed, this perception surely contributed to his attachment to these activities, just as it contributed to Henry's indifferent response to them.

When their teacher brought computers to the classroom, therefore, the two students had very different expectations. Henry knew instantly that this was going to be his thing; without any doubt he would be "best at computer." Brian's reaction mixed a mild curiosity with a twinge of apprehension.

Henry found that the route to making the most of the computer went through establishing a working relationship with the least likely person in the class, Brian the dancer. Brian found for the first time that mathematics could be a personally exciting medium of self-expression and the basis of a genuinely interesting friendship.

The story needs some background information about how the computers were introduced into the classroom. Thelma had attended a summer workshop sponsored by the National Science Foundation on using computers in schools. She had enrolled with little idea of what she would do there, and with some trepidation, for she had never thought of herself as a "technology person." But computers were in the air. She had friends who spoke about the microcomputer revolution, about how these new machines would give ordinary citizens access to information previously monopolized by big corporations and government agencies. She had read that they would lead to new methods of teaching. But, most important, she understood that children loved them, and the same spirit that led her to bring hamsters and plants and posters and all manner of what she called "junk" into her classroom sparked her interest when she heard about the summer course.

Thelma's first contact with computer programming consisted of using Logo to instruct the computer to draw patterns of lines on its screen. She was actually surprised at her surprise at finding that she could make the computer draw something she wanted; even getting it to draw a simple square gave her a sense of pleasure at beginning to "own" a technology so symbolic of what was most modern and most powerful. After a few days her ability to produce more intricate patterns and set objects in motion on the screen evoked associations with computer art and with the special effects in movies like *Star Wars.*

By bringing this kind of programming technique back to her classroom, Thelma inspired the collaboration between Brian and Henry. In her class, creating animation on the screen became the most common choice made by children who were free to do what they wished with the computers.

Some children created realistic animations to tell a story. Not surprisingly, Henry was among those who preferred more stylized forms whose visual interest was in the complexity of shapes and patterns of motion rather than a narrative content. Henry quickly understood the technical side of programming. Earlier than anyone else in the class, he knew exactly how to create figures on the screen and make them move. He had enough visual imagination to try for effects whose nature is evoked by the names he gave them: "Fireworks" or "Star Wars" or "The Big Bang." His talent for mathematics paid off in his easy mastery of techniques for programming an object on the screen to begin moving almost imperceptibly and then gradually accelerate. Something more creative showed itself in what a mathematician would call "generalizing the idea," when he realized that the same techniques could be used to make a sound mount in pitch from a low growl to a high scream and eventually disappear into the ultrasonic range. From a School point of view he was doing very well indeed, but something was missing.

Henry took pleasure in the mathematical cleverness behind his displays but was disappointed by the total effect. His problem was not simply that fellow students drew more "oohs" and "aahs" when they showed their work. He could feel that his creations

lacked something he did not know how to achieve or even name, certain qualities that another fifth-grade student described as "grace" and "excitement." Perhaps for the first time in his life, he felt the pang of awareness of an intellectual limitation. His mind was ready for a breakthrough.

The idea came to him when he saw Brian dancing in a school corridor. Recognizing that Brian's movements had just what his screen displays lacked, Henry was led quickly to the inspired thought that they might work together to produce the best screen choreography ever made! The thought led to a long-term working relationship. Together the two boys created something that neither could even imagine alone, and in doing so learned much more than math test scores are capable of measuring.

They certainly mastered a great deal of technical mathematics. Moving those objects on the screen required a description of the movements in mathematical language that went beyond even Henry's previous knowledge. They represented an object's speed as a variable, and then set up formulas to vary it. They learned to think of directions as angles measured in degrees. They picked up the idea of doing geometry by coordinates in a way much closer to the living and personal discovery through which René Descartes first came upon it than to the deadly formal presentation of math textbooks. But this kind of knowledge was only a small part of what they learned.

Beyond developing technical mathematical skills, they came to experience mathematics in a very different way. It became something to be used purposefully; they felt it as a source of power in pursuing important and deeply personal projects. I am not sure that people who have not experienced mathematics in this way can fully appreciate how heady, how powerful, it can be. An analogy might be the experience of learning to ski. At first one is instructed in a series of awkward movements: Shift your weight, bend your knees, and so on. One obeys the commands but it feels as if one is clumsily acting at being someone else. Then one day comes a conversion experience. One is flying (or so it seems) down the slope. One's own knees are flexing and extending, one's own weight is shifting. One doesn't have to "do" these things; they flow as inseparable parts of a fluent and joyous movement.

Certainly for Brian and possibly for Henry too, their collaborative work had elements of such a conversion experience. Mathematics became more like flying down the hill than like bending one's knees and shifting one's weight at the command of an instructor. This does not mean that doing mathematics became easy: Quite the contrary, just as in the experience of skiing, there was the frustration and never-ending struggle of mastering new techniques and handling new challenges. It became harder as they engaged with more serious problems, but when one is deeply involved in something, "easy" is not what one wants. If it were, one would spend the rest of one's skiing life going down the easiest slopes; but most people, especially young people, seek the challenge of moving on to more interesting terrain.

The analogy with skiing brings out an experiential side of Brian's and Henry's mathematical learning that goes beyond acquiring technical knowledge. The analogy also suggests ways in which their learning went beyond mathematical learning even in the widest sense of mathematics. The use of the word *fluent* in reference to skiing reflects a relationship with activities where the word is more often applied, for example, language or musical performance. I want to generalize this notion to other activities and suggest that Henry and Brian, in rather different ways, were learning to be fluent in the use of mathematics. They were also learning the feel of fluency. I want to suggest that fluency in its own right is an important and insufficiently recognized area of competence.

Brian came to the collaboration with certain kinds of fluency. His fluency in dance, in body movement, was what drew Henry's attention and what provided the basis of the collaboration. But there was more to the pattern of where he was and was not fluent than simple competence in dance. Brian was a fluent talker; he could tell a story in a way that would hold rapt attention. His talking had exactly those qualities of "grace" and "excitement" that were missing in Henry's programming. But an amazing thing happened when he took a pencil to write. What came out was totally lacking in these qualities. What he put on paper was one laboriously wooden sentence after another. The contrast of oral fluency with plodding writing is extremely common and a major cause of illiteracy: Those who know from their oral skills what it is like to use language fluently are repelled by their own clumsiness when forced to write and often end up simply refusing to do it.

For people like Brian, the opportunity to make animations provides a way to extend their domain of fluency into an area that shares essential qualities with speech, body movement, and written language. It may take time to get your screen creation right, but once you do you can move with it; you can feel its excitement in a very direct bodily way. On the other hand, the program is a text that stays still to be examined and edited. In this way it is like writing; indeed, it is writing.

This is the first of many ways in which the computer breaks down the barriers that traditionally separate the preletterate from the letterate, the concrete from the abstract, the bodily from the disembodied. By straddling these divisions it removes an obstacle that has kept many people from crossing from the concrete, body-syntonic orality of childhood to forms of competence that have in the past been accessible only in literate, abstract, and decorporalized forms. This applies most directly to Brian. Henry's most obvious problems with this crossing are seen in the opposite sense: He had moved easily but too thoroughly to the other side and cannot easily come back.

Our culture's supervaluation of the abstract obscures the ways in which Henry may have benefited from his exposure to thinking about the choreography of movements. Acquiring a feel for creating grace and excitement would have stood him in good stead for writing a science report, composing a story, or simply telling a joke. Given time, it could even have affected the way he moved his body. It might have changed his social life. More subtly and more profoundly, it might have opened him to a greater variety of ways of knowing.

Both boys felt what it was like to communicate with one another across a cultural barrier. They had the experience of jointly managing a complex project over many weeks, and, of course—though this in itself was the least of it—they were learning to program computers.

The story of Brian and Henry is not intended to suggest that all students who encounter Logo will have a similar experience. Many other factors besides "Logo" entered into what happened. Perhaps one could sum them up by saying that the teacher succeeded in creating a productive and supportive computer culture in her classroom. And even then, conditions were far from ideal. Many children will have an experience that is less rich, though it is rare that nothing is gained. The story is not meant to be statistically representative of an average event but conceptually representative of a mode of learning very different from School's. The next story is similarly representative of School's "immune response."

Richard had an intensive Logo experience in his fourth- and fifth-grade years at the Hennigan Elementary School in Boston. In the experimental Project Headlight, he had used Logo almost every school day in the spirit shown by Brian and Henry, and had acquired a considerable competence both in the technical aspects of Logo programming and in the spirit of using it as a medium for other work. A few months after Richard graduated from Hennigan, he was visited at his new school by members of the research team who had worked with him and were interested in his progress. Although the researchers knew that access to computers at the new school was much more limited than at Hennigan, they also knew that a large part of this time was devoted to Logo and were looking forward to seeing what Richard was doing with his

proficiency in Logo. To their surprise, they were told that he was not allowed to do it. "But we thought you liked Logo," they said to the teacher. "Yes I do," she replied, "and I have my students spend a lot of time on it. But Richard already knows Logo. So I had him learn something else."

The story captures one of the chief differences between learning at school and all other learning. Generally in life, knowledge is acquired to be used. But school learning more often fits Freire's apt metaphor: Knowledge is treated like money, to be put away in a bank for the future. Something of this way of thinking was present in the attitude of the computer teacher at Richard's new school. Logo is something to be learned rather than something to be used; the students learn it in order to know it; when they know it they put it away in their memory banks (which, incidentally, pay no interest) and go on to the next topic in the curriculum. In the case of computer knowledge, the banking approach is often defended by the argument that it will stand the students in good stead when they grow up and look for jobs that will require computer skills. Nothing could be more ridiculous. If "computer skill" is interpreted in a narrow sense of technical knowledge about computers, there is nothing the children can learn now that is worth banking: By the time they grow up, the computer skills required in the workplace will have evolved into something fundamentally different. But what makes the argument truly ridiculous is that the very idea of banking computer knowledge for use one day in the workplace undermines the only really important "computer skill": the skill and habit of using the computer in doing whatever one is doing. But this is exactly what was given up in shifting the computer into the computer lab.

Another way in which computers can be either integrated into or isolated from the learning process has to do less with the computer as an instrument than with computing as a set of ideas. The issue appears very clearly when one contrasts what has come to be called "computer literacy" with the sense of the word *literacy* used to refer to someone as a literate person. *Computer* *literacy* has come to be defined, especially in the context of School, as a very minimal practical knowledge about computers. Someone who had so minimal a level of knowledge of reading, writing, and literature would be called illiterate; the same considerations ought to lead us to call someone who has an equally minimal knowledge about computers computer-illiterate. Moreover, the difference is not merely one of degree but of one of kinds of knowledge. When we say "X is a very literate person," we do not mean that X is highly skilled at deciphering phonics. At the least, we imply that X knows literature, but beyond this we mean that X has certain ways of understanding the world that derive from an acquaintance with literary culture. In the same way, the term *computer literacy* should refer to the kinds of knowing that derive from a computer culture.

An illustration of this point is provided by a teaching unit designed by teacher Joanne Ronkin at the Hennigan School that combines studying the structure of flowers with studying the structure of computer programs. The two go together intimately and in very simple ways. The student has to make a computer program to draw a flower; the structured style of programming would suggest dividing the job into writing "subprocedures" for the different parts of the flower. The student is then faced with the choice of doing this in a way that matches the structure of the flower or in a way that does not. In my own programming style I tend to be relatively unstructured unless there is a strong reason: One such reason would impel me to be very structured about a flower program, because I see the "design" of the flower as fitting the structured precepts. In fact, I think that the reason for the two structures is much the same. A strong argument for modularized programs is that they facilitate debugging, and it seems plausible to me that the modular structure of biological systems facilitates "debugging" in the course of evolution. This is a small example, but a pregnant one, of how seeing the world through computational concepts leads to insights into familiar phenomena that have no direct connection with computers.

The criticism of the computer lab as neutralizing the computer is not to be taken as denying that computers in a room apart can be used in wonderful ways—so long as the room apart is allowed to become the meeting point of ideas that were previously kept separate.

In a junior high school in Missouri, an unlikely set of teachers got together to develop a joint educational project: the physics teacher, the physical education teacher, and the shop teacher. They intended to develop a workshop for students on robotics, a topic with aspects that appealed to each of the three teachers. The physics teacher was interested in some underlying theoretical issues, the physical education teacher in body movements, and the shop teacher in machine construction.

The project had an importance beyond what was specifically learned in the robotics workshop. The fact that these three teachers were doing something together carried a message for students, a message that one could formulate much too crudely as recognizing that "nerds" and "jocks" might have more in common than they think.

The robotics project provides a simple example of what I call second-order effects or systemic effects of the computer presence. The school did not spend thousands of dollars on computers specifically so that students could have the experience of witnessing a spontaneous alliance among three teachers from strongly separate departments. Computers are usually introduced to achieve specific educational objectives, and their first-order effects are measured by looking at how well these objectives are achieved. But, to an extent that varies enormously from school to school, the computer presence can come to play a less specific, but potentially more powerful, role: By entering the culture of the school it can weave itself into learning in many more ways than its original promoters could possibly have anticipated.

The African textiles project mentioned in chapter 1 illustrates another important way in which a computer lab can give rise to better results than the administration planned or paid for. The teacher, Orlando Mihich, is one of many I have known who contributed personal time to organize sessions in the computer lab outside of school hours, allowing at least some students to work with the computers freely enough for a genuine learning experience. Some of the best examples of computer-based learning projects came from the individual initiative of creative teachers who refused the narrow role of "computer teacher."

Despite many examples of such excellent work, the isolation of the computer presence must be seen as a kind of immune response of School to a foreign body; whether or not the participants were aware that this is what they were doing, it is clear that the logic of the process was to bring the intrusive thing back into line with School's ways. The computer in the classroom was undermining the division of knowledge into subjects; it was turned into a subject of its own. It undermined the idea of curriculum; it was made the topic of a curriculum of its own. But, of course, this mechanism is not confined to computers. In its time, School has normalized other subversive influences too. For example, Piaget was the theorist of learning without curriculum; School spawned the project of developing a Piagetian curriculum.

By recognizing such immune reactions, we are led to seek answers to the question, "Why is there no megachange?" by specifically searching out mechanisms that defend School against megachange. To the extent that we find such mechanisms, we can then start thinking about School in ways that will enable us to foster change more effectively. Thus, the story of Brian and Henry once more enables us to see the tension between the teacher's way and School's way of handling the computer. Developing insight into this tension is a central theme of this book. What is School's way? What is the teacher's way?

I go back to the comparison between education and fields such as medicine, which have undergone megachange. One possible response to the question of why there has not been megachange in education is to argue that the very idea of megachange is

inappropriate to education: School is essentially different from examples of megachanged fields like surgery. Surgery, according to this argument, is susceptible to technologically induced megachange because it is an essentially technical act. But learning is a natural act, like eating, for example, or face-to-face conversation. There have been changes in eating habits, but not megachange. Time travelers from a distant past would certainly have no problem recognizing that we are eating even if they fail to recognize the ingredients. The act of eating is essentially the same whether the food is cooked in microwave ovens, over open fires, or not at all. If there are megadifferences in eating, they lie in the social and not in the technical dimensions.

I would agree that learning is a natural act if we are talking about the kind of learning that happens in a healthy relationship between a mother and her baby or between two people getting to know each other. But schooling is not a natural act. Quite the contrary: The institution of School, with its daily lesson plans, fixed curriculum, standardized tests, and other such paraphernalia tends constantly to reduce learning to a series of technical acts and the teacher to the rôle of a technician. Of course, it never fully succeeds, for teachers resist the role of technician and bring warm, natural human relationships into their classrooms. But what is important for thinking about the potential for megachange is that this situation places the teacher in a state of tension between two poles: School tries to make the teacher into a technician; in most cases a sense of self resists, though in many the teacher will have internalized School's concept of teaching. Each teacher is therefore somewhere along the continuum between technician and what I dare call a true teacher.

The central issue of change in education is the tension between technicalizing and not technicalizing, and here the teacher occupies the fulcrum position.

Not since the printing press has there been so great a surge in the potential to boost technicalized learning. But there is also another side: Paradoxically, the same technology has the potential to detechnicalize learning. Were this to happen, I would count it as a far larger change than the appearance on every desk of a computer programmed to lead the student through the paces of the same old curriculum. But it is not necessary to quibble about which change is more far-reaching. What is necessary is to recognize that the great issue in the future of education is whether technology will strengthen or undermine the technicalness of what has became the theoretical model, and to a large extent the reality, of School. My paradoxical argument is that technology can support megachange in education as far-reaching as what we have seen in medicine, but it will do this through a process directly opposite to what has driven change in modern medicine. Medicine has changed by becoming more and more technical in its nature; in education, change will come by using technical means to shuck off the technical nature of School learning.

4

Teachers

THERE was a time when I believed, as many people do, that teachers would be the most difficult obstacle in the way of transforming School.* This simplistic belief, whose insistent presence is in reality a far greater obstacle to educational change than the fact that some teachers actually are conservative, can be traced back to deeply rooted cultural representations. In my case, I remember being impressed in junior high by George Bernard Shaw's cynical aphorism: "He who can, does; he who cannot, teaches." Someone who "cannot" is not likely to be a constructive partner in bringing about major change.

Culturally shared negative attitudes toward teachers are nourished by personal experiences. As a rebellious child I saw teachers as the enemy. Then, with time, these feelings merged with a theoretical position which had the illogical consequence of further demonizing teachers by identifying them with the roles that School forced on them. I disliked School's coercive methods, and it was the teachers who applied the coercion. I disapproved of judgment by grading, and it was the teacher who gave the grades.

*The ideas in this chapter took shape in conversations with Carol Sperry.