INTELLIGENT SCHOOLHOUSE

Readings on Computers & Learning

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Computer as Mudpie

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I spent nearly six years in Switzerland, at the University of Geneva, working with the psychologist and observer of children, Jean Piaget. I came away from there preoccupied by a dilemma. I was torn, and almost depressed.

If you look at how much children learn in their day-to-day lives, or consider the learning required for them to speak and to find their way around in space, or consider the slightly older child learning how to twist the parents and manipulate people, you will be tremendously impressed with what a remarkable learner the child is. This little being seems to learn spontaneously and joyfully such an enormous amount in so short a time.

Much of what the child learns we don't even notice. Piaget was able, with some ingenious experiments, to demonstrate this fact. If you place six eggs and six egg cups regularly on a table, and ask a four-year-old child, "Are there more eggs or more egg cups?" the child will recognize that there is the same number of each. But if you spread out the eggs and clump together the cups, the child will say there are more eggs. Yet when the child is a year or two older, he or she will say that they are the same. It won't matter how you cluster or spread out the eggs or egg cups; the child will still recognize that they are the same, that the eggs have a one-to-one correspondence with the egg cups.

If you put one water glass next to another glass identical in size and shape, pour water into both glasses up to the same level, and say to a four-year-old, "Is there more here than there?" the child will say "No." The child can see that the same amount of water has been poured into each glass. But if you take this same quantity of water, and—in front of the child's eyes—pour it into a thinner vessel so that the water now comes up to a higher level, although obviously no water was taken away, the child now thinks there is more. All four-year-old children think there is more. Who told them? No one told them. They invented it.

But who told them to think otherwise two years later? Two years later, when you ask the same group of children whether or not you poured more water into the tall thin glass, they will say, "No. It's the same. You didn't put any in, or take any away. It's the same." No one taught children to say that there was the same number of eggs as egg cups, or that the same amount of water existed whether it was in a short fat glass or a tall thin glass. After a certain age, they just knew it was the same. It is clear that no one taught those children anything, and yet they learned something.

This "conservation-of-number" learning happens to all of us, but until Piaget demonstrated it, no one seemed to know. We all forgot the fact that we once didn't know that a tall thin glass might hold the same amount of water as a short fat glass.

I did an experiment once in which every three months I filmed a group of children that went through these same experiments. After they arrived at the age where they all said, "It's the same," I asked them, "Do you remember coming up before?"

They said, "Of course."

I said, "What did you say?"

They replied, "It was the same, of course."

When I showed them the film, what did they say? They did *not* say, "Oh, so that's what happened." They recognized themselves, they recognized the experiment, but somehow they refused to recognize how they responded in the experiment. Instead, they thought the film was faked. "How did you do that?" they asked. Indeed, the children had an amnesia for their earlier responses in the conservation-of-number experiment.

It took a genius, Piaget, to tell us something about children that we could have observed for ourselves—"we" meaning the human species. We could have observed it because we have been living with children since the beginning of time. We've even been children. But it is almost impossible to remember what our initial learning was like.

A Dilemma

Children seem to be such remarkable learners on their own, but then they enter school. Some succeed in school, and it is impressive that they learn as successfully as they do. But many if not most children somehow do not seem to learn very well in school. Why is it that these people who learn so well in one context can so thoroughly falter and fail in another? I think the reason has to do with the following theory: some things—models, materials children think and learn with—are embedded in the natural environment of the child. When the child goes through the tremendously complex and demanding process of learning to speak, for instance, nothing is "taught" in the sense of someone giving lessons for an hour or two a day. Speaking is part of living, and it just happens. It is learned in a natural way.

Children build their own playful structures, although they all need materials with which to build. Important things are there, in the environment of the child, that serve as models, and children learn from them spontaneously. For example, the business of eggs and egg cups, and the one-to-one correspondence they maintain no matter how they are arranged on a table: the world is rich in materials with one-to-one correspondence. The child claps hands, one hand to the other. And it is not an alienated activity that someone else is imposing on the child, while the child wonders, "Why am I doing this?" or "Who is doing this?" Clapping hands originates in the child's desires. Certain kinds of learning emanate naturally from the child's relationship with the surrounding environment. But where the environment is deficient in the materials needed to manipulate certain things, where children are unable to build spontaneously, we have to resort to artificial constructs to fill the gaps. The classroom and the school are supposed to fill those gaps.

Piaget found in his studies that there was a whole class of learning that happened only very late, only by the age of ten or eleven. Learning beginning at that point he called "formal learning." Things learned at the "formal" stage are not rooted in the real life, the social life, the affective life, the natural life, the cultural environment of the child. Such things the child has to learn by a formal process. And I think we understand more thoroughly than ever before Piaget's distinction between "formal learning" and what I call "concrete" or "natural" learning. I believe Piaget was wrong, however, in his idea that particular skills and pieces of knowledge must be learned formally, while others must be learned naturally. I believe that if we didn't clap hands, if we lived in a world where there was only one hand per person, a world that did not contain pairs, conservation of number would need to be learned formally. What is learned during the concrete stage and what is learned during the formal stage depend upon the world in which we live.

We have not been too successful in changing what's easy and what's hard to learn by formal instruction in the classroom because almost inevitably the classroom curriculum is something imposed on the child. I believe the question is not, "How can we improve the imposition of material on the child?" but rather, "What can we do to increase the range of things that are learned naturally, so that the culture of the child is rich in natural learning?"

Computer as Mudpie

One has to be a terrible egomaniac, however, to think that one can change the culture. One can't. What one can do is go out and, like an anthropologist, see what in the culture is happening.

Nearly fifteen years ago it became clear to me that certain changes having to do with computers were going to seep into the culture and become part of everyone's life. These changes would occur because of economic and historical and intellectual forces vastly more powerful than those of any school board, or even the National Science Foundation. The computer is a product of history, a cultural force, and we cannot change that fact. What we can do, however, is try to deviate this force a little. Thus, I arrived at the idea of integrating a programming language with the concrete world of visual events, making graphics available through "turtles," making programming and all the mathematics and conceptual events programming entails—making that concrete instead of abstract.

The importance of the computer is that a whole range of abstract entities which could not physically be manipulated before can be now. They can become concrete. One can play with them, push them around. The computer is a universal machine, and if we are clever enough, if enough of us get involved in the process, perhaps one day we can use it to fill all the gaps. That is the general goal.

I would like to think of the computer as a clapping hand, as a mudpie, as the pencil that you use to scribble on the walls and get into trouble with (because you want to get into trouble too, it's a highly charged thing to do). This is the kind of use of the computer that I think is radically, deeply important for changing the conditions of learning. Needless to say, I am not talking about the computer as a "teaching machine." We all recognize the popular image of the computer being used to teach or to program the child, and I would like to emphasize the absurdity of that.

Certain notions of mathematics are not sufficiently embedded in the culture for children to learn in their natural way, so they come to school to learn them. Once children are in school, we try to impose mathematics on them in much the same way it was imposed on us: we begin by making them work at unimportant and uninteresting problems on little squares of paper. If before we ever allowed children to dance we insisted that they spend hundreds of hours drawing dance steps on square papers, and only when they could pass a test on the ability to draw dance steps on paper would we let them actually get up and dance, many children would find dancing impossibly difficult. Those gifted in dance would give up. And I think this is exactly what we do with mathematics. We teach it to the children in a way quite analogous to drawing dance steps on paper, and only those who can survive twelve years of that ever get to use it, to dance with it.

Now, putting the computer in the hands of the child, and allowing the child to dance with it, or to play with the computer like a mudpie, could mean that the child will learn certain concepts in a natural way. He or she wouldn't need to be "taught" it. The height of perversity is not to allow children to use the computer to acquire concepts in a natural way, so that they can go on not acquiring the concepts, and then come to school where we try to use the computer to improve the process of artificially teaching things that they didn't learn in a natural way. This is contradictory and perverse, and yet, generally speaking, it is what we do. Why? When computers first appeared on the scene they were exotic, expensive, fragile, hard-to-use devices that one had to keep in air-conditioned rooms. There were not very many computers, and so we could give children access to them for only ten or twenty minutes at a time, and then we would make the children go away. Under those conditions there was very little that anyone could do with the computer, except something called "drill and practice," where the computer says: "What is 17 times 8?" and you say, jokingly, "32." And it says, "No, try again."

That way of using the computer does not demand particular access to it. But I would like to consider the computer in a very different way: as mudpie. You can make a mudpie when you want to, and play with it as your personal desires direct you. You do not practice mudpie ten minutes a day, because your schedule says that now it is mudpie time. In other words, I am talking about a world in which children have free access to a computer. They can decide where to go with it, and what they want to do with it. They can play with it without adults standing over their shoulders. They can take possession of it, rather than be possessed by it.

Microworlds

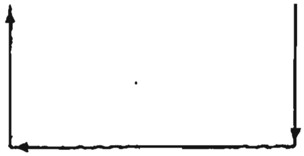
The really profound experience a child can have, that can be a breakthrough in relation to learning, is way beyond the programming language called Logo. It's the experience of struggle and final mastery over this space age object, the computer. It's the feeling of: "Gee, I can master that. I can get the computer to do something."

But let us consider very briefly what the child can do with one aspect of Logo, what I call "turtle geometry." The turtle in turtle geometry is a drawing instrument attached to the computer. It can be either a little robotic turtle that carries a pen underneath itself and moves around over a large sheet of paper, or it can be a little "character" appearing on the screen. As the child causes it to move across the screen, the turtle draws a line of light, in either black and white or color.

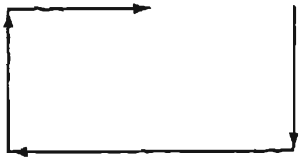
The child is motivated to draw because drawing is naturally engaging. To draw with the turtle, though, first the child needs to program it, that is, to describe in mathematical terms what it means to draw. Let us consider two of the simplest drawing instructions for the turtle: to move forward a certain distance, and to turn a certain number of degrees. To make the turtle move forward, the child might type on the keyboard something like FORWARD 10. The turtle moves forward a short distance on the screen, leaving a short line. Perhaps the child is disappointed with the small size of the line; with minor experimentation, the child discovers that typing FORWARD 50 produces a larger and more satisfying line. Perhaps later, the child will experiment with combining the forward instruction with a much larger number, say 10,939, and discover that the turtle then begins spinning "around" the screen, rushing to one edge of the screen and reappearing on the opposite edge many times, until that particular forward instruction has been carried out.

To make the turtle change the direction of its forward motion on the screen, the child might type in RIGHT, followed by a number. Directional instructions for the turtle are usually based upon the standard idea of 360 degrees in a complete turn. Thus, if the child experiments with forward and turn instructions, and types in something like FORWARD 50 followed by RIGHT 30 followed by FORWARD 50, on the screen the turtle will draw something like the following (with arrow tips added to indicate the direction the turtle moves as it draws):

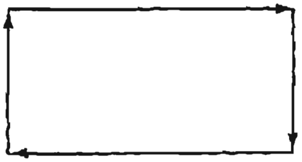
If the child is interested in drawing a square, eventually, he or she will discover that typing in RIGHT 90 will give a "good" corner, a right angle. Perhaps the child plays with the following set of instructions: FORWARD 50, then RIGHT 90, then FORWARD 100, then RIGHT 90, and finally FORWARD 50. The child looks on the screen and sees something remotely resembling a square, but it's not yet a closed figure.



Continuing to experiment, the child tries RIGHT 90 and FORWARD 50, with the following result:



The figure still is not closed, and the child finally learns to close it with an additional FORWARD 50.



The result, of course, is a rectangle instead of a square. And it may take a good deal more play, and trial-and-error experimentation before the child finally recognizes, at least at an intuitive level, that a square is a figure with four equal sides and four right angles.

What has been learned by trying to draw a square, and coming close enough that a rectangle appears on the screen? The child could have drawn a perfectly reasonable rectangle, or a square for that matter, on a sheet of paper. That would have been fun, attractive, and probably of some value. However, by learning to instruct a mathematically oriented turtle how to draw a rectangle, the child has learned at an intuitive level some of the mathematics inherent in Euclidean geometry. The child has learned, for instance, that the number 90 is somehow associated with making that perfect "right angle" turn; that precisely four of those turns will bring the turtle back until it's facing the direction it began; that in order to "close up" this figure with square corners, the sides need to be equal and the top needs to be the same length as the bottom. Eventually the child will learn, at a very fundamental level, that a square resembles a rectangle except that all its sides are the same length.

We might expect that this very simple piece of learning is going to happen to the child anyway, with or without a computer and a turtle. But my point is this: using the computer to concretize learning that is ordinarily abstract, the child absorbs it more quickly and easily, more thoroughly, and at an earlier age. The child can enter a personal relationship with mathematical material.

In fact, there are many, many tools in turtle geometry that the child can learn to use, and use to learn. But out of these two simple operations alone, going forward and changing direction, the child can build an infinite complexity. Just these two little bricks give the power to build an arch. Powerful ideas, in their simplicity, combine together to produce complexity.

The child knows how to make the turtle make a square. Sooner or later the child is going to ask: How do you make a circle? The scandal of education is that every time you "teach" someone something you deprive him or her of the possibility of learning it. So I would be really reluctant to tell the child how to do it. I could take out my compass and draw the circle on paper. Drawing the circle on paper with a compass is fast and convenient, and compass drawing can be very useful for the professional draftsman. It does not, however, really tell one much about the circle. There is another way to make the circle, and that is to put yourself inside it. Walk it. In some sense, walking is closer to the child than drawing a circle with a pencil on paper. Walking is also closer to the computer, to turtle geometry. So, the child walks it. How would the child describe in turtle talk what was done? "I took one step forward, then moved a little to the right, and then another step forward, and then a little to the right."

Having walked the circle, you are ready to instruct the turtle how to walk it. You tell the turtle to move forward a little (say, FORWARD 10), turn to the right a little (say, RIGHT 20), and then continue until the figure is closed. What will you have? Not a circle. But you'll have a closed, equal-sided, equal-angled geometric figure that, in appearance, approaches a circle. And as you experiment, making the angles larger and smaller, making the sides larger and smaller, you will begin learning about the mathematics of equilateral geometric figures, of circles, and of the similarities and differences between the two.

"Mathematics" is what children learn spontaneously, but "math" is what we teach in school. "Math" experience is sometimes an alienated thing that never touches one's body. It's abstract. There are, of course, some people who really learn mathematics from the beginning, and then there are people who learn it from the beginning but soon develop an amnesia, like the children in my film experiment. I suspect that's the more usual case. But I am sure about this: the mathematician is in it always. To do mathematics as a mathematician you must be inside of it. You must get into your body, and think about it. In Euclidean geometry you must put yourself into the world of those triangles, and those transformations, or else you cannot really use your powers. We seldom pass on to our children this insight in the schools, mainly because we have always had to teach our children with pencil and paper, a very externalized experience.

A lot of geometry can be understood by playing turtle, by walking it out physically, because in fact the biggest pool of geometric knowledge you have is what you acquired as a baby when you first began to walk and to find your way around in space. Just getting the feel of doing some mathematics in this more primitive, personal way is a starting point. It can change one's whole feeling about mathematics.

We can see the computer as a cultural event that is coming into the life of the child, and that can change the relationship between learner and the subject matter being learned. Does this mean, then, that we expect all sorts of the knowledge that we teach children in school to evolve automatically, once the computers are in place? Does this mean that we do away with formal teaching? Obviously not. I have just touched on some of the ways that I think this kind of experience of working with computers can make a huge difference. I like to think of the turtle as a particular little "microworld." But it is only one of many possible types of microworld.

Now and the Future

Using the computer as a mudpie, building microworlds from it, presupposes a certain extreme relevance of the computer. It implies a lot more computers than the other way of using them.

Only recently has such an innovation become economically feasible, and perhaps not quite yet is it so economically feasible that no one would dream of anything else. But I believe that right now it would be cost-effective to give every child a computer. I estimate that the tax money spent in an average public school system per child must be about $25,000 over the thirteen-year period. Perhaps the parents spend another $25,000, or more. But let us just consider the tax money, $25,000 a child. For $500 you can buy a computer. If we were doing it in a rational way, then the computers would be purchased without involving intermediaries and stores and advertising, and you could narrow the cost down to $200 or $300. What is $250 out of $25,000? About 1 percent. Thus, if one computer for each child produced a 1 percent improvement in the child's education, it would be cost-effective. In terms of absolute cost, then, giving every child a computer is by no means economically impossible, or even unsound. Of course there are problems of cash flow and politics, but most of these are psychological, in people's heads. Everyone knows that "Computers are expensive," and that "You can't use computers that way."

Consider how a school district, when confronted by the fact that one of its buildings is no longer useful or safe, raises the money to build a new school building. It requires no extraordinary initiative, no imaginative and dynamic and energetic school administration to go out there and do it. There have long been established means in the world to acquire the necessary money for new buildings, by levying taxes or acquiring public loans. But we have not yet created the mechanisms to modernize the insides of buildings. And because we have failed in the past to create mechanisms really to change schools from the inside, it is difficult to do any differently now. The future becomes prisoner of the primitivity of the past, as we're tied down by assumptions that were made during the previous generation. But I think that we have a responsibility to our children and to our world to give children free access to computers.

You might say, "Why not wait?" It's probably true that in five years computers will cost a quarter of what they do now. But five years from now, when computers are flooding the world, is not the time to start thinking about how to use them. That is not the time to have teachers beginning to familiarize themselves, to let the concept of computers flow into their intuitive thinking and be gradually integrated, so that their values and judgments as teachers will be preserved. On the contrary, the crush of computers flowing in vast numbers will be more likely to take over and impose on the educational system its own structure, the technological structure of the technocrat. I think the only way that our culture can preserve its traditional values is by slowly, but right now, beginning to become immersed in the trends of this new technology so that teachers can grow with it and have the technology well in advance, rather than let computers grow up inside factories and industries and burst out ready-made "for schools," by someone outside of the world of education.

I think within five or ten years it's going to be accepted that everyone should have a computer, and use it all the time for just about everything. What does that imply about what we should do right now? Right now it's very hard to have a computer for every child, even every four children. Does that mean that what we do now is irrelevant to where we are going?

Drill and practice might be a good thing. There are some statistics to show that drill and practice will produce some significant improvement in standardized achievement scores, and I don't want to deny that. But if we think of computers in terms of five or ten years from now, is drill and practice going to be a typical use? I think not. Giving to children microworlds that have—whether through Logo, or word processing, or access to the computer in a more creative way—a more child-centered, free-flowing, intuitive approach, *that* style of using the computer is what we need to learn about now, because that's what the future needs. The future needs people asking right now: What we can do with children and computers that opens our minds about the way learning might be, about the way children might be, in very different circumstances that are not very far away from our time?