Action Knowledge and Symbolic Knowledge: The Computer as Mediator

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This chapter addresses a small set of troublesome but pervasive educational issues that are illuminated as we look at the possible roles for computer technology in classrooms. I begin by stating some of these concerns in a rather abrupt fashion, in part as a response to others' views as expressed in earlier chapters. In the remaining sections I play out these initial responses, propose some alternatives, and give one extended example of how such alternatives actually look when played out in an unusual classroom.

- To assume that "knowledge" and "information" are equivalents can be destructive to learning. Information lies quietly in books, is gathered from others, or accessed via the Web. Knowledge is actively developed through experience, interpretation, constructions, questions, failures, successes, values, and so forth.

- Children can be active makers and builders of knowledge, but they are often asked to become passive consumers—the target of selected others' goods and information.

- Children are also makers and builders of things. In this context, "grasping" is not a metaphor as in grasping an idea, the truth. For children living in an unstable, unpredictable world, literally grasping, holding, holding still, holding on is a persistent need.

- For children whose worlds are spinning too fast already, and who are vulnerable to a sense of loss of place—in space, in a family, in a community—using the computer for speedy access to vast spaces and quick, efficient, packaged-up, ready-to-go information may be more confounding than helpful.

**Background: The Laboratory for Making Things**

The work with young children began as a project and a place that we called the Laboratory for Making Things (LMT). It took up residence in the Graham and Parks Alternative Public School in Cambridge, Massachusetts. The project was initially motivated by my interest in a well-recognized but poorly understood phenomenon: children who are virtuosos at building and fixing complicated things in the everyday world around them (bicycles, plumbing, car motors, musical instruments, and music, games and gadgets, or a club house out of junk from the local construction site) are often the same children who have trouble learning in school. They are children who
have the ability to design and build complex systems, who are experts at devising experiments to analyze and test problems confronted along the way, and who can learn by extracting principles from the successful workings of the objects they make. But they are also children who are frequently described as having trouble working with common symbolic expressions—numbers, graphs, simple calculations, written language. With knowledge in schools equated neatly with the ability to deal with conventional symbolic expressions, it is not surprising that attention focuses on what these children cannot do. Thus, instead of seeing these children as virtuous, they are seen as "failing to perform." Thus, my primary question was this: If we could better understand the nature of the knowledge that the children were bringing to us, and how well, could we help them use this knowledge to succeed in school, too?

**Getting Started**

Work at the Graham and Parks School began in the fall of 1985, Susan Jo Russell, who had been a teacher and was now completing her Ed.D. in math education, joined me in starting the project. The school, located in a working neighborhood of Cambridge, is named after Sandra Graham, a social activist and former member of the Cambridge School Committee, and Rosa Parks, well known for the role she played in the struggle for equal rights in the 1960s. The core of the student population mirrors the diverse population of Cambridge, and in addition includes most of the Haitian-Creole-speaking children in the city.

Our initial goals derived from hunches concerning the hands-on knowledge of children, together with the years of experience Susan Jo and I already had in working with children in the computer lab run by Seymour Papert at MIT—called the Logo Lab. We imagined a learning environment where children could use computer technology as a resource for inquiry and invention in a world that fit their size of space/time. It would be an environment where children would not simply alternate between action and symbolic description, between sensorial experience and representations of it, between the virtual world inside the box and the familiar world of their own powerful know-how in real time/space/motion. It would be a world in which children could catch up with their own understandings—seeing events and actions as we literally to grasp the "goings on" of things and how they relate to ideas.

We began with the teachers. All the teachers in the school (grades K-6) were sent an invitation to join the project as having trouble working with common symbolic expressions—that is, working with conventional symbolic expressions. We described it as an opportunity to spend two hours once a week after school talking together about children's learning, through sharing puzzles and insights from the classroom. Teachers would learn how to program a computer. Eventually we would design and equip a lab, and develop activities for the children who the teachers would bring to the lab on a regular basis. We were able to offer participants $300 for the school year. Twelve teachers signed up, with a core group of eight becoming regular participants. We had expected the initial planning period to last perhaps six months, but the teachers felt ready to bring children to the lab only after we had worked together for nearly six months. As it turned out, those six months went critical in shaping the form that the lab itself took.

A month into the planning period, the Apple IIe computers arrived. Unpacking and putting them together was, we believed, a necessary first step toward helping the teachers gain a feeling of intimacy with the machines. Learning the computer language, Logo, was further step toward this sense of intimacy, and it had a surprising spin-off perhaps because "the computer" was a totally new medium, the teachers shed their initial fears and became fascinated, instead, with their own and another's confusions around their interactions with the machine. Probing their confusions came to be seen as a source of insight—what was behind the confusion and how could you find out next?

This new productive source for inquiry had another unexpected spin-off: the conversations about children's learning changed their shape and focus. Stories from the classroom turned now to children's confusions and how to understand them. Just as the teachers came to appreciate their own confusions as a step toward unveling new or previously hidden ideas, so appreciating children's confusions could also be a source of insights into learning. Making the assumption that no matter what a child said or did, is made sense to him, the question was: How could we find the sense he or she was making at the time? As one teacher, Mary Briggs, put it, "I hear a
child saying this weird thing, but if only I could look out from where that child was looking, it would make perfect sense.

During these six months, the lab, a large room in the school, was gradually "furnished" with a great variety of materials for designing and building structures that work—gears and pulleys, Lego blocks, pattern blocks and large building blocks, cuisenaire rods, batteries and burners for building simple circuits, Suncore wood and glue for model house construction, as well as drums and keyboards for making music. And the ten Apple III computers took their place as another medium for building structures that work and make sense—what we came to call "working systems." The children renamed the room the "design lab." The project, including the weekly meetings with the teachers, continued until funds ran out in 1984. Some three hundred children ranging in age from five to twelve participated in lab activities during those seven years.

Emerging Questions

In our work with the teachers, one of our goals was to design projects that were not overly different from the surface, but embedded similar underlying principles: projects that differed in the kinds of objects and materials used, that utilized differing sensory modalities, that held the potential for differing modes of description, but that shared conceptual underpinnings. The idea was that by juxtaposing such projects, shared principles would emerge as conceptual structures in themselves, rather than remain associated with and embodied in just one machine, one kind of material, or one kind of situation. In designing these projects, we were, in fact, drawing on the effective learning strategies that the children brought with them from outside of school: to learn by noticing and drawing out principles from the success of the objects and the actions that worked.

Children were encouraged to move back and forth between making working systems in real time space (Lego cars, huge cardboard gears, pulleys, and rhythms played on drums) and working systems using the Apple computers as a platform (Lego graphics, music, quiz programs).

A cluster of interrelated questions emerged, including: how do children (or any of us) learn to sense continuously moving, organized actions, such as clapping a rhythm, bouncing a ball, circling gears, into static, discrete, symbolic descriptions that represent our experience of these objects and our sensory mastery of them? How do we learn to make descriptions that hold so well to be looked at?

The computer played a role as mediator in answering these questions by helping the children make explicit the shared principles that might otherwise have remained hidden in the objects that embodied them. The computer, as the children would use it, was another medium for designing and building working systems. But unlike making objects through actions in real time space, in making objects in the virtual world of the computer, one has to begin by describing in symbolic form what one wants to happen. Once made, the symbolic description becomes what has been described—symbol becomes object/action! Descriptions written on paper, or voiced loudly, remain static: the person receiving the description has to try to put its pieces together, to imagine what is meant. And it is often difficult to know if the meaning you have gleaned is the meaning intended. Did you get it right? You have to ask the teacher or wait to be told. The computer has a unique capability: you are not left in doubt—descriptions "seen" to the computer instantly turn into the things or actions described.

But these symbolic "instructions" must be made within the constraints of the computer's "understanding"—that is, within the symbolic constraints of some computer language. The result is that the computer as a mediator between description and action often turns into a strangely reflective playground causing provocative surprises along the way. The children needed time to notice and to play with these surprises; rather than turning away, they made experiments to interrogate them—such as they know how to do in finding their bikes or the Lego cars they made in the lab. But the computer experiments had a special quality: because descriptions become actions, the relationships between symbols and actions could be trusted. Indeed, chancing surprises, tracing the path that led to them, turned out to be a very effective way for the children to explore their own confusions. Much as it had been with the teachers, interrogating their confusions was often, for the children, a critical step toward gaining insight. Strange encounters of a special kind.
designing; and
3. closely related to both, the idea of "chunking" or grouping,
which grew out of a specific need in working with the continuousness
of musical objects, but its usefulness crept into designing other objects, too.
Issues around chunking became more concrete in the children's frequently
heard, but rather unexpected, question: "So what is a thing, here?"

Working in the Lab with Children

Teachers brought their whole classes to the lab for scheduled hours during
the regular school day. But on Wednesdays after school Mary Briggs and
I spent the afternoon working with six nine- and ten-year-old children.
Mary knew the children well because, as the special education teacher, she
worked with each of them on a daily basis. She selected these six children
because she believed they would particularly thrive in the design lab
environment. But for me, actually working with children every week—
instead of only listening to the teachers' stories about them—changed
my whole understanding of what those stories were about. While we had
walked a lot about how to make sense of what a child says or does, it came
as a revelation to realize how hard it is to really make contact with a child,
to become intimate with her thinking so as to learn from it—especially a
child for whom life in school has not been especially rewarding. And this
was probably particularly so for a person like me—a middle-class academic
trying to understand children for whom life was so different from anything
I knew. Most of all I came to appreciate the work of teachers: what a huge
difference there is between thinking and talking about schooling, and
actually being there—living there every single day, not just once a week
for an afternoon like I was. Working with Mary and the children made that
one afternoon an intense learning experience—learning that has influenced
almost everything I have done since then.

A Day in the Life of the Design Lab

A glimpse into the children's work during one day in the lab will help
bring some of these ideas to life. The events on this day occurred after a
with the 'body knowledge,' the sensorimotor schemas of a child. You can BE the gear, you can understand how it turns by projecting yourself into its place and turning with it. It is this double-relationship—both abstract and sensory—that gives the gear the power to carry powerful mathematics into the mind. The gear acts, here, as a transitional object."

My lunch was that moving between clapping rhythms and playing with gears could be a particularly lively playground for making this "double relationship" manifest.

While working in the Lego Lab at MIT, I had designed, with the help of others, a music version of Logo called MusicLogo which was now up and running in the design lab. Thus, even within the Lego world of the computer, the children could move across media—sometimes doing graphics, sometimes doing music. The idea was the same as in other design projects: by moving across media and sensory modalities but now keeping the means of procedural designing the same, shared principles would pop out; for example, the same procedure and the principles behind it were used to make a graphic shape get smaller and smaller, to print a "countdown" (10-9-8-7...), and to make a synthesizer drum play faster and faster beats.

On this Wednesday afternoon we moved through several activities—from drumming, to playing with very large cardboard gears (that had been made by a group of slightly older children), to clapping, and eventually to "telling" the computer how to "play" drum patterns using MusicLogo coupled with the virtual percussion instruments of a synthesizer.

Gears and Rhythms

As we moved over to the gears, Mary asked the children, "Now how could these gears and the drumming son be alike?"

Ruth is standing by the gears, spinning them; her hands are actually being the gears as she talks. Harry is sitting at the left with Mary's arms on his shoulders, Leon is at the right. Ruth, like the other children, was having a hard time in her regular classes. But as she turns the gears, watching them go around, the spontaneous makes a proposal:

Ruth: Well, it's a math problem: Like this one has (counting teeth on the small gear) 1, 2, 3, 4, 5, 6, 7, 8—and you bring the
8 around 4 times to get it (the big gear) all the way around. Now how many teeth does that one (bigger gear) have?


Ruth: No, 4 times 8, 32. And the small one goes around 4 times when that one goes around once.

Mary (changing the focus) But I wanna know which one of those wheels is going the fastest.

Harry: The smaller one.

Ruth: Both of them are going at the same speed.

Mary (to Harry) You say the smaller one?

Harry: Oh, the smaller one is going around four times and it's fastest.

Mary: But Ruth said same speed.

Ruth: Because look, you can't make this one go faster. Every time this is going ... Oh, you mean how fast it's going around?

Mary: Well, what do you think?

Ruth: What kind of fastest do you mean?

Mary: What are the choices?

Ruth: Like for one kind of fastest you could say ... like if you could go ... you could say how, like (pointing to intersection of teeth) how each tooth goes in like that, you know? And once kind of fastest you could say how long it takes for one to go around.

Mary: Hmm. So if you say it's the kind of fastest with the teeth, then which one wins? Which is the fastest?

Harry: The smaller one.

Ruth: No, they both go the same.

Mary: O.K. And what about if you say which goes around the fastest?

Ruth: The smallest one.

Clapping the Gears

At this moment, Arthur Ganson, who was also working with the children that day, sees a connection. Catching it on the fly, he turns the conversation around.

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Arthur: So what is the rhythm of that gear?
Mary: The rhythm of that gear? Someone want to play it?
Arthur: Yah, how about playing it?
Harry: I'll play it. (He turns the gears around making them 'play'.)
Jeanne: Yah, how would you play that rhythm?
Sarah: Like this ... hummm.

Sarah taps a slow beat with her left hand and a faster beat with her right. The beats have a 4:1 relationship to one another—that is, for every one tap of her left hand, her right hand makes 4 taps (see Figure 10.3).

Jeanne: Yah, do it again.
Sarah: [Taps out 4:1 rhythm again.]
Jeanne: Which is the small gear?
Sarah: The one that's going ... [taps the faster beat with her right hand.]

Arthur's spur-of-the-moment question nearly brought together the seemingly disparate materials, modalities, and means of description with which the children had been working: gears were a medium for Ruth's mathematics/physics. The gears for Ruth embodied, "held," principles of ratio and also "kinds of fastness". Sarah, in turn, took Ruth's description of the relationships of the two gears and expressed it in the relationship of her two hands in clapping. Two different embodiments of the same "working system." Sarah's two-leveled clapping was a kind of metaphor-in-action for the relative motions of the two meshed gears—she had become the gears. And yet, hiding behind that leap from one medium to the other were embodied shared principles: perhaps the most general being the fundamental idea of a "unit" and what we would call "periodicities"—what the children had been calling simply "beats."

Sarah and Ruth were demonstrating what we had suspected from the beginning: children who are having difficulties learning in school, given its symbolic emphasis, can learn in profound ways by extracting principles from the successful workings of their built objects and their actions on them. The question was, as it had been from the beginning, how could we help the children make functional connections between what they knew how to do already in action and the expression of their know-how in a more general, symbolic form? Ruth was clearly on the way; but what about the others? Could the computer and MusicLogo mediate between action knowledge and symbolic knowledge?

The Computer as Mediator

While Arthur's specific question and Sarah's response were unplanned events, they had been prepared by our juxtaposition of the two activities—drumming rhythms and working with the gears. The next activity was definitely planned in advance. It reflected our intention of using the computer as mediator. The question was: Could the children use the computer as a vehicle for effectively moving between their own body actions in clapping/drumming, the actions of the gears, and now, numeric-symbolic descriptions of the shared, embodied principles? In short, could they turn continuous actions into discrete, symbolic expressions?

I asked the children to gather around the old Apple IIe computers. The new task that I put to them was: "Can you get the two computer synthesizer drums to play what Sarah clapped? Except, to begin with,
we'll make it a little easier. Just try playing ..." And with two hands, like Sarah, I tapped out a simpler, 2:1 rhythm. The children all clapped the two-layered rhythm (see Figure 10.4). The children were already familiar with Logo graphics and with procedural programming—what we called "teaching the computer." Now, in order to "teach" the computer to play the rhythm that I had proposed, the children would need also to find (perhaps give meaning to numbers in this new context—to find out how numbers worked when those numbers were instructions to percussion instruments to play beats. What were the links between the actions and sounds the children made in clapping, the numbers used in doing ordinary arithmetic, numbers used in doing graphics Logo, and new numbers used as instructions to the synthesizer drum?"

The children were used to conversations, like the one around the gears, in which they explained to one another or to an adult how they made sense of something or how they made something work. These conversations usually arose spontaneously in response to a disagreement, to a child's surprising discovery, or when an insight led to solving a particularly intractable problem. Descriptions of such past happenings, however, included organized, symbolic/numeric expressions, while they often pointed to an emergent similarity, descriptions were more often vague or in-action like Sarah's "clapping the gears." Compared with what the children had been used to, the relationship between actions and description would now have to be reversed. Instead of turning back on what had already happened, to make descriptions after the fact and after the act, in the virtual world of the computer they would need to describe what they wanted to happen before the act—that is, as instructions to the computer. And the instructions must be in a symbolic form that the computer can "understand." These were the issues as we moved to the next task and to the computer.

Leon Makes a First Discovery

To help the children get started, I typed the following instructions to MusicLego and we listened.

BONK [5555555]

PM

We heard a steady beat made up of even drum sounds each with a duration of "8." At this point, however, the children (and no doubt, the reader) still had to discover what "8" meant. I gave another example, saying, "This one will go faster."

BONK [6666666]

PM

Jeanne: Now I want to make a still faster one.

Leon (who had not participated in the discussion up to now): But the louder you get the faster it gets.

Jeanne: You answered my question before I asked it.

Sarah: Leon's psychic.

Stephen: Do 1 2 3 4 5 6 7 8?

Jeanne: What do ya think will happen?

Leon: If you put all ones, it'll go fast.

Jeanne types:
MusicLogo and the synthesizer had the capability for making two different drum sounds, BOOM and PING. Each kind of drum could be "instantiated" separately. The command "BOOM" (or "PING") "sells" MusicLogo to make a BOOM (or PING) sound. The list of numbers that follows BOOM or PING indicates the duration of each sound; the number of numbers indicates how many sounds to make in all. The numbers for durations are proportional to one another—\( n \) is twice as long as \( a \); \( a \) is half as long as \( a \). There is no sound while the user is giving instructions. The drums actually plays only when the user types the command, "PM," which stands for Play Music. Upon typing "PM," the 'previously typed instructions are realized in sound—symbol becomes action.

Leon Invents an Experiment

I went around to work with Leon. Leon had been an enigma to all of us: he talked very little, so we were never sure what was going on with him. Leon's teachers were often at a loss as to how to reach him. As in the conversation just reported, however, the children as well as the adults in the group knew that out of his silence came surprising, sometimes extraordinary insights. It was in the lab, too, that we discovered his most notable quality: integrity. If the situation, the problem to be solved, or the teacher's description or definition did not make sense to him, he, unlike more school-smart children, would just turn off rather than go through the motions to get a right answer. Leon needed to understand for himself. And along with this, Leon wanted to take time to think. On this occasion as on others, I learned that we adults needed to slow down to catch up with his thinking.

Leon was the quintessential example of a child for whom grasping an idea could literally be a physical experience. All of us seek ways of holding on to a new idea; but for children growing up poor and living in an unstable, unpredictable world, grasping, holding still, holding on, is a persistent need. Leon's explorations to find out how numbers could "reach" the computer to play the drums made that quite clear. And like probably so many times before, I almost missed it.

Sitting down next to Leon, I saw that he had typed into the computer, "BOOM," followed by a series of \( 1's \).

This was, in fact, just what I had done a moment before in response to Leon's comment about the \( 1's \) going fast. I proposed a further possibility: "Leon, can you make a BOOM sound that goes exactly two times slower? What do you think?" [Pointing to the screen] This is a one and you want each one to be two ones. Leon ignored me which in retrospect was perfectly sensible. My proposal made sense to me, but what could it possibly have meant to him or indeed, to most anyone: "you want each one to be two ones?" Instead, Leon, true to his integrity, continued with his own self-designed task.

Determinedly, slowly, persistently, he typed \( 1's \) and \( 2's \). There was no sound except for his typing. With a kind of steady pulsing, repeated, rocking motion, he used two hands to type—the right hand typing numbers, alternating with left hand pressing the space bar: \( 1 \) space \( 1 \) space \( 1 \) space \( 1 \) space ... \( 2 \) space \( 2 \) space \( 2 \) space \( 2 \) space ... \( 1 \) space \( 1 \) space \( 1 \) space ... he nearly filled up the whole screen with \( 1's \) and \( 2's \).

Despite my best intentions to find reason in what he was doing, I thought: "What can be the use of all this? Filling up the screen just to fill up time? Looks like a waste of time to me." Only later, looking back at the videocassette of the whole session, did I realize how mistaken I was.

After all his work, Leon finally typed "FM." The synthesizer drum dutifully played exactly what he had requested; a series of very fast drum sounds (the \( 1's \)) alternating with a series of drum sounds that went
"exactly two times slower" (the z's). As he listened, Leon followed the numbers on the screen with his finger.

Even though I had been present while all this was happening, it was only later that I realized the significance of what I had seen. I missed the importance of Leon's work because I was focusing on my task, the task I had set for the children—to make two levels of beats in a 2:1 relation. Leon, with his sense of integrity, had to begin with his own questions. What I was watching was an experiment that Leon had designed to answer questions he had silently put to himself: "What have I got here? What is the meaning of 1 and 2 in this context? What do these numbers do? And how can I find out?"

As I studied the videotape, I learned what Leon was up to. Juxtaposing the series of 5's and 2's, the contrast between the very fast 5's and the slower 2's was eminently audible. But listening was not enough; to really grasp the meaning of the numbers, Leon needed to echo their actions in his own actions. As the numbers on the screen played, Leon moved along with them, keeping time. In this way he was literally coordinating symbol with sound and action—but not quite. The 5's were too fast for his finger-following to keep up with, but he clearly acted out the contrast between the 5's and 2's: while the fast 5's were playing, he swept his hand through the series, put his finger on the beginning of the next series of 2's, and waited. When the slower 2's started, he followed along, keeping time with each number and each steady beat as they sounded. The numbers stood still, the beat was sounding/moving, and Leon's "finger-drumming" was grasping them all. Intensively and patiently, Leon continued the process—sweeping his hand through the 5's, waiting for the 2's, keeping time with the 2's as they passed by—until the entire screen had been traversed and the whole "piece" was over.

True to his integrity and his desire to really understand for himself, Leon invented a situation to try to understand numbers meant to Music-Logo, what they did in sound and action. Starting with what he knew already ("The lower you get, the faster it gets... If you put all 5's it'll get fast."), he tested that knowledge, pushed it a little further. Perhaps like a scientist working with the puzzling behavior of cats, Leon needed to differentiate between two slightly different elements and their relations. And like the scientist, he needed repetition—a critical mass of each kind of element repeated over sufficient time, and an environment where their differences could be clearly perceived. To achieve this, Leon lined up strings of elements, each string including one of the symbolic elements (5's or 2's), and each kind of string immediately juxtaposed to the other. Having repeated instances of his essential elements repeating over a sufficiently long time, the "joints" where the two kinds of elements met produced the revealing moments.

Leon was using all the available resources he had to do the work of making meaning. He had invented a way to use the computer and Music-Logo as a mediator between successful actions in real time space and the world of symbols which in school are given privileged status as a measure of knowledge. In retrospect, he taught us, above all, how important it is to be able to slow down, to take time to repeat, to practice literally making correspondences; he made numbers, synthesizer drumming, and his drumming move in perfect synchrony. In this way he literally and physically grasped meaning.

But all of this depended on an environment that exploited the computer in a way that was unique to it: the symbols Leon typed became what
they stood for. He was using the computer as a medium in which a symbol defines itself by becoming what it does. And he was successful! Paraphrasing Papert, for Leon the computer became a mentalized object—a mediator between abstract and sensory experience, carrying the idea of the numbers into his mind. We needed Leon to teach us how that could really work.

A Procedure and a Performance

But there was more. After experimenting further, now trying the other drum sound, PING, and listening to what it did, Leon found he had the makings of a real piece—his own drum piece. Having worked with Logo before, he knew how to make a 'procedure.' Applying what he had learned in the medium of Logo graphics, Leon 'taught the computer' how to play a new drum piece, never before heard. Not precomposed, perhaps not even planned, Leon followed the same process as before except for adding PINGs to his BOOMs, but still staying within the self-imposed limits of 1's and 2's. Probably in a sign of possession, of holding the procedure as his own, Leon, like so many others, gave his name to his procedure: he taught MusicLogo how TO LE0.

I abbreviate his procedure here.

TO LE0

BOOM [2 1 1 1 2] PING [1 1 1 1 1]

BOOM [2 2 2 1 1] PING [1 1 1 1 1]

PING [1 1 1 2 2 2] [ROOM 1 1 2 2 2 1 1] -

END

Typing, "END" and pressing the carriage return," he is "told" by the computer:

LE0 DEFINED

The procedure is clearly his.

The afternoon is almost over and the children are moving about:

Mary: Shhh... Leon's going to play his piece.

Leon (excited): "Here we go again." (He types)

LE0 (which sends the new procedure, LE0, to MusicLogo to be computed) then

PM (which sends the computed procedure to the synthesizer.)

Leon's new piece fills the lab, and the children listen attentively until the end. No one stirs. Leon looks triumphant and the children clap in appreciation.

Mary: O.K., children, we have to go now.

Later Outcomes

What can we assume that Leon actually learned through his experiment? Did he, for instance, come to understand the reinterpreted, proportional relationship between beats of duration "1" and beats of duration "2"—that "1's" go exactly twice as fast as "2's"? Events in subsequent sessions suggest that on this Wednesday afternoon, such awareness was more a glimmer than a grasp—a general idea to build on. But build on it, he did. As usual, Leon chose to move slowly, to practice, to repeat, and to find out for himself. Feeling comfortable enough with the meanings of 1's and 2's, and learning from what the other children were doing, he did try a two-layered rhythm (BOOM in one part, PING in the other), but still using the familiar 2's and 1's. To test the principle that he had embedded in this first example, he devised a new experiment. Figure 10.5 shows how, quite on his own, he developed examples of numbers that embodied the same inner relationship—the 2:1 ratio.

Leon first wrote out each series including all the numbers, and only then typed it into MusicLogo to hear what would happen. Notice that he writes out all the numbers for each example; that is, he repeats the smaller number exactly twice as many times as the larger number. Starting with:
be gets progressively faster (6.3; 4:2) and ends up with the slowest example (10.3). However, the last of the smaller numbers is always crossed out, making one less, because he discovered in listening that wish PING playing the smaller, faster numbers, the two instruments "never came out together." When there were exactly twice as many faster PINGs, there was always one extra. Was the computer making a mistake? Surely, half as big a number meant twice as fast, and that should also mean twice as many to "come out even." The children were intrigued with the puzzle and worked on it for quite awhile.

Conclusions

The activities described in these stories are not intended as a recommendation for something to be literally copied—as "a curriculum" or even as "what to do tomorrow." Nor are they intended as a recommendation for the only way that "the computer" can be effectively used in schools. Leon devised his experiment to explore possible answers to questions he asked; for another child with different questions (even other children that day in the design lab), his strategy could be a total bore from which they would learn nothing.

Rather the stories are meant as a proposal for an approach to learning and a whole context in which children can be helped to thrive—especially children such as Leon who are seen as failing in school, whose lives are rife with instability and disorganization, who often feel that school is irrelevant and reciprocally are made to feel themselves irrelevant, peripheral, in school settings. These are children whose personal, effective knowledge is falling them in school largely because there is no way they can bring it in off the street into the classroom.

For these children, most especially, we propose that a computer can play a special role as a resource for inquiry and invention when they can work at a pace and within a conceptual space that they can grab and that thus feels secure. In this environment, instead of being poor conveyor of other people's fleeting ideas and inaccessible products, children can potentially become makers of new knowledge of which they can feel proud, with which they can give pleasure to others, and through which they can also learn how to learn what is expected of them in the school world and beyond.

The next step is to help teachers invent their own examples of resources and environments where children can make experiments and can learn how to grasp ideas and grasp ideas. To this end, we have recently created the MIT/Wellesley Teacher Education Program. While it is intended primarily for MIT undergraduates who wish to teach math or science.
in middle and high schools, the program sits in the Department of Urban Studies. The association with urban studies is exactly appropriate because we focus on issues around how children in the inner city can be helped to learn and how schools can be helped to appreciate the knowledge children bring with them from their experience outside of school. In 1996-1997, the program celebrated its third year and the education classes continue to grow. Five students have completed their certification and are teaching in local area public schools; ten more will complete their certification in June 1997. The reports back from the field suggest that life is not easy out there, but the students are gaining confidence and engendering confidence in their students as well. Meanwhile, judging from the current students' papers on their observations and tutoring, we seem to be learning how to do it better, too.

Notes
1. Of course, MIT is full of students with the present problem: veterans at pushing symbols, finding and solving equations, but often having trouble making a gadget that works—even when the gadget embodies the principles represented by the equations they know so well.
2. The ten Apple III computers were donated by Apple Computer.
3. Mary Briggs and I continued to work with a variety of children whom we selected over a period of five years.
5. Arthur Ganson, a kinetic sculptor, designed the materials and the tools with which children had built the big gears.
6. Rush, quizzing her own, distinguishes between one kind of focus: where "both of them [the gears] are going at the same speed ... you can't make this one go faster because each one goes in line that ..." this is in contrast to "how fast it's going around ... how long it takes for this one to go around"; that is, she is describing in terms of elements and relations of the gears that she can directly see and feel, the concrete embodiment of principles that in physics terms would be called "linear versus velocity."
7. Music-Logo, developed by Bamberger with the help of others in Paper's lab, has the computer language, Logo, as its base, adding primitives that "talk" to a music synthesizer. Music-Logo thus has all the procedural power of Logo in a dialect of LISP, making it usable for "procedural music composition."
8. All sessions in the lab were videotaped, and many were transcribed for documentation and later study.