# *The Computer in Schools: Machine as Humanizer*

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In this paper I will not be talking about the computer as a machine that teaches children interactively—the machine and the child in isolation. The kind of teaching and learning I am concerned with treats the computer as an adjunct to socially mediated learning, as part of a context, a constellation of children with children at the computer, of teachers with children with computers.

## The Argument

Central to my story is the nature of learning interactions. A great deal hinges on this word "interactive." The phrase "interactive software" refers to software that capitalizes on the fact that the computer as a learning tool is not just another piece of technology. Unlike a passive piece of paper, a tape recorder, or a television screen, the computer reacts. It takes account of the user's behavior. Since the computer's responses can be affected by the receiver's wishes, an information exchange can take place. In noncomputer situations, providing feedback is almost entirely up to the teacher. In the case of the computer, some of that feedback can be built into the system itself, and the child using that feedback appears to be in a self-correcting mode. The dialogue between computer and child can begin to look like a



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teacher-learner interaction. But there is a trap here. Of course the feedback generated during computer-based activity is central to the enterprise. That does not mean, however, that computers will replace teachers. To make such an interpretation presupposes viewing the child's conceptual development strictly in individual terms. Learning cannot be separated from the social interactions in which the individual is engaged.

For growing individuals, learning means making part of their own understanding the knowledge that is shared by the people around them. They internalize that knowledge via interactions. As Vygotsky wrote in the 1930s, cognitive change comes from the transformation of knowledge *among* persons—interpersonal understanding—into knowledge *within* a person—intrapersonal understanding (see Vygotsky, 1978, editors' preface & chap. 4). Since the culture of a group embodies the accumulated knowledge of that group, the individual members of the group acquire that knowledge by interacting with fellow members. This occurs naturally at home and in informal settings as several generations interact with one another. School-based education attempts to continue this natural process in more structured ways by developing curricula and by introducing the language and cultural symbols that serve as receptacles and mediating vehicles for the formal knowledge to be appropriated by the learner.

The nub of my argument about the potential importance of the new technology concerns its role in this process. The computer has generated a new set of cultural symbols, some of which are particularly easy for children to appropriate. Consider, for example, graphics screen objects such as the Logo turtle, which can be manipulated by programming commands that allow students to achieve their own goals.[1] Using these, students can achieve interesting effects, such as animated figures that perform various actions. These computer-generated symbols and operations correspond to symbols and operations associated with important mathematical and scientific concepts. The ready access leads children to acquire from each other considerable information about how to produce a range of effects on the computer, a pragmatic knowledge. So now, in addition to internalizing social knowledge from the adults around them, students suddenly find themselves the producers of knowledge their teachers and parents do not yet have. This ownership is sweet indeed.

We cannot assume, however, that simply putting children with computers will enable them to grasp, by virtue of the juxtaposition, the underlying structure of important ideas in science and mathematics. Students do not, typically, on their own, gain an appreciation of the formal significance of the operations they are performing. The wider application of those operations needs to be made apparent to them; their meaning needs to be explicated. This turns out to be more complicated than was at first assumed. There is a richness about the kind of result-producing knowledge that students pick up during their work with computers that provides a potentially fruitful soil for academic structures. To make the connection to more formal kinds of thinking, the learning interaction requires that one of the participants have an explicitly academic goal in mind: to help the other participants acquire an understanding of the concepts underlying the activity and how these relate to relevant

[1] The Logo programming system was developed by Papert in the 1960s as a language for learning and an accessible way to communicate with the computer (Papert, 1980). It is an interactive system that supports (list processing) programming, graphics and word-processing. The Logo turtle is a graphics object that can be manipulated using simple commands such as FORWARD, BACK, RIGHT TURN, LEFT TURN.

formal systems. To realize this goal, the teacher must understand the pragmatic knowledge the student has developed during interactions with the computer, in order to link it to more formal knowledge, without depriving the student of a sense of identification with and ownership of that pragmatic knowledge. In the rest of the paper I flesh out the details of the argument. Before I do this, I will consider the interaction between computer use and inquiry learning approaches.

## Inquiry Learning and the Computer

The potential power of the computer is that it can support many kinds of exploratory activities, including the doing of mathematics and the doing of science. The important difference between precomputer inquiry learning and the present situation is that the new technology allows exploratory messing about with technical ideas in a way that was previously hard to achieve by all except the most gifted teachers. I am talking about the power of the medium to support direct interactive experience of mathematical and scientific concepts, embodied rather than illustrated, embedded rather than didactically presented (see, for example, diSessa, 1982; Ocko, Papert, & Resnick, 1988; Tinker, 1986; White & Fredericksen, 1987). In this context, when I talk about "messing about" (Hawkins, 1974) in exploratory mode, I am referring to the kinds of playing with ideas and interactions that mature scientists do when they explore a problem. "Being a scientist means investigating the natural world, asking your own questions, finding out what-happens-if" (Barclay, 1987, p. 6). Microcomputer-based laboratories (MBLs) developed by Technical Education Research Centers, Cambridge, Massachusetts, exploit the potential of computer technology to support the doing of mathematics and science. MBLs enable students to perform a wide variety of experiments involving light, temperature, and sound. Using a range of probes linked to the computer, students gather raw data and use software to analyze and display their data. During all these processes, students receive real-time feedback.

Could it be that computers can encourage more open-ended classroom practice because they enable the mix of structure and open-endedness that educators have been looking for? Some possibilities are readily apparent. There is nothing new about educators' concern for the process of learning rather than exclusive interest in the product. It has been difficult, however, for the average teacher to pay more than lip service to this idea. Computers, appropriately programmed, can make it easier for teachers to achieve this goal. The teacher can concentrate on looking at what students actually do, rather than checking on their ability to reproduce the expected answers (Fein, Scholnick, Campbell, Schwartz, & Frank, 1988). There is something about the public nature of the activity. There it all is, up on the screen for all to see, each problem-solving step available for scrutiny in a way that pencil work scribbled in a corner of the page never is. This has earned the computer a label: it can act as a window into the mind. This could turn out to be the computer's most valuable contribution. My own choice to work with the Logo system rested on this particular feature. A striving for good pedagogy is clearly at the heart of the Logo enterprise, as enunciated by its developer, Seymour Papert (1980). Logo activities are designed to respect the need for learners to be actively involved in the construction of their own knowledge. When I watch students as they work at Logo, it helps me understand more about their problem-solving processes and the nature of the restructuring of knowledge that needs to occur as they learn (Weir, 1987).

An important feature of inquiry-learning approaches is their emphasis on allowing a student's own preferred style of working to surface by arranging for the learner to take the initiative in choosing activities. The traditional classroom tends to favor one particular style of working; namely, that of serial thinkers who like to plan their work and can readily verbalize their thinking. Students with contrasting styles have had to be especially talented in order to survive, and many are pushed into the learning-disabled category. In computer-based projects, different students can interpret the project goals differently. Much of my own work has attempted to show how an appropriately programmed computer can provide rich ways to match the learning situation to a student's preferred working mode, and (so to speak) to the strengths of individual learners (Weir, 1987).

## Interactions and Learning: A Sociocultural Approach

From the point of view of the developing individual, three aspects are crucial to the internalization of social knowledge. First, learners must be constantly interacting with other people who will introduce them to the culture; that is, learners must be doing things with others. Second, learners have to become familiar with how the culture has been stored, with cultural symbols. That is, learners have to learn the language. Third, learners need to develop the ability to reflect on their own thinking processes.

In most societies, parents spend time doing things together with their children, introducing them to their culture. A parent would have no difficulty recognizing that collaborative efforts among parents, older siblings, and other caretakers are the stuff of learning to be a "grown-up." Classroom education attempts to continue this natural process in more formally structured ways. In the process, schools have adopted policies and activities that are manifestly less successful than we would like. Typically, teachers are the sole representatives of the culture in classrooms, where they carry a heavy burden as the sole source of information, of help, of criticism, and of inspiration for their students. No wonder a teacher feels drained, worn out by this constant giving. How often does he or she have to pass over the chance to work with a student who clearly needs help, because to concentrate on one student would mean neglecting all the rest? Nor is it surprising that the average classroom teacher hopes to limit the number of children in need of special help, in spite of a general recognition of the advantages of mainstreaming.

Outside school, it is common knowledge that children can do much more with help than on their own. And a crucial feature of doing things together is talking about them. The person-computer interaction is often described as a conversation, and it is exactly this interactive quality that appeals to individuals who prefer working with someone else, and who like to solve problems interactively. For these individuals, working in a try-it-and-see mode on the computer seems to unblock their thinking capacity, and they jump straight in, risking error as they explore. These interactors are likely to get into trouble in a traditional classroom, where the norm is desk work. A child sits at a desk, alone and silent, asking only the teacher for help when needed. No wonder interactive computer environments have such attraction for some students. You will recognize them easily; they are always talking. Of course they talk, since this is how they figure things out, interactively! For them, talking is learning. Under traditional arrangements, these children land in the special needs classroom (Weir, 1987).

One benefit that computers bring is an environment that tilts in favor of the interactor. This is one reason for the success we see among students in the special-needs classroom as they are given opportunities to work with computers. The kind of child I am calling an interactor is typically described as unusually distractible, with a short attention span. When working at the computer, the interactor looks at the screen, taking in and reacting to feedback, and the teacher will be wondering where that "poor attention span" has gone. An increase in attention span and a decrease in distractibility were the most often reported reactions of those at a special school for learning-disabled students as they worked on computers (Weir, 1987). Perhaps we should learn from their "special need" to interact. In interesting ways, the computer as an instrument of interaction becomes a means of engaging students with a variety of different working styles.

Vygotsky introduced the notion of the zone of proximal development, an area of activity defined by the difference between the level of independent problem-solving that individuals can achieve and the level they can accomplish with help (Vygotsky, 1978, chap. 6). Within this zone of proximal development—considered in terms of an individual's developmental history and the cultural tools available in a particular setting—cognitive change takes place. More generally, the concept refers to a collaborative effort among persons working on a problem which some of them could not work on effectively alone. Within this collaboration, interactions take the form of a series of negotiations involving the mutual appropriation of goals—a process in which participants recognize and take account of each other's goals. It is a commonplace observation that the emotional context in which the exchange between teacher and learner takes place is a crucial factor. Good emotional relationships facilitate the mutual recognition of each other's goals. If students have a sense of their own self-worth, they will be less inclined to defend against the goals of others. If students sense common cultural aspirations, they will be more inclined to accept and share the goals of others—in this case, teachers. The interpersonal relations children observe—the way people treat each other, the way they behave under stress, their attitudes toward risk-taking and self-reliance—become internalized and emerge as attitudes and patterns of behavior, such as level of motivation, initiative, trust, risk-taking, caution, and self-belief. What we as teachers do regarding social arrangements in our classrooms can affect these behaviors of our students

In the educational setting, it is usual to focus on the teacher and the teacher's goals. I want to emphasize the need for a mutual appropriation of goals. Interactions between teacher and student will fail to engender cognitive growth when the teacher incorrectly appropriates the child's goals. Teachers need to get better at recognizing their students' goals. At the same time, students need to get better at revealing their goals in an academic setting. For those children whose academic experience has been unfavorable, or whose cultural status alienates them from the schooling enterprise altogether, the teacher's task is not so much to discover the student's goal as to contrive circumstances in which the child can begin to entertain any academic goal at all and see it as relevant. Giving students the freedom to mess about and "play" in appropriately structured computer-based environments provides a stage upon which they can develop their own goals and have experience in choosing and working to realize them.

It may be that the teacher's job is made easier, in the short run, by having a silent class, diligently working away at the assigned task. But, in adopting this arrangement, teachers are surely depriving themselves of many sources of help in their own environment. In practice, help can come from students who have understood the problem that is being tackled. Often, different students have understood different parts of the problem. One setting that allows social interactions to function as the source of intellectual change is group work on projects. The joint goals and shared problems of such a project require negotiated solutions. The resulting talk helps bring knowledge to the level of consciousness. Hearing one learner articulate the problem can help another see it more clearly. Hearing someone else's misunderstanding can help a learner see a better way into a problem.

At the Hennigan School, an inner-city elementary school in Boston, Massachusetts, Seymour Papert has contrived an unusual setting for his current Logo project, which supports a variety of interactions between teacher and student, student and student, and student and computer. One important feature is the geographical layout of computers, arranged in four networks in a large central space into which individual classrooms open. No one in the project can go from point A to point B without crossing that central space. The second feature of the setup is the level of engagement and focused interaction that goes on in that space. Children learn from each other how to do things that excite them. The claim is not that this happens all the time, but that on good days, the large open space becomes a kind of culture cauldron, where the kind of informal cultural interchange that happens in a community occurs in a school setting. At such times, few cross that space without participating at some level in the exchange of ideas and activities.

The significance of the exchange is that students learn from each other. To the extent that the computer supports peer-peer teaching and learning, it can encourage new forms of classroom relationships. Clearly, this requires a change in teacher attitude. Teachers need to feel comfortable in not being the sole provider of knowledge. They need to be prepared to learn from students, to learn with students. Both the changed geographical arrangement and the teachers' changed perception of their role facilitate a change in the flow of information: the traditional vertical flow, from knowledgeable teacher down to naive student, is augmented by a strong horizontal flow of expertise among the student users.

## Mediating Symbols

Central to the changing flow of information are the readily accessible knowledge-mediating symbols that the computer can generate and that the student can manipulate. From the point of view of the individual learner, social representations of knowledge are external to his or her cognitive system. They serve as receptacles of the culture; their meaning can be appropriated during social interactions; they mediate the culture. Language dominates as the mediating symbol system. In addition to language, teachers habitually use explanatory vehicles such as diagrams, graphs, maps, physical models, and the like. It is in terms of its role as a source of mediating symbols that the potential of the computer can best be expressed. The computer is the most recent generator of external representations that we have. Graphics screen objects are a prime example. Computer "objects," such as Logo procedures, variables, and computer conditionals,[2] can act as external representations. When children work with them, they are doing something different from most of what they do in other parts of the curriculum. These are new sym-

[2] Logo provides the ability to combine commands into procedures, which are named by the user and become available as building blocks for larger procedures. Computer conditionals (such as: if *a* is true then *b* is true, else *c* is true) are building blocks by which logical argument can be implemented in a computer program.

bols, and they are powerful mediators, in this case, of logical argument. They support ways of rigorously capturing aspects of a situation, such as the relationship among actions or the presence or absence of particular features. They underpin the notion of qualitative rigor in thinking.

It appears that computer-generated symbols have a special appeal for some individuals. Students differ in what they find easy and what they find difficult, and using the computer in the classroom can increase our understanding of these differences. For example, its use has highlighted the value of the graphics screen for the language-disabled student with spatial ability. Think about what is going on when one student prefers to solve spatial problems while another prefers language problems. The chances are that each is taking in different kinds of information from the situation, and storing and using that information differently. When individuals who are geared to use one kind of information meet a problem expressed in a different representation, it is likely that they will make no connection between that problem "out there" and what's in their minds. Their knowledge about the concept underlying the problem being presented is just not triggered when they see it in this unfamiliar form. There is a failure of recognition, a mismatch between the form taken by the external cultural representation and the internal, mental representation used by such students. Expressed in sociocultural terms, there is a mediational failure. Difference becomes deficit.

As I have said, Logo-generated mediating symbols can be unusually accessible. They are easily picked up by the child in a pragmatic way; in other words, it's not necessary to understand them before they can be used. The child's mastery of computer commands often contrasts sharply with a low level of achievement in other academic contexts. The ease of use provides the framework for interactive experience between learner and computer and, most importantly, between a learner and neighbor. In the Hennigan experiment, students use computers for at least three-quarters of an hour each day. They rapidly acquire a level of understanding of what is going on, and this knowledge spreads through groups of students. What sort of understanding is this pragmatic knowledge, and what relation has it to the formal kind of understanding that traditional curricular approaches are at such pains to develop? I am using the term "pragmatic knowledge" to mean a collection of how-to's used without an understanding of how they work, like the way we are able to ride a bicycle without understanding the underlying mechanics.

There has always been great variation in ways of working with Logo, depending on the teacher's overall teaching style and implicit theory of learning. Among the teachers at Hennigan are some who used project-based methods in their classrooms before the computers arrived, and who have incorporated Logo-based activity into their curricula in an integrated way. Relatively straightforward progress has been made by students who are comfortable with formal reasoning and are above average in academic performance.

For many students this does not happen. The path from informal to formal learning is slow and involves a number of factors. "In everyday situations, thought is in the service of action. Rather than employing formal approaches to solving problems, people devise satisfactory opportunistic solutions" (Rogoff, 1984, p. 7). Witness the behavior of grocery shoppers, who, when the calculation gets complex, will choose an option other than calculation as the basis for deciding the better buy of two varieties of the same food product packaged in different weights (Lave, 1984).

The pragmatic flavor of peer learning in the classroom, intermediate in character between the culture of the street and that of the classroom, particularly engages students who do not usually identify with academic goals. The big trouble in schools is that formal activity is introduced in a way that makes it feel like an alien enterprise for many students, and the more formal, the less accessible it becomes. In contrast, Logo provides a setting for formal activity that does not have this effect. Perhaps this is because graphic objects and procedures are easily understood cultural symbols that are readily transmitted from one child to another. I attach great importance to the nature of the Logo procedure as a significant mediating symbol: when performing operations on graphic objects using a procedure, students can experience directly the connection between visible outcome and the underlying formal mechanism. Instead of focusing on the static figure, as in geometry, or on the symbolic expression, as in algebra, the student alternates between perceptible event and symbolic expression. An opportunity is thereby created for the student to build a relationship of correspondence.

There is great potential here, and this is what makes Logo so educationally interesting to me. But the existence of the relationship is clearly not enough. Are Logo users appreciating these relationships, understanding their significance? In the student-student interactions observed at Hennigan, the shared goal is to achieve an effect. Left to their own devices, students seem, on the whole, not to make the connection to more formal kinds of thinking. For that connection to be made, what is being internalized needs to include both the rich raw experience of manipulating cultural objects and an appreciation of their formal significance. Finding a strategy for making connections between pragmatic knowledge and traditional classroom subjects is not simple, if we take seriously the need for the mutual appropriation of goals in a teacher-learner situation. The students own that pragmatic knowledge. At the point of negotiation—that is, teacher intervention—the student goal is not to lose control.[3]

Leading a student to appreciate the significance of what he or she is doing is a crucially important step. The ease of entry into Logo activities can mislead a teacher into thinking that students know more than they do. The opportunity to build on this ease of entry will be lost unless the educator takes the next step—namely, to engage students in interactions that can lead them to appreciate the wider intellectual significance and implications of what they have learned to do.

## Thinking About Thinking

Understanding significance requires conscious reflection about what one is doing. How is such a consciousness to be developed? Far from being rendered superfluous, teachers now find themselves more challenged! Their teaching takes on a new character. Teachers need to work with the pragmatic understanding gener-

[3] Teachers need to build on the student's pragmatic knowledge. But there are two meanings of "building on." One implies that the teacher starts where the student is and helps the student move forward to where the teacher would like the student to be. I have taken this meaning in the past, and in the process have bumped up against what felt like extreme student conservatism: "Don't take my way away from me!" But building on past experience need not mean explicitly starting there. Rather, the teacher can start at the abstract level, and rely on the presence of related pragmatic knowledge to provide the pieces from which the learner can construct his or her understanding of the formally presented material (for an interesting example of this approach, see Davydov, 1975). The pragmatic knowledge constitutes the zone of proximal development that allows the teacher to take the student forward in a meaningful way, to explicate the links between the new formal material and the already experienced understanding.

ated during student-student interaction to introduce systematicity into that understanding, and to bring the student to a conscious appreciation of that systematicity. As diSessa (1988, p. 49) puts it: "My own view is that the transition [from commonsense reasoning about the physical world] to scientific understanding involves a major structural change toward systematicity, rather than simply a shift in content."

To cultivate conscious appreciation of systematicity in students involves improving their capacity for self-reflection, their metacognitive understanding. The challenge to teachers is twofold. We are, after all, asking them to perform a new task, to restructure their teaching knowledge. Teachers need to acquire an understanding of the students' cognitive strategies, so that they can help students come to understand their own functioning. To be able to do this, teachers need to improve their own powers of self-reflection. I suggest that teachers can be helped with respect to both these tasks by the nature of programming in general and of Logo programming in particular. The Logo setting can act as a model for teachers' thinking about their instructional strategies.

The Logo turtle itself is a representation geared to aid the development of self-reflection. An important function of turtle work should be to act as a bridge between what the student does and what the student knows, to support reflection on his or her learning. Papert (1980) encouraged the metaphor of teaching the turtle to do something. In this mode, an identification of learner with turtle is encouraged, and with it, the blurring of the distinction between what the turtle knows and does and what the learner knows. This can serve a function: whereas some students might have difficulty examining their own thoughts, they may have more success if those thoughts have been externalized to become the "thoughts" of the turtle as expressed in programming language.

It is the nature of representations to enhance some aspects of the element in the real world that is being represented, and play down or omit other features. That is to say, their derivation necessarily involves abstracting away from some of the cluttering detail present in messy real-world situations. In a very important sense computer-generated external representations are halfway between concrete and abstract in nature. They are objects that can be acted upon, yet they serve as visible versions of ideas. They help to conceptualize the domain. This is why I want my students to be programming, as well as using somebody else's software. Logo offers a world halfway between the familiar real world in which things happen and the mental world of analysis, mental diagrams, geometry, and algebra: a quasi-mental, quasi-real world of computational graphics objects, of quasi-real actions. The in-between status can feed into the self-reflective process, since the abstract thought becomes detectable in its concrete form.

The learning path builds on the juxtaposition of the visuo-perceptual with the abstract symbolic form (the Logo procedure, the Logo variable) to a subsequent focus on relating several abstract symbolic expressions to one another (super-procedures, subprocedures, variable procedures). The idea is to use the more intuitive familiarity—for example, with functions and variables—that grows out of Logo programming as a basis for a formal treatment of these notions (Leron & Zazkis, 1986).

These, then, are the kinds of aids to self-reflection that the Logo system can, but does not automatically, provide. In my experience the likelihood of improving systematicity without guided self-reflection is remote. This fact has concerned the Logo community over the past several years. An international group of Logo researchers concerned with the issue of what and how students learn in the context of Logo and mathematics education has formed an informal collaboration, led by Celia Hoyles and Richard Noss at the University of London Institute of Education. Their studies typically involve careful observation of the process of problem-solving; the relationship between Logo programming and mathematical concepts, such as functions and variables; and the kinds of intervention an adult can make that will encourage students to reflect on their activities (Hillel & Samurcay, 1985; Hoyles, 1986; Hoyles & Noss 1987, 1989; Hoyles, Sutherland, & Evans, 1985; Leron, 1983, 1985; Noss, 1986).

## Domain-Specific Metacognition

My concern over the past several years has been with students who have problems in the traditional classroom. Many of these problems can be understood in terms of mismatched mediational means and metacognitive difficulties. Using Logo with learning-disabled children has revealed that some of them are exceptionally talented at spatial reasoning (Weir, 1987). Students who have a flair for spatial problem-solving have highly developed spatial intuitions and metacognitive skills. Language is not a suitable mediational means for them. When mathematics is presented as a series of mathematical sentences, such as *6 * 15 = ?*, the students I am talking about show poor numeric reasoning skills. However, if they are asked to calculate the perimeter of a hexagon of side 15 displayed on the screen, they have no difficulty. These students have successful strategies when operating in a spatial domain that contrast dramatically with their approach to other school work.[4] Their difficulties are twofold: they have few opportunities to display their spatial strengths in an academic setting, and they do not know the connections between the skill they have and the classroom problems they are being asked to tackle; nor, for the most part, do their teachers. Many famous mathematicians have worked in images rather than in words. The difference is that they have known what the connection is. In a school curriculum that is heavily language-based, we have served nonverbal students very poorly. Now, with computers available, we can match the tool to the student and present curricular material with an emphasis on the nonverbal, spatial mode. See, for example, Visual Narratives (Weir, 1987), LEGO-Logo (Ocko, Papert, & Resnick, 1988), and Microcomputer-Based Labs (Zuman & Coombs, 1988).

## Connecting to Mainstream Curricular Goals: How Do We Get There?

The importance of the teacher in determining a successful outcome in the use of computers has been well documented (see, for example, Carmichael, Burnett, Higginson, Moore, & Pollard, 1985). The computer will serve education well only to the extent that the educator gains control over this powerful tool. As a priority, teachers must be provided with an adequate supply of the tools they will need, as summarized in a U.S. Congress, Office of Technology Assessment (OTA) report (September, 1988):

[4] Such children perform well on pattern-matching, figure-completing, and other tests of spatial ability (Weir, 1987), do particularly well at Logo, and also do well at other computer-graphics-intensive materials, for example, MBLs (Zuman & Coombs, 1988). Spatial ability and interactive tendency together produce the phenomenon of the video arcade wizard (Greenfield, 1983; Weir, 1987).

> An increase in the amount and capability of technology in schools will be required if the technology is to realize its potential. Whereas in 1981 fewer than one school in five had a computer, today, almost all do, and over 90 percent have VCR's as well. However, for most schools, this means too few machines to be shared by too many children. (p. 7)

The kind of cultural development taking place at the Hennigan School cannot happen in a one-computer-per-fifty-students setting. Computers once a week for a few weeks will not produce the kind of ownership of knowledge I have been discussing. But tools alone will be of no use without a major effort with respect to teacher preparation. The same OTA report tells us:

> Only one-third of the nation's teachers have had even ten hours of computer training, and most of that has been devoted to learning about the computer, not how to teach with computers. . . . Less than one-third of all recent education school graduates consider themselves prepared to teach with computers. (p. 18)

It is important to realize that we are not talking about a two-week training period in the technical aspects of the use of computers. I have pointed to the great challenge facing teachers. They are being asked to accommodate to a wholly new situation: a changing classroom culture, changing patterns of control in the classroom to allow for group activity and peer teaching and learning. Not every teacher will want to get involved in situations that stress inquiry-based, cooperative learning. We are asking teachers to increase their own metacognitive awareness and to restructure their teaching knowledge. They will need to improve their own powers of self-reflection and to develop a feeling for a whole range of responses so that they will be better able to help students use their own natural abilities to achieve academic success and self-fulfillment. Some teachers will not be interested in inventing alternative approaches to curricular areas, or alternative methods of representing concepts and posing problems.

Add to this the need for teachers to become familiar with alternative assessment procedures that focus on process; instruments that assess students' problem-solving skills, not just their answers; that take account of different representational modes and styles of problem-solving; and, most important, that take account of students' potential for development. Such instruments will measure not only the current, already-achieved knowledge of students, but also what they can achieve, how well they can use help, how they respond to a series of graded hints or helping pointers (Brown, 1984).

Clearly, all this is not going to happen without support. The OTA report surveys a number of means that have been adopted to provide teacher support, from New Hampshire's funding of computers for teachers to telecommunication linkups such as the National Geographic Society Kids Network project. Teachers' comments on the latter are revealing: "I did not realize how much this project has changed my thinking about how to teach science until I sat down to think of next year"; and "I have overcome my 'fear' of latitude and longitude! For the first time in my life I understand it!!!" (Tinker, personal communication, Oct. 1988).

This kind of educational change is not going to appeal to all teachers. A few innovative teachers have instituted project-based, cooperative, computer-using activities. The majority find the prospect too daunting, too difficult to implement. They are not trained for this kind of approach, are unable to manage the logistics, do not understand the subject well enough. Our focus should be on those teachers who would not function in this way on their own, but could do so if given the right help, that is, to provide a zone of proximal development for teachers ready to accept this help. This is where the new technology can come into its own. Telecommunication networks can become the framework for cooperative learning among teachers. The use of telecommunication link-up and software support makes it possible to provide the initial boost, training, and ideas, and then to follow up with ongoing support and expertise—a forum for exchange of ideas and results.[5]

## Conclusion

Achieving a combination of qualitative rigor and open-ended, child-initiated learning in a computer-based environment is much, much more difficult than relying on a piece of software to do the job of teaching; more difficult for the educational technology developers and for teachers. We ought not allow short-term results, such as increased test scores, to obscure the benefits of the long-term, more thoughtful enterprise discussed in this paper. Our focus should be on the potential of the computer as an instrument of interaction that allows us to match learning environment to individual learning style, and above all, that supports the restructuring of knowledge that needs to occur as children learn.

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