Action knowledge and symbolic knowledge. The computer as mediator / Conocimiento basado en la acción y conocimiento simbólico. El equipo informático como

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Abstract
In this paper I address a small set of troublesome but pervasive educational issues that become perhaps surprisingly illuminated as we look at the possible roles for computer technology in classrooms. I begin by stating some of these concerns in rather abrupt fashion. In the remaining sections I expand on these initial concerns, propose some alternatives, and give one extended example of how such alternatives actually look when played out in a rather unusual classroom.
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Introduction

In this paper I address a small set of troublesome but pervasive educational issues that become perhaps surprisingly illuminated as we look at the possible roles for computer technology in classrooms. I begin by stating some of these concerns in rather abrupt fashion. In the remaining sections I illustrate these initial concerns, propose some alternatives, and give one extended example of how such alternatives actually look when played out in a rather unusual classroom.

• To assume that “knowledge” and “information” are equivalent 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 (Vossoughi & Beven 2016)

• 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. (Osberg et al. 2008; Papavlasopoulou, S. et al. 2016)
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• Children are also makers and builders of things. In that context, “grasping” is not a metaphor as in grasping an idea, the truth. For children living in an unstable, unpredictable world in flux, literally grasping, holding, holding still, holding on, is a persistent need (Vossoughi & Bevan 2016)

• 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, uses of the computer for speedy access to vast spaces and quick, efficient, packaged-up, ready-to-go information may be more confounding than useful.

Looking back through the literature for how and where to place these seemingly contemporary issues, I was surprised to find, once again, that Dewey had already been there. I refer in particular to a brief article titled, “The Way Out of Educational Confusion” published originally in 1911 as a pamphlet by the Harvard University Press (Archambault (ed.), 1974, 423-426). Consider, for example, the eerie similarities between Dewey (1911) and an often-quoted comment by Seymour Papert (1980):

There cannot be a problem that is not a problem of something.
(Dewey, 1911/1974);
You cannot think about thinking without thinking about something (Papert, 1980/1993).

More specifically, the work discussed here shares obvious aspects with the current Maker Movement, both harking back to Dewey and his emphasis on ‘learning by doing.’ For instance, Biesta and Burbules say:

Dewey solves this problem by understanding knowledge and learning in terms of action or, more accurately, transaction. (Biesta and Burbules, 2003).

However, there are important differences: The core of the Maker Movement seems well described by the following quote:

Give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking; learning naturally results. (Dewey, J. 1902)

While we are also encouraging students to be “doing” and to be “makers,” our focus is both broader and more specific as compared with the current Maker Movement: We are developing contexts that build on learning as a function of the generative tension between action and symbol: We encourage students to move back and forth between, on one hand, using hands-on action with materials in real
time and space, and on the other, making by creating descriptions/representations that serve as “instructions” in the virtual space of the computer.

**Background: The Laboratory for Making Things**

Our work with young children began in 1985 as a project and a place that we called The Laboratory for Making Things (Bamberger, 1991). It took up residence in the Graham and Parks Alternative Public School in Cambridge, MA. 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 children who are having trouble learning in school. These are children who have the ability to design and build complex systems, who are experts at devising experiments to analyze and test problems confronted on the way, and who can learn by *extracting features and principles* from the successful workings of the things they make. But they are also children who are often described as having trouble working within the discrete spaces of common symbolic expressions--numbers, graphs, simple calculations, written language.
With “knowledge” in schools mostly measured by the student’s ability to work with and understand conventional symbolic expressions, it is not surprising that attention focuses on what these children cannot do. Instead of seeing them as virtuosos, they are seen as “failing to learn.” Thus, my primary question was this: If we could better understand the nature of the knowledge that the children were bringing to what they do so effectively, could we help them use this knowledge to succeed in the classroom as well? ¹

Getting Started

Work at the Graham and Parks School began in the fall of 1985. Susan Jo Russell, who had been a classroom teacher and was now completing her PhD in technology and education, joined me in starting the project. The school, in a working class neighborhood of Cambridge, MA, is named after Sondra 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 ‘60’s. The core of the student population mirrored the diverse

¹ There is a clear relationship between what I am calling “action knowledge” in contrast to “symbolic knowledge” and Ryle’s “knowing how” and “knowing that.” (Ryle, 1949)
population of Cambridge, and in addition included most of the Haitian Creole speaking children in the city.

We began with the teachers. All the teachers in the school (grades K-8) were sent an invitation to join the project. We described it as an opportunity to think together about children’s learning through sharing puzzles and insights from the classroom. Twelve teachers signed up, with a core group of eight becoming regular participants. We had expected the initial planning period to last perhaps two months, but the teachers felt ready to bring children to the Lab only after we had worked together for close to six months. As it turned out, those six months were critical in shaping the form that the Lab took.

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 buzzers for building simple circuitry, foam core, wood and glue for model house construction, as well as drums and keyboards for making music. And the ten Apple IIe computers took their place as another medium for building structures that worked and that made sense—what we came to
call “working systems.”² The children re-named the room, the “Design Lab.” Some 250 children ranging in age from 6 to 14 participated in Lab activities over a period of about four years.

It was a month into working with the teachers that the Apple computers arrived. Unpacking and putting them together was a necessary first step toward helping the teachers gain a feeling of intimacy with the machines. Learning the computer language Logo, was a further step towards this sense of intimacy, and it had a surprising spin-off: Perhaps because the computer was still a totally new medium in 1985, the teachers shed their initial fears and became fascinated, instead, with their own and one another’s confusions around their interactions with the machine. Probing their confusions came to be seen as a source of insight: What was the basis of the confusion and how could you find out?

This new productive source for inquiry had another unexpected spin-off: Stories from the classroom turned to children’s confusions and how to understand them: Making the assumption that no matter what a child said or did, it was making sense to her, the question was,

² The 10 Apple IIE computers were donated by Apple Computer.
How could we find the sense she was making? As one teacher, Mary Briggs, put it, “I hear a child saying this really weird thing, but if only I could look out from where that child is looking, it would make perfect sense.”

Watching the children at work, we often saw learning going on that grew out of the children’s easy moves between hands-on and computer-based thinking and making. While the learning was often elusive, it suggested a possible general design for children’s future projects that would both encourage and perhaps make more explicit the learning that we had begun to see happening in the Lab.
Learning from the children, our goal became to provide an environment in which making occurred in a variety of media (Lego™ cars, geometric blocks, huge cardboard gears, pulleys, foam core houses, drums (for playing rhythms)), along with using the Apple computers as a platform for construction (graphics, music, quiz programs, puzzles). We would design projects that differed in the kinds of objects/materials used, that utilized differing sensory modalities, that held the potential for differing modes of description, but that shared conceptual underpinnings (Bamberger 1991/1995).

In designing this environment, we were, in fact, drawing on what we found to be the effective learning strategies that we saw the children bringing 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. Dewey again:

*It is possible to find problems and projects that come within the scope and capacities of the experience of the learner and which have a sufficiently long span so that they raise new questions, introduce new and related undertakings, and create a demand for fresh knowledge....* Noting the bearing and function of things acquired...has the advantage of being of the kind followed in study and learning outside of school walls
where data and principles do not offer themselves in isolated segments with labels already affixed (Dewey, 1911/1974, 423).

A cluster of interrelated questions also emerged. We asked: How do children (or any of us) learn to turn continuously moving, organized actions----clapping a rhythm, bouncing a ball, circling gears----into static, discrete, symbolic descriptions that are meant to represent our experience of these objects and our sensory/action mastery of them? How do we learn to make descriptions that hold still to be looked at “out there”? And why is this important?

Osberg et al., make the relevant point when they argue that “knowledge” in school is commonly measured and is recognized when it becomes “accurate representation.” In this way, knowledge, by implication, is no longer accepted when embodied in action but only when it becomes “spatial.”

…it can be argued that schooling is organized around a representational epistemology: one which holds that knowledge is an accurate representation of something that is separate from knowledge itself. Since the object of knowledge is assumed to exist
separately from the knowledge itself, this epistemology can also be considered “spatial” (Osberg et al, 2008, 213)

In the Lab, the computer played a role as mediator in addressing these questions as Papert (1980) sees it, the computer is a “transitional object.” While the computer was used as another medium for designing and building working systems, there are stunning differences in its use and function. Indeed, the differences create a potentially generative tension between making things with hands-on materials and making things with the computer.

For example, in the hands-on situation, makers begin with action and rarely, if at all, make verbal or written descriptions of what they know how to do. In the computer situation, makers must begin by describing what they want to happen in a symbolic programming language. Once made, the description is meant to become what they have described—symbol becomes digitized object/action!!

Also by contrast, descriptions written on paper remain static. The individual reading the description must put its described pieces together and often needs to ask, “Did I get it right?” In this regard the computer has a unique capability: You are not left in doubt;
descriptions sent to the computer, immediately *turn into the things or actions described* by the programming language.

But sometimes the computer becomes a strangely reflecting playground as the programmed instructions produce provocative surprises. And these are the critical moments of learning. You ask yourself, “Wow, I wonder why that happened?” “What does that tell me about how I’m understanding the problem?” “How do I probe this puzzlement?”

The children needed time to notice and to play with these surprises. Rather than turning away as if they had failed, they made experiments to interrogate what had happened----much as they knew how to do in fixing their bikes or the Lego cars they made in the Lab.

But the computer experiments had a special quality: Because descriptions became actions (virtual), the relationship between symbol and action could be tested. Indeed, chasing surprises, tracing the paths that led to them, turned out to be a very productive way for the children to explore *their own* understandings and confusions. Much as it had been with the teachers during the six months before the children joined in, interrogating their confusions was often the a
critical and exciting step towards insight. Strange encounters of a special kind.

Thus, rather than joining hand-made and computer-made systems to construct a *single working system* (such as using the computer to control a Lego robot), we urged the children to pay attention to *differences in the kinds of things* that inhabited these two worlds. How did the differences between these design worlds influence what they thought of to think about; what was different in the kinds of problems, confusions, and puzzles they encountered as they moved from the familiar hands-on, real time/space world to the virtual computer world? Confronting the potential tension generated by these differences rather than avoiding them, turned out also to be important in helping the children move more effectively between their “smart hands” and the symbolic text-oriented school world.

Working in the Lab, the children also noticed and helped us notice moments, often caught on-the-fly, when the moves back and forth----between action in real time/space and virtual action in computer space----revealed surprising *similarities*. And, as we had hoped, the seeing of similarities (“Hey, that reminds me of what we did....”) often led to the emergence of a *shared powerful principle* that was
previously hidden. As I will show, capturing these insights and the discussions that led to them, produced some of the most significant learning for both the children and the teacher-researchers.

**Emerging Ideas**

The back-and-forth movement between materials, sensory modalities, and modes of description resulted in certain kinds of ideas becoming part of the Lab culture, illuminating the children’s designing, building, and understanding across all the media. Three of these ideas were particularly present:

1. The notion of a “procedure” which initially developed in their computer designing but was found useful in designing hand-made systems, as well.

2. The sense that it is useful and interesting to look for “patterns” which germinated in hand-made designing but seeped into computer designing.

3. Closely related to both of the above, the idea of grouping or “chunking” and their boundaries.

   Chunking initially grew out of a specific need in working with the continuousness of music. But its usefulness crept into designing with other materials, as well. Issues around “chunking” became
surprisingly evident in children’s often heard, but rather unexpected question. As one student examined another student’s many-pieced construction, we would hear him or her ask, “But what’s a THING, here?”

A Day in the Life of the Design Lab

Once a week after school we worked for two hours in the Lab with six, 9-and 10-year old children. I worked together with Mary Briggs, the special education teacher in the school. Mary had selected the six children that she believed would particularly thrive in the Design Lab environment. She knew the children well, as she worked with each of them on a daily basis.

For me it came as a kind of revelation to realize how hard it is to really make contact with a child, to become intimate with his or her thinking so as to learn from it—especially a child for whom life in school has not been especially rewarding. 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, doing it every single day, not just once a week for an afternoon. Working with Mary and the children was an
intense learning experience--learning that has influenced most everything I have done since.

Gears and Rhythm

Working in the Logo Lab (a section of the Artificial Intelligence Lab) at MIT directed by Seymour Papert, I had designed, with the help of others, a music version of the programming language Logo. It was called MusicLogo and, along with Logo was up and running in the Design Lab for the children to use. While Logo was commonly used for programming graphics, with MusicLogo available, the children could work in multiple media----sometimes doing graphics, sometimes doing music. The idea was much as in working with hands-on design projects: by moving across media and sensory modalities but keeping the underlying means of procedural designing as a constant present, shared principles could seep out. Thus, shaping actions and objects in quite different media could be seen as sharing structural design.

For example, the same computer procedure and the principles behind it (particularly recursion) were used to print a “count-down” (10-9-8-
7....), to make a synthesizer drum play a faster and faster beat, and to make a synthesizer clarinet play a descending scale:²

```
A COUNTDOWN
TO COUNTDOWN :START :DONE
IF :START = :DONE STOP
PRINT :START
COUNTDOWN :START – 1 :DONE
END

COUNTDOWN 12 1
12
11
10
9
8
7
6
5
4
3
2
1

A FASTER BEAT
TO FASTER :START :DONE
IF :START = :DONE STOP
BOOM :START
FASTER :START – 1 :DONE
END
```

² In the procedures that follow, the colon symbol (called “dots”) indicates a variable as input.
FASTER 12 1

Figure 2: A Faster Beat

A DESCENDING SCALE

TO DOWNPITCH :START :DONE
IF :START = :DONE STOP
PLAY :START – 1 :DONE
DOWNPITCH :START – 1
END
DOWNPITCH 12 1

Figure 3: A descending Scale

The Gears

Gears also played an important role in the Lab as a means for helping children see and feel shared principles across media and sensory modalities—e.g., kinds of fast and slow, a counting unit, periodicity.

As Seymour Papert has pointed out:
The gear, as well as connecting with the formal knowledge of mathematics, it also connects with the “body knowledge”, the sensorimotor schemata 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. (Papert, 1980, viii)

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

On this particular Wednesday afternoon we moved through several activities----from drumming, to walking, to playing with very large, cardboard gears, to clapping, and eventually to “telling” the computer how to “play” drum patterns using MusicLogo. The gears were designed by Arthur Ganson and built by a group of slightly older children.³⁵

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³⁵ Arthur Ganson, a kinetic sculptor, designed both the materials and the tools with which children had built the cardboard gears.
³ For more on the children’s drumming and walking together, see Bamberger, 2013 (208-224).
Mary asked the children as we moved over to the gears (see Figure 4), “Now how could these gears the walking, and the drumming we did sort of be alike?”

*Figure 4: Meshed gears*

Rachel is standing by the gears, her hands actually *being* the gears as she talks. (see Figure 5). As she turns the gears, watching them go around, she spontaneously makes a proposal.

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4 For more on the children’s drumming and walking together, see Bamberger, 2013 208-224.
Figure 5: Rachel and the gears
Rachel: Oh, it’s a math problem: Like this one has *(counting teeth on the smaller gear)* 1 2 3 4 5 6 7 8 --- And you bring the 8 around 4 times to get it [the bigger gear] all the way around once. Now how many teeth does that one [bigger gear] have?

Rosa: 24

Rachel: 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.

Steve: The smaller one.

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

Mary (to Steve): You say the smaller one?

Steve: Yah, the smaller one is going around 4 times and it’s fastest.

Mary: But Rachel said same speed.

Rachel: 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, I don’t know, what do you think?

Rachel: What kind of fastness do you mean?

Mary: What are the choices?

Rachel: Like for one kind of fastest you could say...like you could go...like *(pointing to meshing of teeth)* how each teeth goes in like
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that, ya know? And one kind of fastest you could say how long it takes for this one to go around.

Mary:    Hmm. So if you say it’s the kind of fastness with the teeth?
Steve:   The smaller one.
Rachel:  No, they both are going the same speed.
Mary:    O.K. And what about if you say which goes around the fastest?
Rachel:  The smallest one.

Clapping the Gears

At this moment, Arthur Ganson, who was also working with the children that day, sees a connection

Arthur:  So what is the rhythm of those gears?
Mary:    The rhythm of that gear? Someone want to play it?
Arthur:  Yah, how about playing it?
Steve:   I’ll play it. [He turns the gears around as if making them “play.”]
Jeanne:  Yah, how would you play that rhythm?

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5Arthur Ganson, a kinetic sculptor, designed both the materials and the tools with which children had built the cardboard gears.
Leah: Like this...hmmm

Figure 6: Leah taps the gear rhythm with both hands (4:1)$^6$

| Left Hand: |   |   |   |   | Big gear |
| Right Hand: |   |   |   |   | Small gear |

Figure 7: Clapping 4:1$^6$

Jeanne: Yah. Which is the small gear?

Leah: The one that’s going...[taps with her right hand]

Leah’s hands in clapping, act out the 4:1 relationship of the

$^6$Graphic representations such as this are actually given within the Impromptu software.
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two gears.. That is, each tap of her left hand is the bigger gear going around once; each group of four taps of her right hand is the smaller gear going around four times.

Arthur’s spur-of-the-moment question neatly brought together the seemingly disparate materials, modalities, and means of description with which the children had been working: Leah’s clapping was a kind of metaphor-in-action for the relative motions of the two meshed gears----she had become the gears. For Rachel the motion of the two gears embodied principles of ratio and “kinds of fastness.” And yet, hiding behind each students’ moves from one medium and mode of expression to another were shared principles. Perhaps the most generalizable shared principle was the fundamental idea of a “unit” cumulating to make related “periodicities” -- what the group of children had been calling simply “beats.”

Leah and Rachel were demonstrating what we had hunches from the beginning: Children who are having difficulties learning in school, can learn in profound ways by extracting principles from the successful workings of their built objects and their actions on and
with them. The question still was, as it had been from the beginning, could we help the children make working, functional connections in the tension between what they knew how to do already in action, and the know-about as expressed in more general symbolic form (see also G. Ryle, 1949). Rachel was clearly on the way; Leah was making moves in that direction, but what about the others? Could the computer and MusicLogo enable more students to mediate between action knowledge and symbolic knowledge?

The Computer as Mediator

While Arthur’s specific question and Leah’s response were unplanned events, they had been prepared by our juxtaposing the activities of clapping rhythms and working with the gears. The next activity was definitely planned in advance. It reflected our earlier intention of using the computer as mediator between action and symbol.

The question was: Could the children use the computer as a vehicle for effectively moving between the actions of the gears, their own body actions in clapping/drumming, and now, the numeric-symbolic instructions given to the computer. In short, could they transform the results of their own continuous body actions into discrete, symbolic expressions that would, in turn, become computer procedures for generating virtual sound/actions? This would be a prime example of confronting the tension between action and symbol.
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The new task as I put to the children was: “Can you get the computer synthesizer drums to play what Leah clapped? Except, to begin with, we’ll make it a little easier.” Using two hands as Leah had, I tapped out a simpler 2:1 rhythm. The children all clapped the two-layered rhythm, as well.

![Figure 8: I tapped a 2:1 rhythm](image)

The children had already become familiar with procedural programming and with the meanings of numbers in doing Logo graphics --what we called “teaching the computer.” Now the children would need to give meaning to numbers in this new MusicLogo context. 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 now numbers used as instructions indicating the temporal relations between synthesized drumbeats?

The children were also used to conversations when they got stuck while building; they would explain to one another or to an adult what they were trying to do to get something to work. However, descriptions of such real-time building didn’t usually include
symbolic/numeric expressions even after the act. Thus, compared with what the children were used to would now be reversed: Instead of reflecting back to make descriptions after the fact and after the act, they would need to describe, as instructions to the computer, what they wanted to happen before the act. And instructions must be in the symbolic form of a computer language—i.e., Logo. These were some of the issues as we moved to the computers and to the next task.

*An Example: Laf Invents an Experiment*

MusicLogo could make the synthesizer play two different drum sounds called BOOM and PING. The number of numbers in a list that follows BOOM or PING indicates how many sounds to make in all. The numbers, themselves, determine the “duration” of each event. Or more exactly, the proportional relations of the time from one sound attack to the next.

To help the children get started, I typed the following instructions and we listened (PM is the command for PlayMusic):

```
BOOM [8 8 8 8 8 8 8] PM
```

We heard seven BOOM sounds each with a duration of "8." However, at this point the children still had to discover what "8" meant. I gave another example, saying, "This one will go faster":

```
BOOM [6 6 6 6 6 6 6] PM
```

Jeanne: Now I want to make a still faster one.
Laf: *(who had not participated in the discussion up to now):* But the lower you get the faster it gets.

Jeanne: You answered my question before I asked it.

Leah: Laf’s psychic.

Steph: Do 1 1 1 1 1 1 1

Jeanne: What do ya think will happen?

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

Jeanne types:

```
BOOM [1 1 1 1 1 1] PM
```

And it did "go fast."

I also showed the children how Logo could play BOOM and PING together, each in a separate “voice.”
As the children went to work on their computers, I went around to work with Laf. Laf was a quintessential example of a child for whom to “grasp an idea” was literally a physical experience. All of us seek ways of holding on to a new idea. But for most children, especially those growing up living in an unstable, unpredictable world, grasping, holding still, is a persistent need. Laf’s explorations to find out how numbers could “teach” the computer to play the drums, made that quite clear. And like probably so many times before, I almost missed it.

Laf talked very little; it was in the Lab that we discovered his most notable quality: integrity. Unlike more school-smart children, he would just turn off rather than going through the motions to get a right answer. He needed to understand for himself. However, on this occasion as on so many others in watching a child work, I learned that we adults often need to slow down in order to catch up with another’s thinking.
Sitting down next to Laf, I saw that he was determinedly, slowly, persistently, typing BOOM or PING followed by rows of 1’s and 2’s.
Despite my best intentions I found it difficult to find reason in what Laf was doing. Only later, looking at the video of the whole session, did I realize how wrong I was. Because I was focusing on my task—to make two levels of beats in a 2:1 relationship, I missed the significance of Laf’s work. True to his integrity, Laf had designed an organized experiment to answer questions he had silently put to himself: What is the difference between BOOM and PING and between 1 and 2 in this context? What exactly do these numbers do? And how can I find out? Listening, participating in his own experiment, he confirmed his previous understanding; the contrast between the very fast 1’s and the slower 2’s was eminently hearable.
To further confirm his understanding, Laf, followed the numbers on the screen with his finger, relating his own actions to the computer’s sound and virtual actions. Laf was literally, *physically* grasping the meaning of the 1’s and 2’s. Attentively and patiently, he continued until the whole screen
had been traversed. Looking back, I see this as a first example of
coordinating symbol with sound and action. The numbers stood still, the
beats were sounding/moving, and Laf’s “finger- drumming” was marking
each of them in action as time went along.

Starting with what he knew already (“The lower you get the faster it
gets. . . If you put all 1's it'll go fast”), he tested that knowledge in action.
Perhaps like a scientist working with the puzzling behavior of molecules,
Laf needed to differentiate between two closely related but slightly
different elements (“1” & “2”). And like the scientist, he needed
repetition----a critical sample size of each element repeated over sufficient
time, and in a controlled environment where their differences and
similarities could be clearly perceived as regularities,

Having observed instances of his essential elements behaving over a
sufficiently long time, and having confirmed that the behaviors of “1” and
“2” do not vary between the BOOM context and the PING context, Laf
found that the "joints" where the 1’s and 2’s met produced the revealing
moments.
Figure 12: BOOMs, and PINGS, 1’s and 2’s filling up the screen

Laf was using his available resources to do the work of making meaning. He had invented a way to use the computer and MusicLogo as mediator between the virtual world of symbols and his actions in real-time/space. And in retrospect, he taught me how important it is to be able to slow down and take the time to repeat so as literally to practice grasping meaning.

But there was more. Building on his experiment, Laf now used what he had learned, to make a whole piece of music. Not surprisingly, he named his Logo procedure TO LAF.
Seeing and hearing what Laf had done, Mary gathered the children’s attention:

Mary: Shhhh..Laf is going to play his piece.

Looking very excited, Laf said, "Here we go again" and he typed:

LAF  PM

Laf's procedure filled the Lab as the children listened attentively all the way to the end. The usually quiet Laf looked triumphant and the children clapped in appreciation.


Moving farther towards symbolic representation

The biggest surprise came the next week when the children returned to the Lab the following week. Clearly feeling comfortable enough with the meaning of 1’s and 2’s and perhaps learning from what he had seen and heard the other children doing, Laf went on to make a two-voiced experiment—BOOM in one voice (V 1) and PING in the other voice (V 2). Beginning with the familiar 1’s and 2’s, he surprisingly moved ahead to make a further 1:2 relationship—4:8 (see Figure 14).

Figure 14: BOOMs and PINGs playing together in 1:2 relationships.

Continuing in this way, by the end of the session Laf had gone on to make a table of examples (see Figure 15).
Figure 15: Laf’s table of 2:1 drummings.

We see BOOMS and PINGS playing together consistently in a 2:1 ratio: 8:4, 6:3, 4:2, 10:5. Laf’s first experiment, which had seemed at the time a rather mindless activity, turns out to have been a playground for gathering, grasping, mulling over and finally developing and giving meaning to a whole symbolic table of shared
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2:1 drumming ratios. As further evidence of the importance Laf gives to time passing, notice that with each pair, the PINGS, which go twice as fast as the BOOMS, also have *twice as many* iterations as the BOOMS. Thus, each pair of BOOMS and PINGS will come out together ----equal in total time. The computer literally becomes a mediator helping to integrate symbol, sound, and action. Through building his interactive experiment, his repeated runs of 1’s and 2’s, Laf built himself a powerful idea. Following his quiet, steady work patiently, we see one child’s process of slowly transforming his continuous actions into evolving static images culminating in the invention of a fully developed symbolic representation.

But wait: On the basis of this table, it was easy to assume that in building on and generalizing upon his previous experiments with 1’s and 2’s, Laf had developed the powerful idea of *ratio* But notice the difference between the repeated form of my descriptions (8:4, 6:3...) and Laf’s depictions in his table. Put most simply, I have imposed my representation and attributed it to Laf. And in that process, I have taken away time and action! Laf has carefully marked each action, each iteration in moving through time onto paper space. Each of the numbers in the table reflects an action or a reaction— a BOOM, a PING, Laf’s finger drumming as he follows the computer’s “performance.” My ratio representation, 6:3, 10:5, has obliterated
actual iterations in motion and time, collapsed them into a single symbolic representation—many events have become one (see Figure 16):

![Figure 16: Many actions collapsed into a single symbol.](image)

The table does not actually show Laf grasping the concept of ratio. Rather it is a snapshot of conceptual solidifying in an evolutionary process of learning. We are seeing an on-the-way “abstracting process:” continuous actions and time are extracted, made discrete, held still, gradually transforming into the symbolic expressions that we teach in school.

*Abstraction can be defined as a mental activity by means of which parts of a unit are detached from the whole and separate qualities --color, form, etc.--are experienced in isolation.* (Werner, 234)

. Nevertheless, I will argue that Laf’s insights depend deeply on an environment that exploits the computer in a way that is unique to it: Using the computer as a medium in which a symbol defines itself by becoming what it does. To paraphrase Papert,
Laf used the computer as a “transitional object.” He was on the way to the productive tension between action and symbol yielding the powerful idea of shared ratios.

**Conclusions**

The activities described in these stories are not intended as recommendations to be literally copied—e.g., “a curriculum,” or even “what to do in class tomorrow.” Nor are they intended as a general recommendation for how the computer may be effectively used in classrooms. The stories are meant rather as examples of a context and an approach to learning.

To recapitulate, the approach centers on confronting the potentially generative tension between action and symbol with the computer as mediator. In turn, the stories are meant to encourage educators to design creative means for helping children come to see and value know how and know about in new ways as the means and the children evolve and mingle with one another.

The examples are perhaps most relevant for those children whose personal, powerful know how is failing them in school largely because it has no way of coming in off the street into the classroom. These are the children who often feel that school is
irrelevant and reciprocally are made to perceive themselves as irrelevant, peripheral, in school settings

In sum, I argue that the computer may play a special role as a resource for inquiry and invention when children can work at a *pace* and within a *conceptual space* that feels familiar, that they can grasp, and that thus feels secure. In this environment, instead of poor consumers of other people’s ideas and products, children can potentially become makers of new knowledge of which they can feel proud. And through this empowerment they may also discover strategies for learning how to learn within the school world and beyond.

References


