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## Yearners and Schoolers

**I**MAGINE a party of time travelers from an earlier century, among them one group of surgeons and another of schoolteachers, each group eager to see how much things have changed in their profession a hundred or more years into the future. Imagine the bewilderment of the surgeons finding themselves in the operating room of a modern hospital. Although they would know that an operation of some sort was being performed, and might even be able to guess at the target organ, they would in almost all cases be unable to figure out what the surgeon was trying to accomplish or what was the purpose of the many strange devices he and the surgical staff were employing. The rituals of antiseptics and anesthesia, the beeping electronics, and even the bright lights, all so familiar to television audiences, would be utterly unfamiliar to them.

The time-traveling teachers would respond very differently to a modern elementary school classroom. They might be puzzled by a few strange objects. They might notice that some standard techniques had changed—and would likely disagree among themselves about whether the changes they saw were for the better or the worse—but they would fully see the point of most of what

was being attempted and could quite easily take over the class. I use this parable to provide a rough-and-ready measure of the unevenness of progress across the broad front of historical change. In the wake of the startling growth of science and technology in our recent past, some areas of human activity have undergone megachange. Telecommunications, entertainment, and transportation, as well as medicine, are among them. School is a notable example of an area that has not. One cannot say that there has been no change at all in the way we dish out education to our students. Of course there has; the parable gives me a way of pointing out what most of us know about our system of schooling: Yes, it has changed, but not in ways that have substantially altered its nature. The parable sets up the question: Why, through a period when so much human activity has been revolutionized, have we not seen comparable change in the way we help our children learn?

I have posed this question in situations ranging from casual conversation to formal seminars, and with audiences ranging from children who have had only a few years of contact with School to professional educators who have spent a lifetime in it. Although the answers I have received are as varied as the expected range of responses to a Rorschach inkblot test, the distribution is far from even from one extreme to the other. Most fall on one side or the other of a great divide.

People on one side, the Schoolers, are taken aback by my question, surprised that I seem to be looking for megachange. They acknowledge that School has problems (who doesn't today?) and are very concerned about solving them. But megachange? What can you possibly mean?

Many become indignant. Talking about megachange feels to them like fiddling while Rome burns. Education today is faced with immediate, urgent problems. Tell us how to use your computers to solve some of the many immediate practical problems we have, they say.

On the other side of the great divide are the Yearners, who

respond by citing impediments to change in education such as cost, politics, the immense power of the vested interests of school bureaucrats, or the lack of scientific research on new forms of learning. These people do not say, "I can't imagine what you could possibly be looking for," because they have themselves felt the yearning for something different.

Many individual Yearners—from parents to teachers to administrators—simply find ways to get around School, particularly when they find School's problems directly constraining their aspirations for their own children. Some parents keep their children at home: There are several hundred thousand home-schoolers in the United States. Others actively seek out alternative schools or even help to create schools that offer such alternatives.

Another important class of Yearners operates as a sort of fifth column within School itself: Large numbers of teachers manage to create within the walls of their own classrooms oases of learning profoundly at odds with the education philosophy publicly espoused by their administrators; some public school districts, perhaps those where Yearners have moved into administration, have made space for Yearners within School by allowing for the establishment of alternative programs within the School system, allowing such programs to deviate from district policies on method and curriculum.

But despite the many manifestations of a widespread desire for something different, the education establishment, including most of its research community, remains largely committed to the educational philosophy of the late nineteenth and early twentieth centuries, and so far none of those who challenge these hallowed traditions has been able to loosen the hold of the educational establishment on how children are taught.

The time-traveling teachers of my parable who saw nothing in the modern classroom they did not recognize would have found many surprises had they simply gone home with one or two of the students. For there they would have found that with an industriousness and eagerness that School can seldom generate, many of

the students had become intensely involved in learning the rules and strategies of what appeared at first glance to be a process much more demanding than any homework assignment. The students would define the subject as video games and what they were doing as play.

While the technology itself might first catch the eye of our visitors, they would in time, being teachers, be struck by the level of intellectual effort that the children were putting into this activity and the level of learning that was taking place, a level that seemed far beyond that which had taken place just a few hours earlier in school. The most open and honest of our time-traveling teachers might well observe that never before had they seen so much being learned in such a confined space and in so short a time.

School would have parents—who honestly don't know how to interpret their children's obvious love affair with video games—believe that children love them and dislike homework because the first is easy and the second hard. In reality, the reverse is more often true. Any adult who thinks these games are easy need only sit down and try to master one. Most are hard, with complex information—as well as techniques—to be mastered, the information often much more difficult and time consuming to master than the technique.

If that argument did not convince parents that the games are not serious, surely a second argument would: Video games are toys—electronic toys, no doubt, but toys—and of course children like toys better than homework. By definition, play is entertaining, homework is not. What some parents may not realize, however, is that video games, being the first example of computer technology applied to toy making, have nonetheless been the entryway for children into the world of computers. These toys, by empowering children to test out ideas about working within pre-fixed rules and structures in a way few other toys are capable of doing, have proved capable of teaching students about the possibilities and drawbacks of a newly presented system in ways many adults should envy.

Video games teach children what computers are beginning to teach adults—that some forms of learning are fast-paced, immensely compelling, and rewarding. The fact that they are enormously demanding of one's time and require new ways of thinking remains a small price to pay (and is perhaps even an advantage) to be vaulted into the future. Not surprisingly, by comparison School strikes many young people as slow, boring, and frankly out of touch.

The introduction of computers is not the first challenge to education values. For example, John Dewey began his campaign for a more active and self-directed style of learning in schools over a hundred years ago, and in these intervening years numerous more or less radical reformers have strived to change School. Back then Dewey undertook his formidable task armed with little more than a strong philosophical sense about the way children develop, for at the time there was no strong movement from society in general for change in schools. There was certainly no dissatisfaction with education in Dewey's time as strong as the current one, which seems at times willing to accept the virtual destruction of the public school system rather than have things continue as they now are. Dewey remains a hero to those who believe in a twentieth-century vision of a child as a person with the right to intellectual self-determination, and there can be little doubt that a child treated with respect and encouragement rather than threatened with rejection and punishment will fare better under any system of education. But while Dewey's influence has surely removed some of the cruelest impediments to the healthy development of the child, it has been so diluted that it barely addresses the next serious question: In trying to teach children what adults want them to know, does School utilize the way human beings most naturally learn in nonschool settings?

The failure of past reformers to bring about dramatically better learning has armed those within the educational establishment with the argument that future proposals will prove no more capable of bringing about radically improved learning. Some may well

believe that the best argument against megachange is this: If it has so long been so desperately needed, why have previous calls for it not caught fire? But the establishment may be in for a shock. This book is informed and shaped by the belief that strong feelings of dissatisfaction within society at large are rapidly making it impossible to save education as we know it by continuing to tinker around at its edges. Not the least of these dissatisfactions are the feelings of children. In the past, children may not have liked School, but they were persuaded to believe that it was the passport to success in life. To the extent that children reject School as out of touch with contemporary life, they become active agents in creating pressure for change. Like any other social structure, School needs to be accepted by its participants. It will not survive very long beyond the time when children can no longer be persuaded to accord it a degree of legitimation.

With much more persuasive power than the philosophy of even so radical a thinker as Dewey, the computer, in all its various manifestations, is offering the Yearners new opportunities to craft alternatives. The only question that remains is, Will such alternatives be created democratically? Will public education lead the way or, as in most things, will the change first enhance the lives of the children of the wealthy and powerful and only slowly and with much effort find its way into the lives of the children of the rest of us? Will School continue to impose a single way of knowing on everyone, or will it adapt to an epistemological pluralism? Because I am committed to democratic choice, much of this book will be devoted to looking at samples of what Yearners have done with the few opportunities they have had for bringing about change in public elementary schools. Most of the examples I use will be realistically modest in scale. They are offered not as exact pictures of the future but rather as an intimation of the rich potential that the future might hold. The following story, part fact and part fantasy, will help illustrate where I hope to go with this book.

The factual part involves an encounter I had with a four-year-old preschooler. Jennifer heard that I had grown up in Africa and

asked me whether I knew how giraffes sleep. "They have such long necks," she said, and wondered where they put their heads when they rest. I said (truthfully) that I didn't know, and asked what she thought. She explained her problem with a gesture of cozying her head in folded arms: "My dog cuddles her head when she sleeps and so do I, but the giraffe's head is so far away." I pursued the conversation with other children who joined us, and gleaned a bumper crop of good theories. One suggested that the giraffe sleeps standing up "like a horse." This set off an animated discussion, which kept coming back to the question of where the animal puts its head. No one offered that the head might stay up high. Someone said it can put its head on the ground if it does a split. Jennifer, who had moved over to the idea of their sleeping standing up, showed obvious delight when she hit on a theory: "It finds a tree with a branch for its neck." I asked what would happen if there were no tree. She looked at me disdainfully and informed me that of course there would be trees—giraffes eat the tops of trees; that's why they have such long necks.

In this conversation we see two sides of the intellectual life of children of this age: the coexistence of a remarkable capacity for making theories with a nearly helpless dependence on adults for information that will test the theories or otherwise bring them into contact with reality. Jennifer is in a stage of transition. Younger children are more completely engrossed by a world within the range of immediate exploration. At a later age, unless, as too often happens, the spirit of inquiry has been extinguished, they will be able to explore a world beyond touch and sight.

Back in my own home that evening, still stimulated by my talk with the children, I threw myself into an exploration of giraffes with the intensity and perhaps even the immediacy of Jennifer's interactions with her puppy. I do not keep a pet giraffe, but I do have a library of books, of which quite a few were soon strewn all over my work area as I continued, with diversions en route, a rewarding chase after information about the sleep habits of

giraffes. I was able to explore this world because the books gave me an extended immediacy.

Until recently it would have sounded silly to ask why this extended immediacy could not be available to Jennifer. Children her age cannot read, or even if they can they would not be able to conduct that kind of search. But this answer is no longer convincing. No technical obstacle stands in the way of making a machine—let's call it the Knowledge Machine—that would put the power to know what others know into Jennifer's hands. It is almost twenty years since my MIT colleague Nicholas Negroponte built a machine that allowed the vicarious exploration of the small town of Aspen, Colorado, through a computer. Extremely primitive examples are now trickling into commercial production under names like "interactive video" or electronic book, "ebook" or "CDI," or, in slightly more elaborate versions, "virtual reality."

What separates these endeavors from a true Knowledge Machine is no longer a lack of storage or access technology but the size of the effort needed to bring together the knowledge. But the enormous potential market for a Knowledge Machine makes its eventual appearance inevitable.

Such a system would enable a Jennifer of the future to explore a world significantly richer than what I was offered by my printed books. Using speech, touch, or gestures, she would steer the machine to the topic of interest, quickly navigating through a knowledge space much broader than the contents of any printed encyclopedia. Whether she is interested in giraffes or panthers or fleas, whether she wants to see them eating, sleeping, walking, running, jumping, fighting, birthing, or copulating, she would be able to find her way to the relevant sounds and images she believes would help her understand what she wants to understand. Though nothing in my argument here depends on it, this availability will one day be extended to experiencing the very smell and touch and maybe the kinesthesia of being with the animals.

The Knowledge Machine so described barely scratches the surface of how new media will change children's relationships with knowledge. But even the most superficial consideration of this



question requires one elemental but consequential concession: Children who grow up with the opportunity to explore the jungles and the cities and the deep oceans and ancient myths and outer space will be even less likely than the players of video games to sit quietly through anything even vaguely resembling the elementary-school curriculum as we have known it up to now!

A less superficial consideration leads one to ask: How would the introduction of Knowledge Machines into the School environment compromise the primacy with which we view reading and writing—that is, children's fluency in using the alphabetic language?

In the literature on education there has long been a pervasive tendency to assume that reading is the principal access route to knowledge for students. Someone who cannot read is said to be doomed to ignorance, or at least to dependence on that limited amount of important information that can be obtained orally.

The educational development of children is therefore seen as rigidly dependent on learning to read in a timely way. The prospect of the Knowledge Machine suggests that this basic assumption may not necessarily be true for all time, and indeed may start to unravel within a decade or two. I am not suggesting that the written language is likely to be abandoned. I am suggesting that new thinking is needed about the position assigned to it as the prerequisite to the accumulation by students of useful knowledge, or at least as the first route to be opened to children when they begin their formal educations.

I have even firmer convictions about another kind of issue raised by the Knowledge Machine and the primacy of reading in our present culture as the essential route to knowledge. Learning to read and write is an important part of what is happening to Jennifer in the first grade, but it is not necessarily at the core of what is being communicated to her about what learning is all about. Jennifer's transition is really epistemic; although she is totally unaware of it, she is being shifted from reliance on one dominant way of knowing to reliance on another.

As an infant she acquired knowledge by exploration. She was

in charge of her learning. Though her parents put knowledge in her path, she chose what she would investigate, determining for herself what she would think about and how she would think about it. This is not to say that adults did not try to a lesser or greater extent to control her and her learning. But it is well documented that preschoolers do not deposit the knowledge adults try to feed them in their memory banks in the same way they learn to do later on, when they go to school. It is metabolized, assimilated with all their other direct experiences of the world.

When Jennifer asked me about the giraffe, however, she was at a stage when more questions were coming up in her mind than she could answer by direct exploration of her immediate world. She responded in a way she had been taught to respond: Ask a sympathetic adult who would reward her curiosity with praise. While pressure toward this mode of learning—by being told, by accepting authority—has its roots in a student's own curiosity, it will in the course of the educational experience of most children be massively reinforced by School. Where Jennifer will come out in the end will depend on many social, psychological, and accidental factors. What is clear is that she is entering a period of transition that will have a profound and perhaps brutal and dangerous impact on her intellectual development. Common School parlance often uses the word *literacy* to refer to the state of being able to read and write. However, thinkers who try to look more deeply into what education means have written scathingly in criticism of the idea that illiteracy can be remedied by teaching children the mechanical skill of decoding black marks on white paper. Much more is involved. Paulo Freire enjoins us not to dissociate "reading the word" from "reading the world." Becoming literate means thinking differently than one did previously, seeing the world differently, and this suggests that there are many different literacies.

In this sense, the choice of name for the process becomes epistemological; writers have more recently suggested as substitutes for this *literacy* the term *ways of knowing*. I am entirely in

sympathy with the intentions of these writers but feel deprived of a word for the distinction between a literal sense of literacy and the various more sophisticated senses the idea evokes.

In desperation I have coined the words *letteracy* and *letterate* to refer to the special skill involved in reading words made up of alphabetical letters. Outside this more narrow definition will remain the opportunities, offered for the most part by the new media represented symbolically by the Knowledge Machine, allowing students to become highly literate independent of their progress toward letteracy.

The need for such linguistic maneuvers reflects the radical nature of the revolution in media introduced by the computer. Without risk of serious oversimplification one can say that there have been, up to now, two widely used media for the transmission of information and ideas and only one major historical transition.

For most of human history speech stood alone as the transmitter of what had previously been learned. Drawings, smoke signals, and gestures were important supplements to speech but never threatened the monopoly of speech in determining what information people in any society would share, group to group or even generation to generation. Writing was the first significant departure from the oral tradition, and whether the emergence of written language dates back to Egyptian hieroglyphics or Gutenberg is a matter of detail.

Filmmakers, painters, and other users of evolving media may be slighted by my decision to count computer-based media as the next substantive advance. But I think that Jennifer's story captures better than abstract words an important aspect of what makes the new media qualitatively different. It especially makes clear by showing us an alternative to the risk children are placed in by the fact that literacy and letteracy are virtually synonymous. They are at risk because they do not have access to a wider immediacy for exploration and have only very limited sources to which they can address questions. They are doubly at risk because the situation

consolidates School in its traditional role of imposing literacy and all the rigidity that goes with that role.

It is not surprising, given the newness of this technology, that we have developed no universally accepted language to use in talking about it. But this does not mean that we should be unaware that a revolution is in the making, or that we should not do everything possible to guide its development. For in regard to the questions of how to reform elementary education, the movement from literacy to media-based knowledge acquisition may be even more important than the movement from preletterate to letterate culture.

It is important to remember that the literacy revolution (that is to say, the advent of writing and printing) did not directly touch the primary ways in which most two- or four- or even six-year-olds explore the world and learn about it. Of course, the really big questions about the future of literacy and letteracy are beyond the scope of this book. But what is important here is that the Knowledge Machine offers children a transition between preschool learning and true literacy in a way that is more personal, more negotiational, more gradual, and so less precarious than the abrupt transition we now ask children to make as they move from learning through direct experience to using the printed word as the source of important information.

Why, then, would anyone fail to take seriously, as Schoolers do, something that could be so consequential for the educational process? Willfulness? A stubborn refusal to abandon old ways? These factors are present in any challenge to long-established procedures. The problem in education has an additional element. Most honest Schoolers are locked into the assumption that School's way is the only way because they have never seen or imagined convincing alternatives in the ability to impart certain kinds of knowledge.

Even the most confirmed Schooler will readily concede that some important learning happens very successfully under conditions very different from School: Babies learn to talk without

curriculum or formal lessons; people develop skill at hobbies without teachers; social behavior is picked up other than through classroom instruction. A Schooler might grant that a Knowledge Machine could extend the scope of such learning to include far-away giraffes as well as nearby puppies, but still be worried by not having heard of anyone, except perhaps some highly gifted exceptions, who managed to become learned in such difficult disciplines as geometry or algebra through other than well-established and time-tested educational programs of instruction.

These skeptics have no trouble imagining, for example, a teacher leading a class of students by “Socratic questions” to “discover for themselves” some formula in mathematics. But they don’t see this as significantly different than a good explanation of the formula. I have to agree with them. Although I have always yearned for ways of learning in which children act as creators rather than consumers of knowledge, the methods that have been proposed have always seemed to me marginally superior, if at all, to the old ways.

A turning point came for me in the early 1960s, when computers changed the fabric of my own work. What struck me most forcibly was that certain problems that had been abstract and hard to grasp became concrete and transparent, and certain projects that had seemed interesting but too complex to undertake became manageable. At the same time I had my first experience of the excitement and the holding power that keeps people working all night with their computers. I realized that children might be able to enjoy the same advantages—a thought that changed my life.

My goal became to strive to create an environment in which all children—whatever their culture, gender, or personality—could learn algebra and geometry and spelling and history in ways more like the informal learning of the unschooled toddler or the exceptional child than the educational process followed in schools. Stated in the language of the skeptical Schooler, my driving question was whether “exceptional children” learned differently because they were exceptional or whether, as I suspected, they

became exceptional because circumstances allowed them to learn differently.

I can hear many Schoolers saying to themselves as they read this: "Yes, yes, we've heard that before. It's the old refrain of progressive education. That's been tried and it didn't work. You yourself have just poked fun at the discovery method in algebra."

There is a family resemblance (and I shall accept the word *progressive* to name it) between the vision of learning I am presenting here and certain philosophical principles expressed in the diverse forms of innovations that go under such names as *progressive* or *open* or *child-centered* or *constructivist* or *radical* education. I certainly share with this broad movement the criticism of School as casting the child in the role of passive recipient of knowledge. Paulo Freire expresses the criticism most vividly in his description of School as following a "banking model" in which information is deposited in the child's mind like money in a savings account. Other writers express the same thought by accusing School of treating the child's mind as a "vessel to be filled" or as the receiver at the end of a transmission line.

One way in which I am at variance with progressive education becomes apparent when we turn from criticizing School to inventing new methods. In my view almost all experiments purporting to implement progressive education have been disappointing because they simply did not go far enough in making the student the subject of the process rather than the object. In some cases this came about because the experimenters were too timid; the experiments failed just as the test of any medical treatment would fail if the treating doctors were afraid to give the drugs in effective dosages.

In most cases there were reasons deeper than timidity in holding them back. Early designers of experiments in progressive education lacked the *tools* that would allow them to create new methods in a reliable and systematic fashion. With very limited means at their disposal, they were forced to rely too heavily on the specific talents of individual teachers or a specific match with a

particular social context. As a result, what successes they had often could not be generalized.

Another parable will emphasize this point and also clarify where I see my main new contribution to the old debate. My hypothetical Schoolers said that progressive education has been tried and did not work. I agree that it hasn't worked very well—but in something like the sense in which Leonardo da Vinci failed in his attempts to invent an airplane. Making an airplane in Leonardo's time needed more than a creative manipulation of all that was known about aeronautics. His failure to make a workable airplane did not prove him wrong in his assumptions about the feasibility of flying machines.

Leonardo's airplane had to wait for the development of something that could come about only through great changes in the way society managed its resources. The Wright Brothers could succeed where Leonardo could only dream because a technological infrastructure supplied materials and tools and engines and fuels, while a scientific culture (which developed in coevolution with this infrastructure) supplied ideas that drew on the peculiar capabilities of these new resources.

Educational innovators even in the very recent past were in a situation analogous to Leonardo's. They could and did formulate bold perspectives: for example, John Dewey's idea that children would learn better if learning were truly a part of living experience; or Freire's idea that they would learn better if they were truly in charge of their own learning processes; or Jean Piaget's idea that intelligence emerges from an evolutionary process in which many factors must have time to find their equilibrium; or Lev Vygotsky's idea that conversation plays a crucial role in learning. Such ideas have always appealed to Yearners; they resonate with a respectful attitude toward children and a democratic social philosophy.

Sadly, in practice they just wouldn't fly. When educators tried to craft an actual school based on these general principles, it was as if Leonardo had tried to make an airplane out of oak and power

it with a mule. Most practitioners who tried to follow the seminal thinkers in education were forced to compromise so deeply that the original intent was lost. For example, the "discovery method" may take a step in the direction of Dewey's dream, but it is a minuscule step, utterly insufficient to make the kind of difference expressed in the grand vision of empowered children learning through living experience. It is simply double-talk to ask children to take charge of their own learning and at the same time order them to "discover" something that can have no role in helping them understand anything they care about or are interested in or curious about.

As a mode of access to knowledge of the kind Jennifer was seeking, the machine will not be more than a suggestive metaphor for some time yet to come because the quantity of factual knowledge needed to make it work is so vast. But there are other areas of knowledge where the epistemic transition is even more brutal for many children, and where a machine that will provide a context for softening it is very much closer at hand. One such area is mathematics.

If the idea of a transition from oral to letterate ways of knowing seems less applicable to mathematics, this is largely because our culture is inclined to reserve the name *mathematics* for the letterate kind of mathematics taught in school and perhaps a minimal intuitive basis directly connected with it. But by closing off a much larger basis of knowledge that should serve as a foundation for formal mathematics, we have cut off the route to better learning. Every preschool child has amassed on his or her own special mathematical knowledge about quantities, about space, about the reliability of various reasoning processes, elements that will be useful later in the math class. The enormous quantity of this "oral" mathematics constructed and retained by every child has been well documented by Jean Piaget.

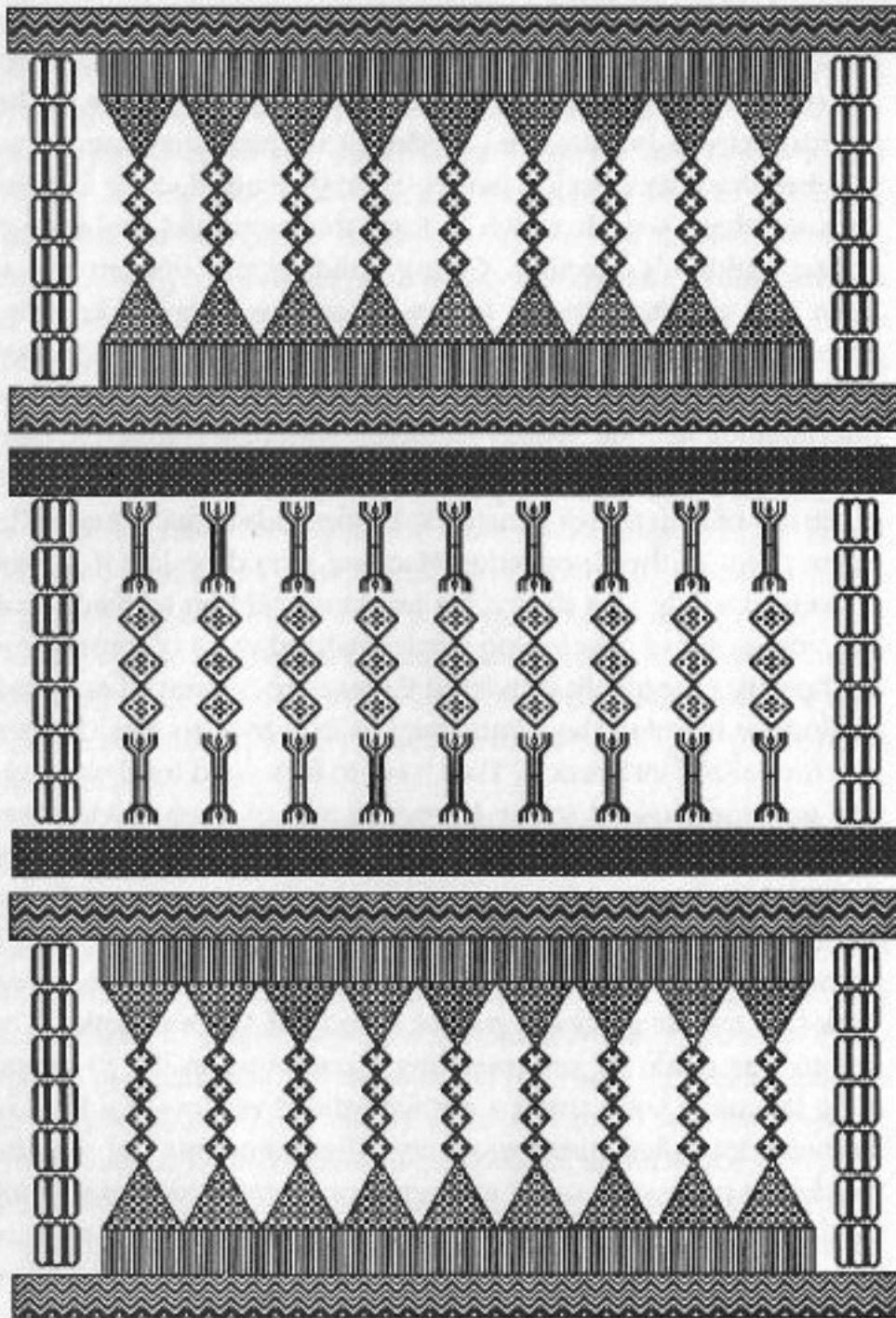
The central problem for math education is to find ways to draw on the child's vast experience of oral mathematics. Computers can do this.



The most powerful use made of computers in changing the epistemological structure of children's learning to date has been the construction of microworlds, in which children pursue mathematical activity because the world into which they are drawn requires that they develop particular mathematical skills. Simultaneously, these worlds match in form the successful oral style of young children's learning. Giving children the opportunity to learn and use mathematics in a nonformalized way of knowing encourages rather than inhibits the eventual adoption of a formalized way as well, just as the Knowledge Machine, rather than discouraging reading, would eventually stimulate children to read.

In saying this I must emphasize a difference with many trends in the use of concrete or constructivist methods to teach math. The entire point of the Knowledge Machine would be lost if it were conceived solely as a device for teaching children to read. Similarly, the point of developing nonformalized ways of knowing in mathematics is entirely subverted if these are conceived as a scaffolding for learning the formal way or as a trick to lure children into formalized instruction. They have to be valued for themselves and genuinely useful to the learner in and of themselves. Many more examples of this distinction will be found in later chapters.

Here I make the point simply by looking at the original design on the next page that was made (in magnificent color, which unfortunately cannot be reproduced here) by children in a New York City middle school as part of a study of African textiles. The design was made by programming a computer in the programming language Logo using a nonformalized version of a kind of mathematics called turtle geometry. These students did not use the design process in order to learn more formal geometry. They used a kind of geometry that matched their preferred way of knowing in order to pursue ideas about African design. Geometry is not there for being learned. It is there for being used. The main exception I would make is a big one: Both geometry and learning it can be objects of love, in which case use might fall by the wayside.



The African textiles design. The drawing at right was also generated by children, using Logo to program computers in the classroom.



These remarks about formal and other geometries might be offensive to many Yearners as well as to most Schoolers. For I seem to be saying that some students should be satisfied with a kind of useful geometry other than the real McCoy, and this might be read as if it had an undertone of elitism. What I am really saying, and will develop particularly in chapter 9, is that there is room for much rethinking about what knowledge, and what ways of knowing, should have a privileged status. Certainly School has not earned the right to decide for us. Those Yearners who yearn for better ways to teach what School has decreed everyone should know have not quite accepted the idea of megachange. I hope, after reading this book, they will have moved toward questioning not only how School teaches but what as well.

A bigger departure from the curriculum is shown by a project in which children invent and build artificial creatures using a version of Lego extended to include tiny computers, which take in information from sensors and control motors. The computer can be programmed in Logo to make the creatures move in a "purposeful" way. For example, an eight-year-old girl constructed a model "mother cat" and its "kitten." Both would roam until the kitten beeped and flashed a light mounted on its head; at this

signal the cat would begin to move toward it. Other children have built snakes and monsters. One team built an "intelligent" model house that cleaned itself.

The idea of programming such behavior might sound difficult. In fact, the latest user-friendly versions of Logo (such as *Microworlds Logo*) make it so easy that technological construction and the underlying scientific principles become as natural a medium for the expression of fantasy as for drawing or speech. Thus one of the subject lines that splits School's epistemology is blurred: Traditionally in School, the art and writing classes might have time for fantasy, but science deals with facts. No wonder many children find it cold. A second subject line is blurred by the union of technology with biology. Making an artificial animal is no substitute for studying real ones, but it does provide insight into aspects of real animals, for example, the principle of "feedback" that enables the Lego cat to find its kitten. The situation is analogous to the way in which the principle of lift lies behind the flight of birds and airplanes, but there is a big difference in the social importance of the two cases. While it does not matter very much whether people understand lift, feedback is a key concept for thinking about systems. The lack of ability to think fluently about the environment, the economy, or even one's family as a system matters very much indeed.

The concept of feedback illustrates how artificial it is to confine science to the precisely stated kind of knowledge favored by literacy. The Lego cat never "knows" at all precisely where the light is located; all it "knows" is vaguely whether it is more to the left or more to the right. The program makes the cat turn a little in the appropriate direction, move a little forward, and repeat the cycle; turning one degree or ten degrees on each round will work equally well. Thus, what the cat "knows" is more in tune with the qualitative knowledge of a preletterate child than with anything precise and quantitative. The fact that it can nevertheless find its way to the exact destination is empowering for all qualitative thinkers and especially for children. It allows them to enter science through a region where scientific thinking is most like their own thinking.

The idea that partial and qualitative knowledge can be good knowledge is applicable to a discussion of whether building a Lego model is really relevant to the scientific study of biology. If one rejects all inexact knowledge, one might believe that the only way a model can elucidate nature is by simulating it precisely. The model cat shows a different kind of simulation, a "soft simulation" that provides qualitative understanding of a complex system by constructing a simple one with which it shares a principle.

The computer graphics and the artificial creature projects give a glimpse of directions of change for School that move toward megachange. The rest of this book is structured by three themes that bear on the likelihood of School actually doing so. The most down-to-earth of the three is a look at what is happening in schools. In chapter 3 I look at the response of School as an institution to the images of change I have anticipated here. Chapter 4 discusses teachers and chapter 10 discusses issues of strategy for change. The next theme is directed at developing a better sense of the evolution of the technology itself and the ideas and cultures that have come with it. This discussion permeates the entire book but is specifically focused in chapters 8 and 9. The final theme is the most controversial. I believe that if we are to have new forms of learning, we need a very different kind of theory of learning. The theories that have been developed by educational psychologists, and by academic psychologists in general, are matched to a specific kind of learning, School's kind. As long as these ways of thinking about learning remain dominant, it will be very hard to make a serious shift from the traditional form of School.

In the next chapter I give a first view of the direction in which I would look in order to find new ways of thinking. In its briefest description, this direction is within ourselves. In chapter 5 I propose giving a name to a new kind of theory of learning which will reflect the fact that human experience gives all of us a vaster store of knowledge about learning than has been accumulated by all the white-coated academics in their laboratories.