4 MICROWORLDS: TRANSFORMING EDUCATION [1]

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Looking at how computers are used in education, one is tempted to start classifying. It's a little dangerous to do this, but I would like to start off with a very crude classification of three ways of using computers, just to place a certain set of problems into perspective. First, as tutorials in one sense or another – which is by far the most widespread, best known, and earliest use – where the computer serves as a sort of mechanized instructor. Secondly, as tools for doing something else: as calculators, word processors, simulators, or whatever. And thirdly, a different concept altogether: as microworlds. Here I shall concentrate on the notion of microworld and talk about its relations both to computers and to theories of learning. The other uses of computers surely have a role – but they are not what will revolutionize education.

One microworld which is already widely known is the Logo turtle microworld. Briefly, this world is inhabited by a small object on the screen. In some versions, it is shaped like a triangle, in others, like an actual turtle. To make it move and draw lines, you talk to it by typing commands on the keyboard. For example, if you say FORWARD 50, the turtle will move in the direction it's facing and draw a line 50 units long, 50 "turtle steps" children might say. Then if you say RIGHT 90, it will turn 90 degrees. And then you can tell it to go forward again, or back, turn through any angle, or lift its pen up so it moves without leaving a trace. In principle, you can draw anything – even curves, because you can go forward a little, turn a little, go forward a little, and so on until you get the curve you want. Anything that can be drawn can also be described in this turtle talk, the turtle's coordinate system.

This is a microworld in the sense that it's a little world, a little slice of reality. It's strictly limited, completely defined by the turtle and the ways

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[1] This paper is based on a presentation given 14 March 1984 at the ITT Key Issues Conference held at the Annenberg School of Communications of the University of Southern California.

it can be made to move and draw. But it is rich. Inside this microworld, a child explores by manipulating the turtle: making it draw squares and circles, repeating and rotating designs, whatever the child can imagine. The microworld is created and designed as a safe place for exploring. You can try all sorts of things. You will never get into trouble. You will never feel "stupid." It will never say a rude thing to you; it will never embarrass you; it will never fall to pieces or bite you or give you a low grade. You are totally safe in this little world. And yet while being safe, it is also designed to be discovery-rich in the sense that little nuggets of knowledge have been scattered around in it for you to find.

The question "Now that we have the turtle, what other manipulable computational objects can we create?" led to a theme of ongoing research at MIT and elsewhere. At some future time, complex networks of microworlds that touch on many sectors of knowledge will be the staple diet of learning, and will replace the present concept of "curriculum". It will take some time to develop microworlds fundamentally different from the turtle paradigm. In this paper, I talk only about the example closest to the turtle. This is a world inhabited by objects known as sprites which, in a simple form, have already been implemented in some Logo systems and are already giving rise to a number of new observations about how children learn.

The Sprite world is a kind of turtle world that is novel in several ways. First, it has many turtles – as many as 32 can be conjured up. Then, unlike the classical turtle, sprites don't have any intrinsic shape. You can give them any shape you like. You can make one look like a cat, or an airplane, or a tree, or a flower, or a bird. Finally, perhaps most importantly, they can easily be put in motion. They are dynamic, hence their nickname "sprites."

Sprites are still turtles in that they obey commands in the Logo programming language. But there are also new commands. You might say SETSHAPE :BIRD to one of these sprites, meaning it should look like a bird, and it will say it doesn't know what :BIRD means. You have to say that :BIRD means this shape that you've drawn. So you draw the shape you want and tell it :BIRD means this shape – you can even draw an elephant and call it :BIRD if you want – and now saying SETSHAPE :BIRD will make it take on this shape. You can SETCOLOR :RED or SETCOLOR :GREEN, make it whatever color you like. And there are lots of other things you can do with these sprites as well.

Sprite Logo has the familiar characteristics of the microworld. It's a simplified piece of reality which you can explore, and again there's no right or wrong. In this way, it's like a construction kit, an erector set, mud pies, building with blocks. In all these activities, you can do whatever you want, subject only to the constraints of the laws of the little world you are in. Blocks won't stay up unless they are supported, and mud pies won't fly.

There are limits for each of these slices of reality. And I'm going to suggest that in a very general way, not only in the computer context but probably in all important learning, an essential and central mechanism is to confine yourself to a little piece of reality that is simple enough to understand. It's by looking at little slices of reality at a time that you learn to understand the greater complexities of the whole world, the macroworld.

With these sprites, for example, SETSPEED 20 makes them start moving continuously and steadily at a speed of 20 arbitrarily chosen "units." The first story I want to share with you here is about those speeds – as well as the way that microworlds allow you to learn about things in an entirely new way. On the screen there are a number of objects flying around, say six bright red balls, all at the same speed. When you say SETSPEED 20, they plod along like Sunday drivers. If you say SETSPEED 100, they zoom around really fast. In front of the screen, a little girl of six is typing SETSPEED – which has been abbreviated to S. She says S 4, and they creep across the screen. Then she says S 1, and they go *so* very slowly you can hardly see them moving. Then she says S 0, and they stop. And she says S 10 and they move, and S 0 and they stop. She looks at the screen for a long time and then she jumps up and goes and calls all her friends to come and look.

Now what was she getting excited about? This story is quite poignant for me because I saw this happen and for a while, I didn't see what it was all about. And I might still be wrong but I've become pretty sure what was happening. I think she was excited because she had *discovered zero.* They tell us in school that the Greek mathematicians, Pythagoras and Euclid and others, these incredibly inventive people, didn't know about zero. And it's true, in a certain sense, that zero was discovered quite a bit later by Hindu mathematicians.

I don't know what you imagined when people told you that zero was discovered by Hindu mathematicians. In wracking my memory, I think what I imagined was that they discovered using a little circle for zero. Of course they discovered something much more fundamental, and this girl was in a certain sense repeating that discovery.

You might say it like this: what that girl found exciting was the following paradox: that standing still is *moving.* Standing still is moving with speed zero, and moving with speed zero is standing still. Now she couldn't say that, so I'm not entirely sure what was in her mind, but I think it was something like that.

This understanding of zero is an important scientific principle so subtle that it usually passes us by. We get into a lot of trouble when we're trying to understand laws of physics because we haven't really registered that when we say motion, we should include standing still as a case of motion. In physics, anyway, there's nothing special about standing still. In the end, that's the moral of relativity – and if we understood that, we wouldn't be so upset when we hear about Gallilean frames of reference or relativity and other topics many of you found quite esoteric at school.

Since then, I've watched and set other people to watch for this phenomenon. Of course not every child reacts like that, but a scattering here and there do. Whenever children are exposed to this sort of thing, a certain number of children seem to get caught by discovering zero. Others get excited about other things.

The fact that not every child discovers zero this way reflects an essential property of the learning process. No two people follow the same path of learnings, discoveries, and revelations. You learn in the deepest way when something happens that makes you fall in love with a particular piece of knowledge. For example, I fell in love with that particular incident with that girl. It has played an important role in my thinking and my life since then. But colleagues who think much like I do picked up different incidents. The girl in my story came to think about motion because she was struck by speed zero. Someone else comes to the same understanding through different encounters. What's great about these turtle microworlds is that they are rich in opportunities for discovery of this sort. The protean quality of the computer as an intellectual medium means that every child can find a rich intellectual activity with which to fall in love. It is through such "intellectual love affairs" that people acquire the taste for rigor and creativity.

Another story goes back to the very first experiments that we did with these sprites in the Lamplighter School in Texas.[2] When these computers were introduced, the teachers of the various grade levels decided that each grade would learn certain aspects of this system. They had Logo with sprites and Logo with turtles, and they decided that the first and second grades should not learn to do the SETSPEED stuff.

Now they did have a reason. They weren't just being prejudiced against the children or trying to deny them. Their reason was that when you use SETSPEED, you must give it not only a speed but a direction as well. It's got to go somewhere. In fancier science talk, we would say that velocity is a "vector quantity" having both magnitude and direction. The way we give direction in Logo is to say SETHEADING 270 to go west,

[2] Descriptions of this and several other children's differing responses to and interactions with sprites and Logo can be found in Chapter 3 of Turkle, 1984.

and SETHEADING 90 to go east (or left and right on the screen). The teachers figured that numbers like 270 are so outside the ken of the younger children that there's no point in introducing them to this double confusion of learning about degrees and angles. Actually, there are many ways the teachers could have gotten around that problem. For example, they could have reprogrammed Logo (which is a flexible language) to allow commands like FACE NORTH, FACE EAST, etc. But we didn't interfere, and it's just as well we didn't because the children had some very interesting learning experiences.

So the younger children were shown how to work with the sprites in a static way. They could change the sprites' shapes and put them in different positions to make pleasing tableaux on the screen. It was fun and they were learning a lot, there's no question about that, but it was a very unstable situation. Soon the younger children saw the sprites moving on the older children's screens and began to ask them: "How do you do that?" The first few times they asked, they didn't get enough of an answer to be able to do anything with it. But one day, as the older children became more confident and articulate, and as the younger ones also become more understanding about the whole system, a threshold was crossed where it was now possible for one second grader to bring back just enough knowledge about dynamics so that his classmates could work with it.

One cannot say that the second grader fully understood the concept of angle, or the use of such numbers as 270. He came away from his conversation with something more important than the educator's mythical concept of "full understanding." What he acquired instead was a fragment of knowledge that enabled him to work on gaining a deeper and deeper understanding. He came over to the investigator in the middle of the next day with an air of having gotten at some subversive, taboo knowledge – I think this subversive aspect is a very important part of learning – and he was saying, very proudly too, that he's got the great idea, he understands what it's all about. He put it in a marvelous way, assimilating it to ideas he understood well. He said, "I got it. Numbers are secret codes for directions." He explained that they didn't yet know the code, "but we're working on it."

In fact, there were fourteen of them working on this code, and what was exciting about it was that yes, they didn't know what 270 meant, and yes, they didn't know what degrees meant, but they did know that they could bring this into a conceptual frame that they understood very well: codes. And so by bringing it into codes, they could work on it. A few weeks later, they were doing pretty well – and a few months later, they had objects flying all over the screen under perfect control, they knew about 270 degrees, they knew about degrees and angles and these big numbers, and they knew all sorts of things because they had broken this code.

There are a number of important points I'd like to emphasize here. For one, I'm not sure that I understand what to do about the subversive angle.[3] It raises questions like, "Suppose we hadn't made certain knowledge taboo. Would these children have been less well off? Should we deny children access to knowledge so that they can fight for it?" I think obviously not. That wouldn't be acceptable in any moral standard that I would believe in. Fortunately, we don't have to. There is plenty of room for subversion created by an essential conflict in the socialization process itself – between the children's wanting to do it their way and the society, the culture, imposing something that goes against that. There's a sense of taboo and conflict and subversion going on all the time in growing up. Growing up *is* a subversive activity. So perhaps we don't have to worry about providing special conditions for subversiveness; it's always there – whether we like it or not, and whether we see it or not.

The second point is that again, like the child who discovered zero, this second-grader did something self-motivated. For whatever reason, this child decided, "I want to understand that," and he had enough sportive entrepreneurship to go out and pursue it. In other words, he took charge of his own learning process. These microworlds ought to make it possible and easier to do that. I think that's perhaps the most important aspect of them: that they create better and richer conditions for children – and for others, grown-ups as well – to take charge of their own learning.

Now, finally, I'd like to mention a concept that I've been concerned about, almost preoccupied with, in my theoretical thinking in the last little while. That's a concept that I'm calling fractured knowledge, broken knowledge, although I may devise a better name for it at some time.

There's a model in the education world of how one communicates knowledge. The teacher knows how to do the long division algorithm – a piece of knowledge to be communicated to the child as a whole package. Well, that might or might not work sometimes, but it goes wrong in ways that you could very easily and obviously describe as: "It gets broken in transmission." The teacher might be trying and the child might be trying too, but maybe the child didn't hear a little, or maybe couldn't understand it, or didn't want to, or didn't have some prerequisite. What comes across is fractured knowledge, not the whole piece but a broken piece. And I think one central epistemological question in the theory of learning becomes: Un-

[3] The idea that subversive or revolutionary energy fuels learning has been brilliantly developed by the Brazilian Paolo Freire in *Pedagogy of the Oppressed*.

der what conditions and by what processes can fractured knowledge be repaired? How can it be built up? From the fractured pieces, how do you get back to some whole – not necessarily the same whole that was being contemplated by the transmitter?

In the case of the second grader and the knowledge about the sprites' directionality, you see very clearly that those fourteen children working at cracking this code each had little pieces of knowledge. They managed to put them together because they were in a situation where, first of all, they could communicate and, secondly, they could experiment. Having the computer meant they could try out ideas with it and get objective results – as opposed to a situation where they could only think about it inside their heads, unable to externalize those ideas and see the results. So the computer plays a powerful role in enabling you to put fractured knowledge together to produce whole knowledge.

The story of the stolen knowledge about motion depends essentially on the fact that both the older and younger children were working with the same material – the turtles or sprites. This goes directly counter to the view of educational curriculum theory where you try very hard to chop everything up and say, "This is for first grade, this is for second, this is for third," and so on – where you do each thing at the proper set time, and very little belongs to more than one grade.

In contrast, the turtle microworld (and Logo generally) was deliberately designed to be interesting to people at different stages of development. Pre-school children can do interesting things with Logo because it's very easy to start moving the turtle around. Yet adults (including high school and college students) can also get into it and exercise some very complex, subtle, sophisticated issues of both programming and geometry. Now, of course, they're doing different things with it, but there *is* a continuity. In our story about the moving sprites, this continuity played an important role: the younger children saw the older ones doing something more complicated with the same system that they were using. Because it *was* the same system, they could communicate and exchange knowledge about ways of looking at the system. This aspect of microworlds is an essential one: that you can explore one when you're five – and then again when you're six or fifteen, or continually at all ages, doing more complex operations and projects as you go along, yet with a single, continuous entity.

These concepts I've been discussing – of fractured knowledge and exploration and discovery, of falling in love with something you discover, of having the opportunity to pursue the things that capture your imagination – these are features which I think are quite essential to the way we should think of the forms in education. The microworld concept gives us a way of doing that which is particularly powerful in relation to all of these –

and especially that last goal of having something that is not age- or level-dependent. Like reality, you can manipulate it at different ages.

The kind of learning I associate with artificially created microworlds occurs very typically in natural settings. A particularly clear example is the acquisition of a spoken language like English. Babies learn English by creating a "mini-microworld" of baby talk in which they manipulate pieces of the larger whole in order to master them. Yet nowhere in the world is a language restricted to baby talk. The child continues to be immersed in the same language that poets and philosophers find a suitable instrument for their sophisticated purposes. Language is a model of something that spreads across the entire spectrum of ages and levels – personality types, too, for that matter and maybe cultural types as well – to be picked up by different individuals, each in an individual way.

In bringing the computer into the education system, the microworld is the richest concept that we have to work with, and it should be used as the central one. My concept of how to create a curriculum (and by this word I mean a coherent set of materials to aid learning through the whole school period – and before and after, as well) is to create a network of microworlds, each one focusing on different areas of knowledge.

The two I've mentioned are mainly geometric microworlds, although these sprites do overlap with extremely important ideas in physics – in particular, ideas about motion that are especially hard for the beginning student to assimilate. In physics, dynamics is traditionally taught after statics, even though this is obviously perverse. In the history of physics, it's clear that dynamics provides the fundamental driving force: the fundamental ideas about how things move. The notion of force is linked to acceleration and to the motion of objects. Nevertheless, statics is taught first and the idea of force is then introduced, one might say grafted onto statics, in a very confused and confusing way.

There are obvious reasons for this. Again, it's not because the teachers are confused, but because they don't have a satisfactory way of teaching young students how to work with motion. The only ways we've had to work with motion up to now have been rather disconnected from each other. There's the totally intuitive way where you can throw things and catch them and run and move – and you've got a lot of intuitive knowledge of this sort, but it's not formalized at all. (It's also restricted by the influence of gravity and friction.) The only time you formalize it satisfactorily is when you get into calculus – and to get into calculus, you have to take this long complicated path through arithmetic and algebra and so on, so you're probably not going to get there very well.

On the other hand, these children of five and six and seven who are writing little programs to control motion on the screen *are* working with motion in a formal way. If you look more closely at what's happening, they are using representations of numbers – vectors, directions and speed – and an equivalent of differential equations, in order to manipulate the sprites. In other words, they are able to play with motion in this and other microworlds in ways that have only been possible with static forces in the past. So this microworld is not just mathematical, it's physics as well. It allows children to develop both intuitive *and* formal experience with motion in an integrated way.

I'd like to make a distinction here between microworlds and simulations. To made the distinction, I'll describe another way we can work with motion – and that's to create a kind of turtle called a "dynaturtle" which simulates the behavior of a Newtonian object.

Imagine a ball rolling upwards on the computer screen as if it were moving out in space, and you hit it from the side. Where is it going to go? Children think it's going to move sideways – at a right angle to its original movement. My colleague Andrea diSessa has shown that MIT undergraduates have markedly similar intuitions, even though they were selected by the MIT Admissions process for being super-science stars at school. These students don't actually think the ball will go sideways. They know better. But if you bury the problem ever so slightly in a more complex situation, their more deep-seated intuitive ideas about motion take over – and they *do* predict the equivalent of moving sideways. That is, the addition of vectors is something they learned formally, but did not really absorb into their intuitive thinking about physics.

One way to improve the situation is to make dynaturtles and give children and other learners these worlds to play with. They will become familiar with all sorts of problems and situations using Newtonian objects and, by exploring these worlds, will learn the fundamental laws of dynamics in an intuitive as well as a formal way. We have seen this happen to some extent in experiments conducted by diSessa and by Barbara White.[4] Dynaturtles and similar worlds allow children to discern things that advanced students have trouble understanding.

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[4] This work has been reported in the following articles: Andrea diSessa, "Unlearning Aristotelian Physics: A Study of Knowledge-Based Learning," *Cognitive Science*, Vol. 6, 1982, pp. 37-75; Barbara Y. White, "Designing Computer Games to Facilitate Learning," Ph.D. thesis, Department of Electrical Engineering and Computer Science, MIT, January 1981; Barbara Y. White, "Designing Computer Games to Help Physics Students Understand Newton's Laws of Motion," in *Cognition and Instruction*, Vol. 1, January 1984.

And that's what I would call a simulation. It is a microworld inhabited by dynaturtles, but it's a special kind of microworld, one that tries to copy a certain part of reality thought to be important in science. However, there's another approach which I think is more fundamental in the long run, something that's really going to turn around the learning of physics. This one takes a slightly more distanced approach to what we want children to learn.

The problem with learning dynamics in physics is not so much the particular laws of physics that we're teaching these children. It's that they're not really used to thinking about motion at all. So, let's build some microworlds where objects move in a lawful way, but with simple laws of motion rather than those of Newtonian physics.

The Sprite world is like that. You can make the sprites move in all sorts of ways. They can bounce off each other, pass through one another, move in different directions and speeds, make kaleidoscopic patterns, and even play Follow-the-Leader. You can make them explode from the center – just like in the Big Bang – and then reverse their speeds (from SETSPEED 25 to SETSPEED -25) so they retrace their paths. Exploring this simpler context gives you a clear grasp of the *idea* of laws of motion, and a framework for learning Newtonian ones.

A microworld like this gives you an entirely new kind of object – a transitional object between the ones that you can touch and push (like tables and wooden blocks) and the kind of objects that you know in science, in philosophy, and in mathematics. Science is full of stuff like electrons, genes, and quasars. Mathematics is full of the square root of minus one, or even the number 562.

These are not things you can really touch. Many children and older students have quite a lot of trouble when they first run across objects like these. What are they like – these created, formal, theoretical objects? A sprite is something you can touch; it's there, it's an object. It has a color and a movement. You can give it a shape and you can change its shape. You can do something to it and it will change and it will act. So, in some ways, it's like these things we work with in the real world, and in some ways, it's like those abstract things. It's a transitional object that helps you manipulate the abstract ones. This ability to create transitional objects gives us a way of closing the gap between intuitive and formal learning.

The more I worked with microworlds and came to recognize their importance in the computer context, the more intrigued I became with pre-computer microworlds and the role that microworlds generally hold in the theory of learning. I gradually began to understand that the microworld concept leads to a different way of thinking about much that is in Piaget and in other developmental theorists as well.

Looking at the important moments in Piaget's life, one was his book with Szeminska on the child's concept of number.[5] This was a turning point. Until then, he'd been studying the child's concept of dreams and play and language. The book on number started a new phase where he was going to study speed, spontaneous geometry, physics, and the child's concepts of all the important areas of knowledge.

The remarkable thing about that book is how little of it is directly about number. One would think that a book on number and how children learn it would be full of how you add 3 and 5, and of learning the properties of number as they are taught in school for example. There's hardly any of that. What *is* in the book is something very different.

Piaget says that behind number there are three structures, or *groupements* – groupings. There's the structure of things being ordered: if you don't have a firm grasp of the concept of ordering things, you can't begin to understand number. There's a concept of combining formal objects: you can take two numbers and put them together. But it's not really that 3 plus 4 makes 7 that's important, it's just the *idea* of taking two things and putting them together. And there's a concept of nearness: what's near and what's far, qualitative topology: objects arranged in a line are successively farther from one another. So are numbers.

You can think of these concepts in several ways. You might say, "Well, it's obvious that you can't have a notion of number without having mastered these concepts that are clearly its precursors." Ordering, for example. If you don't have the idea of one thing following another in a certain order, it's very difficult to get to number. And, in fact, you find this with four-year-old children. If you ask them to count four objects, they might point and say, "One, two, three, four, five, six," taking them in any old order and repeating them. For the four-year-old, there's no difference between doing that and what you do when you count them in this orderly way. So the idea of order and sequence has to be acquired.

The idea of microworld gives another way of thinking about the relationship between Piaget's structures and number. One can see ordering as a microworld created by the child. A set of situations – those involving order – come to be perceived as having a commonality, as being of one kind.

[5] Jean Piaget and Alina Szeminska, *La Genese du Nombre Chez l'Enfant*, Delachaux & Niestle, 1941. English translations in 1961, 1964, 1965: *The Child's Conception of Number.*

At certain periods of life, the child becomes fascinated with a certain kind of relationship – like comparing things, or lining them up, or putting one in front of the other.

This is a microworld in the same sense I was talking about earlier. If you look carefully at what Piaget is saying about the acquisition, it's as if the child is giving itself advice about how to learn about number: "Don't try and learn such a complex thing. Instead, concentrate on one aspect, on one substructure: say order. And when you have mastered that, concentrate on something else." In other words, the child imposes a certain microworld structure on the world by saying, "I'm going to look only at a small piece of it. And I'm going to master that small piece, even if it's only a partial mastery."[6]

One of our students at MIT, Robert Lawler, wrote a Ph.D. thesis[7] years ago based on his observation of a six-year-old child. Over a period of six months, he observed this child almost continuously, never missing as much as a half hour. He devoted himself essentially full-time to observing the intellectual development of this child, who, in fact, considered herself to be a collaborator in the project and was also engaged full-time in trying to reveal what she was doing. The fact that the subject was a collaborator might have deformed the experiment, but I don't think so. He discovered something very interesting in relation to the idea of microworlds and presents it in his book *Computer Experience and Cognitive Development.*

When people study the learning process, they usually study a hundred children for several hours each, and Lawler showed very conclusively what you might have known anyway, that you lose a lot of very important information that way. By being around all the time, he saw things with this child that he certainly would never have caught from occasional samplings in the laboratory. I think Lawler's methods are sure to become a paradigm for how to do this kind of research, and indeed, many people are already using this approach, particularly in the area of language acquisition.

What Lawler discovered about microworlds is well illustrated by one example. During this period, the subject figured out how to add multi-digit

[6] Curiously, this striving to master one small piece sometimes seems to undo one's mastery of another piece. In English, for example, when children start acquiring the "rule" of *stem*-plus-*ed* for past tenses, they suddenly start saying things like "bringed" and "goed," even though they had previously used "brought" and "went." Correct usage of the irregular forms does return – though it may take several months and each exception to the rule comes back individually. This phenomenon has been frequently described. See, for example, Miller & Ervin, 1964.

[7] Lawler, 1979.

numbers. A year later, she had gotten mixed up and confused on the rules, but that's not really important. What I'd like to recount to you is *how* Miriam started adding numbers.

First of all, Lawler found by watching Miriam in detail that when she added numbers, she used very different procedures. He describes these as "thinking about different microworlds." If she had to add three and four, she would use her fingers. She would say, "One, two, three, four," and then "One, two, three, four – five, six, seven." She did it in an obvious sort of way, using her fingers, but she would only do that for small numbers. The second number especially had to be pretty small.

With certain other numbers, she used different microworlds. For example, she had a money microworld where she knew about quarters and dimes and nickels. So she knew that 25 and 25 made 50, and that 4 times 25 made 100; she knew that 25 and 5 made 30, that 10 and 10 and 5 made 25, several things like that.

So she had a pocket of knowledge about what you can do with your fingers, and a pocket of knowledge about what you can do with money facts. These little pockets are probably shared by almost all young children in some form or another, but Miriam had a third one because she had been exposed to turtle geometry: a turtle angle world. She knew, for example, this exotic fact that 90 plus 90 makes 180. Not, as you might suppose, because 9 plus 9 makes 18, which she didn't know. She couldn't add 9 and 9 to get 18 because it's too big for the fingers, it's too far from the money numbers, and she'd never thought of 18 as one-tenth of 180 (who would?), and so she didn't know that piece. Nevertheless, she knew that 90 plus 90 makes 180, and 180 plus 180 makes 360, and several other facts in that world too. The turtle angles were important to her, so she had explored their properties pretty thoroughly.

But the essence that I'd like to emphasize here is how each of these little worlds, of money and fingers and turtles, gave her some fractured knowledge, pieces of knowledge that correspond to these pieces of reality. Like Piaget's structures or *groupements*, these little worlds give pieces of number, and what happened to Miriam during this period while she was being observed was *not* that she discovered these worlds, for she had already acquired them. Instead, it occurred to her for the first time that she could put them together. She began deliberately combining them, trying to refer backward and forward between the worlds to solve a problem. So she would say "25 and 28, that's 50," and then counting on her fingers, "26, 27, 28, 53." She became quite expert for a while at adding, but then as I mentioned she deteriorated again, maybe because she became too ambitious and tried to do things outside of what she could handle.[8]

Piaget's epistemological thesis is a somewhat different version of the idea that the way to solve a problem is to split the difficulties, to subdivide the problem. An old heuristic idea: if you want to do something complex, take the parts separately. This is an aspect of Piaget's thinking that hasn't penetrated in its full impact – and can be restated as a microworld thesis in this sense. But the child isn't creating microworlds in order to solve a problem. It's not subdividing a problem, it's subdividing the world. So it's a somewhat different view of the same kind of principle, that something in the child's innate capacity allows this subdivision of the world into microworlds, that these microworlds are elaborated and then put together. The process of putting them together is probably easier to understand than the making of them in the first place.

The point about these stories is that what we are doing in creating microworlds for the computer is not new. Microworlds have always played a role in children's learning. Some are deliberately made; for example, the worlds of blocks and construction kits. One might say each of those *groupements* is a microworld constructed partly by the child, and partly by the culture. The culture's role is seen in the kind of objects the child has and the kind of language that the child picks up. "Bigger than/smaller than" draws attention to the idea of putting things in order. So the language and the kind of objects available make certain microworlds easy to pick up – although ultimately these microworlds are self-constructed in the head by each child.

What's new about the computer in this regard is twofold. First of all, the possibilities of microworlds that can be made for the computer are vast, beyond anything that one could do with any other material. So the computer has opened up a new technology of being able to do things that are not so different in themselves – but in terms of how much you can do with it, it's just a different ballpark altogether. That's quantitatively.

Qualitatively, it becomes possible to make specific kinds of microworlds with the computer that couldn't be made before, and these new microworlds correspond to certain gaps in the natural learning process. To return to Piaget, I think that one can be most respectful to him by pointing out some respects in which he was wrong in a literal sense, specifically in his identification of the formal stage as something that necessarily comes later, at ages like 11 and 12 rather than five or six or seven when you have the so-called concrete operations.

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[8] Such a deterioration appeared in the performance of another subject, as reported in Lawler et al., 1986, but not in the case to which Papert refers here. *Editor's Note, RWL.*

For Piaget, what makes up the formal stage is really symbol manipulations. Propositions that refer to propositions. Thinking that refers not to a concrete reality but to a representation of the reality and to all the possible situations that could arise under given real constraints. For people who don't know what the formal stage is, there isn't time to define it here. For those who do, I'd like to suggest that in defining the formal stage, Piaget pointed almost uncannily to exactly those things that you can do best with a computer. One might say that the formal stage arrived so late precisely because there were no computers. Take the one aspect of manipulating symbols. You can readily manipulate blocks or the technology of wood, but until now, you could only manipulate symbols by doing it in your head, or with the very abstracted means of pencil and paper. We didn't have any good way of externalizing the manipulation of symbols (and still don't except for the computer), and certainly no way that's accessible to very young children.

So there are certain microworlds we can create with the computer that happen to correspond exactly to a big gap that was pointed out by Piaget and others in the natural learning development of children. I think this coincidence gives us some real hope for the computer being not just another accidental technology that might help education, but *the* technology that comes just now to fill up an identifiable gap in that educational world.

If it's true that knowledge is normally appropriated in a process like microworld construction – that is, something like the creation of little pockets of reality, where you can dominate it and feel at home with it – some kinds of knowledge split up into a form that can be easily appropriated in that way. Others don't, and that's where we get into trouble: areas where our culture doesn't allow that kind of appropriation. Writing, mathematics, and science have been such areas, but the computer now makes it possible to create microworlds which can transform the rather clumsy educational process, as practiced in schools today, into a more natural and spontaneous one, similar to the way children learn language.

REFERENCES

Abelson, H., & DiSessa, A. (1980). *Turtle Geometry*. Cambridge, MA: MIT Press.

Freire, P. (19xx). *Pedagogy of the Oppressed*.

Lawler, R. (1979). One child's learning: an intimate study. Ph.D. thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology. See Lawler, 1985.

Lawler, R. (1985). *Computer Experience and Cognitive Development*. New York: John Wiley, Inc.

Lawler, R., DuBoulay, B., Hughes, M., & MacLeod, H. (1986). *Cognition and Computers*. New York: John Wiley, Inc.

Miller, W., & Ervin, S. (1964). The development of grammar in child language. In Ursula Bellugi and Roger Brown (Eds.), *The Acquisition of Language*, Monographs of the Society for Research in Child Development.

Turkle, S. (1984). *The Second Self: Computers and the Human Spirit*. New York: Simon & Schuster.