LOGO 85
Theoretical Papers

LOGO 85

THEORETICAL PAPERS

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LOGO 85 THEORETICAL PAPERS
COMPILED AND EDITED BY
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ACKNOWLEDGEMENTS

The Organizing Committee would like to thank the Contributors to Logo 85 for sponsoring this journal.

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CONTRIBUTORS SCHEDULE

Listed below is the schedule for presentations and demonstrations by the Contributors to LOGO 85. All presentations will be held in Little Kresge, Kresge Auditorium.

Commercial products and exhibits will be displayed throughout the Conference in the Sala de Puerto Rico, MIT Student Center.

TANDY CORPORATION	Session II Tuesday, 10:30 AM - 12:00 PM
TERRAPIN, INC.	Session III Tuesday, 4:00 - 5:30 PM
APPLE COMPUTER, INC.	Session IV Wednesday, 8:30 - 10:00 AM
EXPERTELLIGENCE, INC.	Session V Wednesday, 10:30 AM - 12:00 PM
LCSI	Session VI Wednesday, 4:00 - 5:30 PM
IBM CORPORATION	Session VII Thursday, 8:30 - 10:00 AM

PREFACE

Seymour Papert
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It has become clear that the Logo community needs a forum for papers like those in this collection. The LOGO 85 Steering Committee discussed the idea of launching a full-fledged journal with a slightly expanded version of the collection serving as Volume 1 Number 1. In the end, we decided on a less structured arrangement. There will be no fixed publication dates. Papers are invited for submission and will be published when ready. Manuscripts can be of any length. Larger ones will be put out individually (like the old MIT LOGO MEMO series), and smaller ones will be combined into collections. We hope that people will take the initiative in proposing and organizing collections around themes. Two advantages of a regular journal are a name and an editorial board. These publications are provisionally named LOGO STUDIES. A board of editors will be set up during LOGO 85.

No formal definition can be given of the range of papers that will be acceptable. Certainly, it is neither necessary nor sufficient that a paper be explicitly about Logo. Nor are we proposing to create an open forum for every kind of discussion of education. We have to assume that there is a sufficiently strong sense of being part of "the Logo culture" for contributors and subscribers to know by family resemblance whether this is for them or not. And conversely, the existence of LOGO STUDIES will shape the future growth of the Logo culture.

Why now? A few historical remarks on timing and precursors might help thinking about what this publication series ought to become.

The Logo movement we know today was scarcely recognizable in the embryo that already carried its name in the late 1960s. There were no turtles and no graphics. Arithmetic was infix and in integers. Multiplication was left to students to write as an interesting mathematics project. We had not yet learned to introduce Logo to young children: students in the experimental classes in the 1960s were more typically in junior high than in elementary school. And, most strikingly, there was not yet either a community or a culture. It was a period of gestation. Logo had been conceived but not quite born.

The 1970s were a period of growing up in the protective environment of a cozy family. Ideas flourished and a small but energetic Logo family grew. A need for publication became apparent and two series of papers were started in the MIT Artificial Intelligence Laboratory: the LOGO MEMO series, whose back numbers are still actively sought, and the more informal LOGO WORKING PAPER series which has slipped into the archives (carrying some very interesting material with it that I hope someone will revive one day).

This kind of publication was ideal for the tempo and size of the community as it was then. The papers were longish, informal pieces written at a leisurely pace for friends. When one happened to be ready, it was reproduced in the simplest available way. They were sent out to a small Logo network in the United States or exchanged for similar papers from a few new Logo Labs that had begun to develop, notably in Edinburgh, in Montreal and in France. There was a steady, slow growth of ideas.

In the early 1980s, the pace changed. The long-awaited microcomputers were here. It was like moving into adolescence. Pressures were different. Some of us who had been incubating ideas over the years felt the need to get them out in forms that could be taken up by what already looked like the beginnings of a mass movement. The long, leisurely paper for a LOGO MEMO no longer felt appropriate. Ideas were either elaborated into books or put out quickly by writing short articles, giving lectures or interviews -- and even by getting involved with the actual production of Logo implementations. The LOGO MEMO series came to a stop.

There is now a swing of the pendulum and the need for a modern form of what we had through the 1970s. The publication of books and the presence of Logo on a large scale and in varied forms in the schools has created an intellectual climate in which ideas are taking root and proliferating. This climate is further stimulated by a broader awareness that there is a crisis in education which technology ought to be able to help. In addition, we are beginning to see the first stirrings of a serious critical movement that will challenge us on a deeper intellectual basis than the superficial debates and emotion-driven criticisms we have had up to now.

Uri Leron, in his contribution to the present collection, talks about a gap in the flow of Logo ideas. As I see it, we have not witnessed a gap, but an incubation phenomenon. A new situation was created in which it became possible for a much larger Logo community to take form. Three or four years is not too short a time for this community to grow from birth to the stage of having a need for self-expression like the smaller Logo family had in the 1970s. Thus, I expect the LOGO STUDIES to revive and wonderfully extend the function for which we started the LOGO MEMO series fifteen years ago.

COMPUTERS AND EXPERIENCE IN LEARNING SCIENCE

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The relation between computers and human experience is a complex one. In fact, my purpose is not at all to reach a conclusion on this subject, but merely to open a few perspectives on it so that the complexity is clear. Some of these perspectives begin from a point of view which, at the first level, is often used to criticize the potential of computers in education. But I hope to show that judgments that classify computational experience as, for example, necessarily artificial or symbolic in comparison to "real world" experiences are premature at best, often based on preconceptions which disappear on closer inspection.

Naturally my own point of view is generally optimistic. I have had vivid personal experiences with computers, and vicariously enjoyed experiences of my students which go to the heart of an enriched scientific and mathematical appreciation. In this regard, and for those who are less skeptical about computers and education than the critics I am indirectly referring to, this paper is a reflection on some things we have seen so as to show us directions to look forward to, things to avoid, and some issues concerning which we clearly are not yet settled.

Thinking about science education and experience goes back a long way. Theoretically, of course, Piaget is a seminal figure. But it is the tradition of activity-oriented science education of the 1960s and 1970s, notably ESS, with the likes of David Hawkins and Philip Morrison as spokesmen, that I am most interested in building on here.

AUTOMATONS? -- TIME ON TASK

Images are powerful. I have an image in my mind of a classroom of children sitting before CRTs. The children are all neatly arranged in rows, they are all looking forward -- we see them from behind at an angle -- and there is a green glow, like an aura, around each child's head.

What are these children doing, aside from being irradiated by their computer terminals? I am not sure, but it is a safe bet they are all doing the same thing. One doesn't even ask when they will be doing something else. That is not part of the image.

Such an image is frightening. I feel, like everyone else, "What are they doing to my child!"

Contrast: My son is lying on the floor, doodling with a pencil on a sheet of paper that was some abandoned homework. The sun is shining in the window. He's bored with homework and doodling, so he gets up to go out to play.

Now in this new image, I would like to substitute a computer for the pencil and paper -- not an Apple II with a green monitor, but a flat slate (liquid crystal displays don't glow or radiate) with keyboard attached, but which one often works by drawing on or poking at the touch sensitive screen. If we are aiming at large issues, we must not be bound by images from present and passing technology.

It is important that the instrument, pencil or computer, doesn't care whether it is used for homework or play. My son can let his intentions slip from one to the other without interruption, and the instrument is equally good at supporting each activity. There is more than "work or play", too. Work sometimes means an intensely personal project. This does happen with work, even school work. Sometimes it means a less satisfying set of exercises that we have, with reluctance, decided is useful for our child, and he apparently doesn't mind doing. Is writing a note to his grandparents work or play? How do we classify making a pretty thing spontaneously as a gift to his parents? There are so many very different kinds of things to do with this instrument that, if our image of children in front of green screens were not so vivid, we wouldn't even think to classify the time as "computer time." Does it make sense to count up the time you've spent with a pencil today, including "work", keeping score at bowling, doodling and writing telephone messages?

I am not at all unhappy that restless bodies want to get up and run occasionally, nor that computers make lousy replacements for frisbees. They have a place which is pretty big as any individual instrument goes. Two hours a day for a young elementary school child? Probably less. Compare that to four hours we spend on occasion in front of a television. There's plenty of time left, and I don't want to discourage my son from writing a letter to his grandparents in the most convenient way possible.

Computers will not, in my view, dominate our children's experience. Instead, they will play a part in it, or rather, many small parts. We should have more faith in the expression of our needs and in our own good sense as human beings about spending time. The vast majority will have no trouble striking a balance with a device which is, after all, considerably less interesting than a good friend.

ARTIFICIAL IS AS ARTIFICIAL DOES

Perception without conception is blind; conception without perception is empty.

I. Kant

I don't like the word "simulation." It sounds like a cheap substitute for the real thing -- and it often is. Do we really want a cheap substitute for the real world in doing science education?

Hardly. I don't think highly of replacing with simulation the rich kinesthetics of dancing or even just pushing and pulling, nor the complex beauty of drops of water splashing one by one with minute variations into a bowl. When I take my children into the woods, I want them to know how to penetrate beneath the pleasant surroundings, see the peculiar, *productively* wonder why. I almost certainly wouldn't buy a video disc, computer-animated "trip in the woods" if I could.

A number of years ago, I made a thing that even I occasionally call a "simulation" of a Newtonian object. It is a graphical object called a dynaturtle, which behaves as Newton said all objects do -- travelling in a straight line with constant velocity except when pushed, and obeying $F = ma$ on being pushed. Now why did I make that simulation?

The simple fact is that the world of sensory experience is not Newtonian. More than a little research shows that children and adults learn many things about the physical world through their experience, but they do not learn about Newton's laws. In fact, in many ways they learn the opposite: that things spontaneously slow down; that when you push on an object, it moves in the direction you push it rather than, as $F = ma$ has it, that a push *adds* to previous motion. In fact, things are worse than that. While it sounds more than plausible that force is a thing that is more or less directly perceived, that is not the case. Consider a ball moving left to right in front of you and you thrust your hand straight out to push it away from you. Unfortunately, it is almost impossible to push straight out in this circumstance without also causing a drag on the ball, effectively pushing it diagonally to the left, which has the result of the ball moving closer to straight out than it otherwise would. Intention and motion dominate our perception to the point that physical force is something we must carefully learn to see *between* the twin saliences of our intentions and their results. The best "frictionless" pucks on air tables can't make forces salient. Instead, we still see agency and intention, so real in our experience, but mere projections from our internal world.

In a deep sense, physics is not about the physical world as we naturally *perceive it*, but about abstractions that have been put together with great effort over hundreds of years which happen to be very powerful once we have learned to interpret the world in terms of them.

I don't think that we can or should insist that ontogeny recapitulate philogeny in terms of scientific knowledge, that children start only with their own "real world" experience and dig themselves out to stand above it without help. So we make a Newtonian object for our students that, far from being a replacement, is more of a Newtonian object than they will ever experience with their hands. Intentions become forces since all you can do with a dynaturtle is push it in some direction; you can only through some incredible accident or force of will *intend* to push it in some direction and really give it a different push. The real world is full of invisible forces like friction and those due to imperceptible deformations. Making things like dynaturtles may be the best we can do at making some of the real objects of science experiential.

I frequently hear the objection that dynaturtles will be treated by children just like computer games, as imaginary, artificial worlds to adapt to, but with no real significance. But I always recall my first experience with children who, upon discovering that things don't always go in the direction you push them in the dynaturtle world, complained that the computer was broken or that I hadn't programmed it correctly! Incidentally, one sees a perhaps surprising sophistication about the relation between programs and reality in these remarks. Moreover, when I took them away from the computer to try the same things out with a mallet and ball, they were frequently just as surprised. This may be shocking, but it is a common occurrence in Piagetian circles: children don't necessarily believe what might be obvious to adults or scientists. In fact, researchers at the University of Washington (unfortunately, unpublished) set up nearly the same experiment as the dynaturtle, where air pucks replaced the dynaturtle and blasts of air replaced the commands, and found an uncanny similarity in the reactions and strategies of their students to mine. The fact that their students were from a university and mine were sixth graders may be even more shocking. People don't think "abstractly" about simulations like dynaturtles; they apply the real world knowledge they have, such as it is.

Do children automatically think differently about the physical world after learning to deal with the dynaturtle? Not at all. The task of consolidating their new experience in such a way that it can reinterpret almost every event of their personal, everyday experience is a difficult one. While it is tempting to think of this as a question of belief, I do not think that is the case. Rather it is that everyday thinking is so fragmented that a little learning in any context spreads to others only slowly and with effort -- much more on this later. The point about dynaturtle is not that this new but rich experience *directly* with Newton's Laws (as directly as we can make it) does the whole job of transforming our world view. But it is a step. And it is a painless, fun step to boot.

Computers are indicted as artificial, but we should take a look at how children treat them. Dynaturtle shows that it is quite possible for people to think of computer-implemented objects as they do of real ones. The more fundamental point about learning science is that, by this stage in history, we should be more clever about the relation of the inner world to the outer than to assume that immediate perceptions, even carefully considered, are any sort of direct pipeline to scientific reality. Perceptions occasionally need the help of ideas, and we should not be embarrassed to give ideas a little boost toward making them sentient. The trick is not to turn experiences into abstractions with a computer, but to turn abstractions, like laws of physics, into new experiences.

RE-EXPERIENCING THE WORLD

Let me begin to question in a different way the notion of experience as something that necessarily involves putting me, the subject, in touch with things, the reality out there, via my senses. I can do this by relating a personal experience.

I can recall as a child an episode of playing catch with myself, tossing a tennis ball into the air and catching it. I was in a neighbor's yard. It was about five o'clock in the afternoon, a time of long shadows, but still bright Rocky Mountain sun and a stark blue sky. There are so many details alive in my mind about the experience that it seems to capture, in a sort of Proustian way, the essence of a part of my childhood. Indeed, I believe that this and a few other events I could relate played an important role in convincing me that science was a wonderful thing that I wanted to do "when I grew up."

The moon was quite high in the sky, and as it caught my eye, I began to imagine that the ball I threw up was caught suspended at the peak of its trajectory -- another little moon. I tossed the ball up near the moon in my line of sight. I don't know how my attention shifted to the lighted part of the ball, but suddenly it struck me that I was seeing the phase of my little tennis ball/moon and that it was the same as the phase of the real moon! The ball/moon was more of a model than my imagination had initially grasped.

Thinking about the sun shining on both the moon and my ball, I was entirely awe-struck to realize how far away the moon was -- I probably knew the numbers -- yet I held in my hands an equivalent globe. I was impressed at how distant the sun must be to cast the same shadow on the ball and the moon; that 250,000 miles between the moon and the tennis ball was, on the scale set by the distance to the sun, just a next-door neighbor distance.

Self-consciously trying to see myself as a viewer far enough away to see the moon and ball as right next to one another in relation to the sun, I began to wonder about the earth which was, after all, *really* right next to the ball. It too must have the same illumination! So I tried to locate myself with respect to that illumination. If the tennis ball was the earth, where was I? I'm not sure if I could say how, but it occurred to me that I must be directly on top of the tennis ball/earth. How shocking! Having been carefully weaned of egocentrism in my scientific view of the universe, I was quite surprised to find myself "straight up" right on top of my model earth.

I could now see on the tennis ball how far it was from me (on top) to the twilight line, and I began to wonder what it looks like to stand on that line. I then began to wonder which way the tennis ball/earth was spinning, how was I moving toward that line? I think I got a vague impression that the North Pole was behind me about a quarter globe circumference away (I was facing South; one always knows which way one is facing in Denver with the emptiness of the Great Plains on one side and the mountains on the other). Again how strange it felt to be on top with global landmarks like the North Pole on a tilt.

The first point to make about this little event is how much of it was in my head. The tennis ball was a good prop, but a good simulation that allowed zooming in and out, taking differing perspectives, would in this case have served as well. The important thing was the idea of unifying all the different perspectives and partial models I had about phases, earth, sun, and so on. Except for the accidental observation of real world objects that happened to start a chain of ideas, I did the rest essentially as a thought experiment. The whole event could better be described as re-experiencing the world, putting things together that hadn't gone together before. Having a planetarium model of the solar system firmly and artificially fixed in "fried-egg" orientation in my head and even knowing some numbers was at least as important as physical sensations.

Experiences rely in all sorts of complex ways on past experiences, and when one looks at these complexities in some detail there is no reason computers should be left out of the web. Abstracting from this little anecdote, computers might provide models that one day find their place in the "real world." I would hope a child, after having played with dynaturtle, might push a cup across the table and, wondering where were the anti-kicks that slow it down, re-discover friction. Or a computer might, in the guise of a simulation of a solar system, instigate a thought experiment. We could take it as our job to design computer experiences to provoke or support important events like the joining of perspectives. For example, might we not improve the moon thought experiment by making it possible actually to perform the operations of movement and scale change (in space *and* time) that convert a view of a tennis ball on the infinite plane of the earth into a lopsided view of the spinning earth in a nearly vertically oriented solar system?

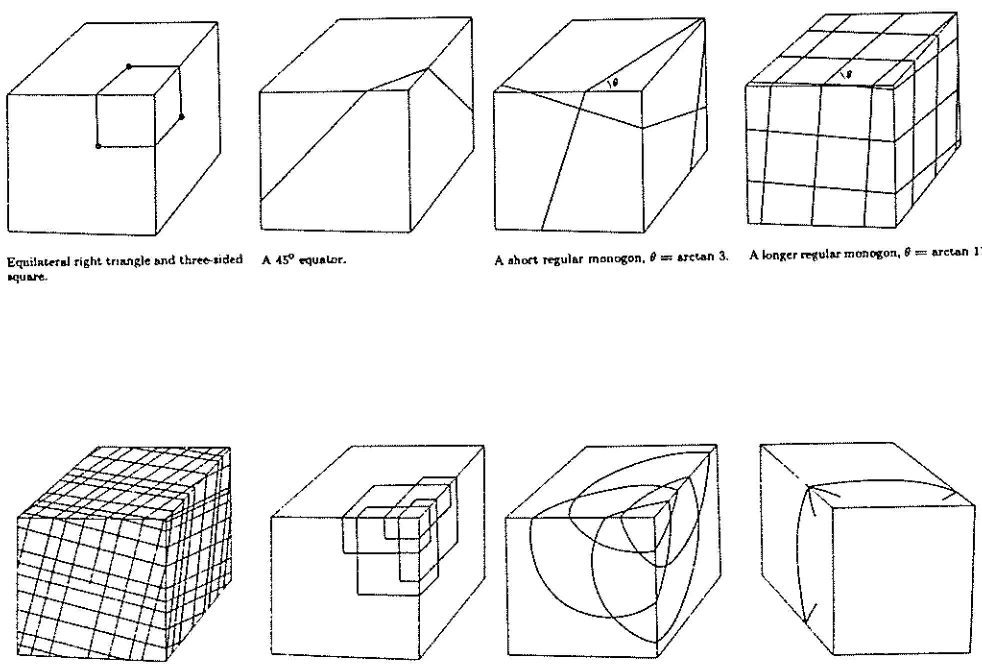
More generally, I propose that re-experiencing the world, the act of reinterpreting common ways of thinking from another perhaps broader perspective, is one of the most central and powerful experiences of science. The value of the computer in that context is not in simulating or replacing reality, but to provide complementary experiences that combine with mundane ones, to provoke and support re-experiences that we want students to have.

DISCOVERY

In the last section, I looked at a non-computer experience I considered important to my scientific education. It was a thought experiment and, as such, I hope it is at least plausible that computers could play roles such as instigating or preparing experiments as well as other materials. This section aims for more than plausibility. I will look at some computer experiences to see what they are like. The point will again be that experience is a highly ambiguous word, and once we refine it analytically or empirically with actual examples, the aura of "abstract" and "symbolic" that surrounds computers fades. One sees more clearly how they can contribute to what I hope we can all agree are important scientific experiences. The case in point has to do with experiences of discovery, what we mean by discovery and how we can help it happen.

About a dozen years ago, Hal Abelson and I were exploring the possibilities of non-standard geometries as subjects of study from a computational perspective. We wanted to follow up planar turtle geometry, which was successful as an exploratory computational microworld having significant and interesting mathematical structure. I had the idea that if we put a turtle on a cube, good things would happen.

After a week or two of off-and-on work, though, we were very disappointed. The only theorem we could come up with was, coarsely stated, that as long as the turtle doesn't wrap around corners, the geometry on a cube is exactly the same as on a plane. The surprising fact here is that the edges of a cube are not special in any intrinsic geometric way. The turtle program that draws a five-pointed star in the plane can, if you are careful not to have it circumnaviagate a corner, draw a five-pointed star on a cube, appearing like a starfish draped over the cube. This is a good illustration of the important geometric fact that intrinsic and extrinsic properties are not well correlated (edges are extrinsically defined, but are operationally the same as the flat parts of the cube). But we were not looking for an isolated illustration or two.



Equilateral right triangle and three-sided square. A 45° equator. A short regular monogon, $\theta = \arctan 3$. A longer regular monogon, $\theta = \arctan 11$.

A nonclosing turtle walk. A 12-sided square. A POLY circle; FORWARD a bit, RIGHT a bit,... Circumference= $6\pi r$. A radial circle, points equidistant from a center. Circumference= $2\pi r$.

Figure 1. Some sample phenomena of cubical turtle geometry.

In any case, I decided that implementing a cubical turtle would be a good exercise and wrote the program. Within a couple of days, we ran into dozens of interesting phenomena. Figure 1 shows a sample. Some of the more notable and obvious phenomena are that any turtle program which closes in the plane will also close on a cube, though it may need to be repeated up to four times; any "straight line", the path of a turtle which doesn't turn, always crosses itself at right angles. One also finds surprising equators -- straight lines that eventually close. But some straight lines seem to go on forever. Luckily, it turns out that many of the phenomena often discovered within a few minutes of sitting down with the cubical turtle are partially or completely understandable from very elementary considerations. Yet, for the advanced or ambitious student, there are deep challenges that can occupy weeks of effort. Having that range, from simple to very difficult in the same environment, is a particular educational boon. It means that students on very different levels can be doing the "same thing" very differently.

For me, the cube has become a prototype of a discovery-rich environment. Besides a density of observable phenomena -- potential theorems -- it seems that salient events like paths closing or crossing each other at right angles happen to be correlated with good, investigable and solvable problems. The cube is also a good environment for exploration, in part because there are tremendous possibilities for intervention, experimentation and play by writing little programs for the turtle. In contrast, it turns out that spherical geometry is just as rich with mathematical phenomena, but these are so subtle from a phenomenological perspective, that spherical geometry fails as an exploratory environment. Spheres are most useful as an expositional device where one can pretend that the good questions we as teachers know to ask are obvious and in the agendas of our students.

Discovery and explanation are like re-experiencing in that they are not like finding a lost glove. These are internal events, crucial for students to have and learn to deal with, but having little to do with preconceived notions of real and artificial experiences. This particular environment is about geometry; one thinks and sees lines, intersections, angles and all the rest, undiminished by the fact that between thinking and seeing, one must push keys with symbols on them.[1] Far from being artificial, the computer cube makes it possible to productively manipulate and get feedback from this geometric microcosm.

If having experiences of discovery is important to us, environments like the cube show that computers, properly used, don't abstract or artificialize learning, but instead, they may well be the best means of insuring the reliable occurrence of such experiences. Computers do not necessarily make good exploratory environments. The sphere shows that. But the point is that the criteria for discovery-rich environments have nothing intrinsically to do with "computerishness." We must think of engineering discovery-rich environments with computers in the same way as we have with all conventional instructional materials, with patience and imagination.

I would like to make two subsidiary points about turtles on a cube. The first follows up on the fact that bringing a discovery to mathematical fruition requires more than time and playing around. Explaining or proving can be supported with tools for exploration and experiment, but the depth of our students' experience will depend as much on what they bring to the experiences, on their inclinations, ideas and strategies that we hopefully have cultivated in previous contexts. If students don't know how to

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[1]Even more, computer implemented, process-oriented geometries like turtle geometry can make better use than static geometries of human's prior real world geometric experiences of moving and orienting one's self. A student's use of this prior knowledge will add more to the perceived reality of this mathematical experience. This is an argument that has been made in other places by both computer fans, see Papert's *Mindstorms*, and mathematicians, Freudenthal et al., concerned with making mathematics more experiential.

follow up on discoveries or even that they should (some students consider discovery a waste of time -- "Why don't teachers just give us the results?"), discovery-rich environments are a ruse. The crucial thing about making discovery part of mathematics education is not only the materials we provide or the activities that we suggest in the short run, but as much or more the long-term perspective on learning that we foster.

The second subsidiary point comes from my observations of a particular student with the cube. In order to help himself think about the things he discovered, he began to draw (with paper and pencil) trajectories on a cube cut up and laid flat. At first he was apologetic about this "obviously" non-mathematical play. Indeed, it bears little superficial resemblance to the clean, slick and apparently universal formalisms that we are taught in math classes. But gradually, over several weeks, he learned to deal with his representation ever more efficiently, until he saw confidently that he had developed a respectable formalism for dealing with problems of cubical geometry. It is an important property of the cube that it allowed this student to build his own way of thinking about it. My conviction is that building little formalisms like this over an extended period of time can be one of the most profound experiences of mathematics: *Mathematics can be made*.

PRE-SCIENCE

What I have said so far is subject to the following criticism. Many of the events I talked about are syntheses based on lots of experiences more on the level of "raw" experience. To be sure, we should aim toward such syntheses, but they are only to be expected to occur near the end of a long path which starts with inarticulate, direct observation and manipulation of the world. From the Piagetian point of view, intelligence begins with action schemas which are far removed from being reflectively accessible. To be more pointed, my own experience about the moon must have relied on developing a great deal of visual and perspective knowledge that undoubtedly is drawn better from the real world, given the multi-modality of touch and sight that is plausibly quite important in developing capability with points of view.

In this section, I consider the kind of knowledge that "raw experience" with the physical world generates, and see what computers may have to do with that.

It is quite fair to say that no one knows much about this kind of knowledge. So what I wish to present here is a pre-theoretical "educated guess." It has, however, empirical support from work of my own and others about intuitive physics, the way people expect the world to operate before they encounter science in classrooms. The assumption is that this intuitive physics is learned from experience with the world, and that it is relatively generic in the sense that much experiential knowledge in other domains (interpersonal knowledge, intuitive mathematical notions, etc.) should have similar characteristics.

The picture I have drawn of intuitive physics[2] involves a rather large vocabulary of relatively simple knowledge elements, most of which come from simple abstractions of everyday experiences. I call these elements *phenomenological primitives*, *p-prims* for short. The "p" part is to emphasize p-prims' proximity to the experienced world (phenomenology). The "primitive" part refers to the fact that, in many cases, people have no explanation for them: eTheyy just happen"' For example, why is it that when one works harder, one gets more effect? It is so obvious that one is at a loss to answer.

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[2]A. diSessa, "Phenomenology and the Evolution of Intuitions," in *Mental Models*, Dedre Gentner and Al Stevens, (Eds.), Lawrence Erlbaum Press, Hillsdale, NJ (1983).

Let me give a few more examples of p-prims. Intuitive physics is full of agency, intention, effort and the "results" of that effort. As mentioned above, one expects that more effort gives more results. This is one of the most important and generally useful p-prims. It interprets not only the physical world, but also social and interpersonal relations such as influencing. I have already mentioned that people often mistakenly think that giving an object a shove results in movement in the direction of that shove. Conflicting efforts may "balance" each other out. However, if one becomes stronger, it may "overcome" the other, negating the influence of the weaker effort.

These are some of the most broadly useful and most powerful of p-prims relating to conventional physics. I conjecture that there are many, many more that have less generality and less persuasive application. For example, most people are not surprised that slow moving objects wobble and move erratically. People also accept without question that effects often take some time to bloom into fullness after the effort of the cause has passed.

The following are the essential (conjectured) points about p-prims and the system of intuitive knowledge that they constitute.

1. P-prims are easy to generate. Since they are simple abstractions, all that is necessary is that the phenomenon that forms the basis of the abstraction (a) be amenable to description within the current knowledge system, and (b) may be made salient in an experience.

2. Compared to scientific knowledge, intuitive knowledge is very broad and not at all deep. Thus, while in scientific knowledge, a few laws and explicitly defined concepts constitute the core of the theory, which is supported by many methods, examples, special cases, evidence, etc., intuitive elements are much less stratified and, indeed, relatively isolated. Thus, if there is a conflict in which several p-prims seem to apply, it is unlikely that there will be any knowledge-based method for resolving the conflict. This contrasts with elaborate applicability conditions which are explicitly part of scientific knowledge.

   Some of the fragmentation of intuitive ideas can be shown by asking questions that to a physicist are all the same, but asking in slightly varying contexts. Children and physics naive adults often think completely differently about the different circumstances because of situation specifics. Centrifugal force may work on a ball turning in a circle on the end of a string, but not on a ball inside a circular tube.[3] In other cases, just the phrasing or modality of presentation can affect the way people think about it. For example, people asked to predict motion may give radically different assessments when they are simply asked to watch motions and react to their plausibilities.

3. Though fragmented and shallow by scientific standards, intuitive physics shows a degree of depth and coherence. This coherence, relations among p-prims, is important. For example, some p-prims are much more central and important than others. Their status is determined by their relations in the knowledge system; some may organize much experience and may even explain subordinate p-prims. For example, the fact that released objects fall down might be an independently encoded piece of knowledge. But it may be explained or justified by the "force of gravity" which can be felt when one holds an object up. The "intended" effect of that force is realized when a blocking object (e.g.,

[3] T. Globerson and A. diSessa, "The Effect of Age and Cognitive Style on Children's Intuitions of Motion," paper presented at *Logo 84*, Cambridge, MA, June 1984.

the hand holding it up) is no longer there.

The kind and breadth of coherence is one of the principal dimensions of development from intuitive physics to "textbook" physics. Coherence, initially determined by similarity, common attributes that determine a class of p-prims (like agency) and other non-logical, non-theoretical relations, becomes a richer system that supports interpretations such as justification, definition of terms, etc.

4. Many p-prims actually come to find essential places in more expert knowledge. For example, once modified and extended in scope, intuitive notions of agency come to form a commonsense interpretation of the unusual formulation of Newtonian physics centering on force (as the universal means of effective agency). In other ways, fragments of intuitive knowledge form parts of developing scientific knowledge such as qualitative versions of laws, partially explanatory "cover stories," etc.

   More examples: Intuitive notions of conservation are refined and reused to develop technical ideas like conservation of energy and momentum. "Greater effort begets greater effect" is virtually a paraphrase of Ohm's Law.

   This involvement of intuitive knowledge in scientific domains accounts for the ability of a scientist to make a smooth transition between his commonsense experience and the more and more technical characterizations of it. The lack of it accounts for the brittleness of many students' understanding.

Pre-Science -- I wish to use the above to formulate a conception of science and science teaching that differs in significant ways from almost all current practice. Above all, we want to teach science that (1) is contiguous with the previous knowledge that children have, that (2) develops largely through the use of the same mechanisms as their intuitive knowledge so that we can expect it to feel easy and natural, but that (3) incorporates some of the substantial structural changes that distinguish science from intuition. Item (1) means the image of p-prims and their collective knowledge system will serve as a guide to the initial state of students and the kind of knowledge we have to build with. Item (2) means the program for teaching will largely be experiential. Item (3) means that one of the core objectives will be to build a new level of unity and coherence that is easily perceptible to us and to our students. To emphasize the status of this view of the science that we wish to teach, intermediate between intuitive physics and formal symbolic science, I will call it *pre-science*. The idea is to build a solid but flexible platform of knowledge that is not specifically aimed at, but will be easily extended to incorporate many of the trappings such as propositions, explicit definitions, and so on that are usually taken to define science.

Let me elaborate these points.

1. Qualitative understanding of basic mechanism forms an essential core to understanding the physical world that transcends any particular formal means (equations, etc.) of expression. Work with dynaturtle and university students (and other intuitive physics studies) shows that current schooling is failing here. Students may be able to recite F = ma and solve equations flawlessly, yet may not have adjusted their world view to accommodate the concepts that those equations represent. In comparison to standard high school or university courses, the emphasis on qualitative understanding in pre-science will be jarring. Especially during an extended initial phase, one won't see the usual veneer of propositions, definitions and formalisms normally associated with

science.

2. Once we understand the complexity and richness of intuitive knowledge, despite its shortcomings, we have good reason to believe we can develop a pre-science in children through a proximate development of their existing knowledge using means similar to the mechanisms that develop intuitive knowledge. Indeed, once we realize how much of science *is* reorganized intuition, the task of building science in this way is immediately more plausible. Thus, pre-science is essentially an experiential program, building on experience through new experiences. In practical terms this means that student activities will be in many instances more like "messing about" than reading texts or even than "doing experiments."

3. This point is particularly important. It is not usually recognized how complex a well-developed qualitative understanding can be, how much needs to be collected and integrated, and how much power results from that work. Rich, multi-faceted understanding of "simple" relationships characterizes scientific understanding (in contrast to intuitive understanding) far better than the particular content. If we can develop a few examples of ideas of wide scope and powerful application, we may have much greater impact on a child in terms of giving him a sense of what science is like than with any sort of broad coverage.

   One of the essential gaps in public education is its failure to convey the sense of incredible complexity, interrelation and depth of scientific knowledge as compared to commonsense reasoning. One finds a significant proportion of the population that believes there is evidence for ESP so as to place it on a par with other "theories" of contemporary science or that believes creationism has, if only as one theory among others, a legitimate scientific status. These are not failures of teaching "the right thing", but failures to teach any example at all of the depth and breadth of any well-developed scientific notion.

   One of the characteristic features of aiming for new levels of integration is that students will have substantial re-experiences of events that they ordinarily interpret in context-dependent ways so as to see connections to broader, more invariant perspectives. In comparison to the usual aims of elementary school science, pre-science is considerably more ambitious.

Developing a program of pre-science will be significantly different from any curriculum attempted in the past. But my claim, based on the above notions, is that teaching pre-science will be a much more reliable way of giving children access to what is substantively and epistemologically essential about science.

Methodology -- The core of the pre-science program is to experientialize a subject by finding or imagining the essential phenomena that may conspire to produce an understanding of the subject. This is a task I have called in other places "a genetic task analysis", and it necessarily involves significant empirical work with children with an eye towards reforming and reorganizing their knowledge. One must then invent environments and experiences to develop children's ideas in small clusters.

There are two important estimates of complexity of the task of experiential learning that have a great impact on designing environments and experiences. First, any even relatively constrained set of materials/experiences (an "activity" in the Montessori sense) will only make salient a relatively small set of phenomena. This is not to say we must specify activities in infinite detail, laying out a curriculum of little experiences. On the contrary, such specificity would defeat any semblance of personal initiative and playfulness in pre-science. But it is to say that the level of analytical detail that says roughly what a certain activity gives the student in terms of experience and how that contributes to the overall program is important for designers and teachers. Particularly if a student is having difficulty, we will need this level of analysis to suggest how to refocus the student's attention to overcome that difficulty.

Secondly, we will have to assume several different (certainly overlapping) activities to collect enough of the enhanced and elaborated p-prims to meld into a pre-science "unit." This is a "multiple-perspective" principle that no single "simple model" or perspective on pre-science concepts can suffice, that pre-science is essentially the development of a coordinated scheme of perspectives.

These two remarks are estimates of the scale of the task of learning science on the foundation of the essentially fragmented intuitive knowledge system. The first is an estimate of (1) how much of one's knowledge system can be engaged so as to be significantly changed in an experience (not much), and (2) how much needs to be engaged and changed to pass from intuition to pre-science (quite a significant amount more).

I need to say a bit more about unifying experiences. In some cases where overlap between activities is sufficient, it may happen automatically. This is the ideal case, where the set of activities in a pre-science unit have enough overlap and continuity that students spontaneously build from one experience to the others. In some cases, however, we may specifically design activities aimed at re-experiencing some of the activities on the basis of ideas more salient in others. My constant example is that after building a conceptual model so as to have integrity in its own terms, we may wish to work at implanting that model in students' experiences of the world.

In some cases, more elaborate unifying experiences might be designed. For example, a formalism that can be interpreted by means of the experiences might serve this role. (I do not want to write symbols and propositions out of the program entirely, but to place them in the proper context.) One might culminate teaching a pre-science unit with a more standard science unit using text, definitions, problem sets or other more narrowly constrained activities. Indeed, the success of such a course as compared with what happens to students taking it without having the pre-science unit might make an excellent evaluation.[4] Indeed, evaluation needs more consideration than I can give it here. Our measures of student success will need to change with our new program. They will need to be more like the flexibility of thought that comes from knowing a great number of ways of thinking about something than understanding measured by quickly solving examples of a fixed class of problems. Learning that can be carried on after a pre-science unit makes a nearly ideal example of this kind of flexibility.

Note that we have not worried specifically about the task of developing p-prims one by one. If the task turns out so difficult as to require such care, we will have failed to define the task properly. One will have to go back to the genetic task analysis stage and start again, staying closer to the naive state of our students.

Finally, we come to an essential point beyond what we have said about p-prims. Since the coherence

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[4] This is an idea originated with S. Papert

of the new system is by assumption beyond the initial perception of students, even more so since we have partitioned the system, to some extent, into more manageable chunks, each of the activities must have its own coherence. Experiences must locally drive themselves on the basis of things that people know how and want to do, not on the basis of some invisible teleology or on the instructor's interest. This is an example of Papert's Poetry Principle.

Computers and Pre-Science -- Before taking an example in detail, let us consider what this program has to do with computers? Nothing and everything. The program can be formulated without computers specifically in mind. Indeed, this program has resonances with ideas that have been around in the "science-and-experience" community for decades -- ideas like "messing about", "meaning before words." I depart from that community in the optimistic stand I take about being explicit about knowledge elements, and in the emphasis on unifying experiences into a level between intuitive knowledge and what would be more easily recognized as science. I depart from that community more substantially in my belief that, in some areas at least, the computer is an order of magnitude more flexible and precise in crafting experiences that can lead to essential insights. We should soon see breakthroughs in the level of achievement of learning through experience and in the public acceptance of such educational strategies.

I would like to emphasize again that computers have a character that better adapts them to some areas than others -- in particular, to areas where the essential structure is visual, geometric and dynamic. Thus the topic of motion, which will constitute our major example, is nearly ideally suited. In contrast, in working on a similar program having to do with weighing and balancing, Marlene Kliman and I have not found the use of computers particularly compelling and we are proceeding at this point with standard materials.

An Example: Beyond Dynaturtles -- Let me illustrate the pre-science program with a perspective on dynaturtles. The dynaturtle and target game, through which most people know it, constitutes a good example of an activity in a pre-science program. It is self-motivating, satisfying the poetry principle, and has a relatively short list of essential phenomena that students reliably run into. This fraction of the "curriculum" consists of ideas such as the specialness and importance of the stopped state (only when things are stopped do they necessarily go in the direction you push them), the notion of cancelling motion with opposite "anti-kicks", and qualitative versions of combining kicks with existing motion ("compromise", etc.).

In my original paper on the subject,[5] I proposed building a curriculum directly on this experience alone. I now believe this was overly optimistic for two reasons, both of which are versions of the multiple-perspective principle. First, as I noted at the time, there are a number of "advanced topics" that adults often seemed to get to, while children did not. These did not seem to be experientially contiguous in the target game context. Second, even if children got relatively proficient with dynaturtle, they often had very significant problems with mildly altered environments, like a lunar lander. (That is basically a dynaturtle with the additional complication of gravity.) If dynaturtle by itself constituted a complete pre-science module, students should have been flexible enough to engage this slightly altered environment with less difficulty. In retrospect, we should have guessed this difficulty because, while understanding dynaturtle "completely" would be quite sufficient to cope with lunar lander, the phenomenological projection that one encounters in the target game leaves out some essential ideas that must be salient to deal with lunar lander. In particular, the notion of

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[5] A. diSessa, "Unlearning Aristotelian Physics: A Study of Knowledge-Based Learning," *Cognitive Science*, Vol. 6 (1982), pp. 37-75.

components of motion and independent control of them (which, incidentally, is in the neighborhood of the advanced topics noted for adults, but not children, in the target game) is not well represented in dynaturtle, but terribly important to the lunar lander. For the sake of specificity, let me briefly mention two more topics that I believe it is essential to treat experientially before we can expect to develop a critical mass of experience necessary to transcend intuitions about motion.

The first is the phenomenology of simple relative motion and frames of reference. Frames of reference are important to understanding the motion of dynaturtles because it is through this perspective that one unifies, once again, what happens in the stopped and moving cases. Provided one takes the frame moving with the dynaturtle when it is kicked, the dynaturtle does, indeed, always go in the direction of the kick! It is quite easy to develop dynaturtle activities that make relative motion more salient. It is also easy to imagine defining multiple frames of reference in these activities and watching events from those different points of view. Linda Morecroft at MIT is doing related work here.

The second topic (actually, class of topics) is the phenomenology of velocity, acceleration, distance and time in a more restricted sense. An example of this class of ideas is to understand that distance is, in a fundamental way, just an accumulation (adding up) of velocities or to readily compare the speeds of different objects or simply to see that an object is accelerating or not. Again, I cannot take the time to describe in detail the computer activities related to this, but substantial work has been completed with Mitch Resnick and Steve Ocko from Microworld Learning, Inc. (Incidentally, from the perspective of a standard curriculum, these time, rate and distance ideas are clear prerequisites to understanding what kicks do to a dynaturtle. The definition of velocity must be made before the definition of kicks (changes in velocity). But from an experiential perspective, children have independent routes into both sets of topics. We discovered empirically that children can learn a great deal from dynaturtle without having a prior formalized notion of velocity. The fragmentation of the intuitive knowledge system gives us degrees of freedom; we need not be so firm in ordering the curriculum since what stood as a prerequisite is now a co-requisite for a deeper, unified understanding.)

In this section, I have again not attempted to craft an airtight, logical case that computational experience is not in any essential way different from "real" experience. Nor have I tried to present irrefutable empirical evidence. There is evidence, but our thrust is not to convince the most skeptical. Instead, it is to point the way to uses of computers that are consonant with the goals of many who are skeptical of computers. The point is that if our task is construed as changing the ecology of experience in such a way as to draw out more scientific understanding from activities that children will find enjoyable and natural -- in short, some version of the pre-science program -- then computation should not be ignored. I do not deny that the computational experiences in a pre-science program would rely in a profound way on prior "real world" experiences that develop children's ideas about motion and their abilities to watch and interpret it. But the best experiences always carry forward the successes of the past. If computers can do that, it is enough.

SUMMARY

In this paper, I have tried to locate computers properly in the world of experience. It is easy to feel warm and comfortable with experiences in the natural surroundings and frightened of the artificiality of computers. Yet, once one looks carefully at good experiences in either context, these initial feelings must give way to more careful concern for what makes a good experience, independent of the instrument used to support that experience. I have looked at natural experiences (re-experiencing the moon) to show that the props we use are often a small factor, that the relation of those props to prior experience, of whatever sort, is crucial. I have looked at computer experiences (dynaturtle) to find that sometimes it is quite clear that computer experiences are not treated as artificial at all by children, but that in some respects their artificiality (making the structure of physical laws salient) is the best thing about them. When it comes to bringing discovery into the classroom, whether some activity is computer-based or not seems much less the point than what that activity makes visible, manipulable, and what kinds of thinking excursions it engenders in our students.

Finally, I have sketched a program that I call pre-science for making experience a much more central part of science education. I have tried to make it clear that the extent to which computers can contribute to this program is not foreordained, but instead depends on how well we understand both what experience is, and what our students' experienced world is like. As with all materials, the character of the medium may set some broad constraints on its use, but much more depends on our imagination and skill in crafting those materials to good ends and on setting the proper context for their use.

DEVELOPING A CONTEXT FOR LOGO IN SCHOOL MATHEMATICS

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This paper is concerned with the integration of Logo into the mathematics curriculum and has as its particular focus the contextual factors that influence learning mathematics in school. An attempt is made to analyze firstly, what is educationally valuable in working with Logo from the theoretical perspective of a mathematics educator, and secondly, the implications of this analysis for educational practice. Information about what is known in mathematics education at the present time is used as a basis from which to identify priorities for curriculum change. Logo, the language and underlying philosophy, is seen as the catalyst for the changes identified and the means of provoking mathematics educators to reconsider what is appropriate in the mathematics curriculum in terms of conceptual content, ways of representing content, ways of drawing together "cross-curricula" mathematical experiences (from areas such as art, craft and science), and finally, organization and methods in the classroom. In addition, Logo activities in the mathematics classroom have specific educational functions within the priorities identified and these are discussed using, as illustration, extracts from the case study research presently underway in London secondary mathematics classrooms (1). Finally, the implications of the discussion for the purposes and goals that mathematics teachers hold for their pupils' learning will be considered.

BACKGROUND: THE STATE OF MATHEMATICS EDUCATION

So, what can be said about the situation in mathematics education? Despite many and various attempts at curriculum innovation, school mathematics still tends to be fragmented and hierarchical, with few pupils experiencing or learning to appreciate any synthesis between topics. Social interaction between teacher and pupils reflects and reinforces a transmission model of teaching and learning in which knowledge and expertise is assumed to reside solely with the teacher. Bauersfeld (1980) has identified a consistent pattern of "funnel-like" communication in mathematics classrooms where teachers' questions are reduced to eliciting expected partial answers and the pupil has the task of guessing what is in the mind of the teacher (2). Mathematical concepts and operations are taught to essentially passive recipients largely through verbal definition divorced from context and referential meaning. Teachers and pupils seem to "connive together" in both insisting on a repetitive and highly structured curriculum and in covering up their mutual failure to communicate in any real sense. As Lorenz (1980) noted, "There is no other subject in which the teacher is so tempted to misinterpret a (numerically) correct student response as an insight into the underlying problem structure. And nowhere is the student more willing to accept overt or covert prompts in order to conceal his problems in understanding." (Lorenz, 1980, p.18). Correct verbal reproduction of a term by a pupil is therefore seen by the teacher as equal to its meaning.

The effects of this state of affairs are well documented. The majority of pupils are either anxious about mathematics, alienated from it, or simply bored by it (3). Pupils rarely become **involved** in mathematical activity, not expecting it to demand their thought or creativity, but rather perceiving it as an "obstacle" to overcome or avoid. Problems are classified as hard or easy and solutions as right or wrong in ways usually perceived to be completely beyond personal control or comprehension. Typical pupil reaction to mathematics are illustrated in the following extracts from pupil interviews:

> *"...(It's) always the same; we never do anything different and then we never learn anything...we don't learn nothing and then next year, because we haven't learnt nothing, we will have to do it again...."*
>
> *"Well, there is maths all year. I just cannot do it. I cannot remember what it was even, but it should all be easy. I just find it hard and it is all the easy stuff...I keep trying and trying and nothing comes out. I feel so tight inside I want to explode...when I am sitting there I know I will not be able to do it...."* (Hoyles, 1982).

As well as this widespread negative affective response to school mathematics, actual pupil performance on items which test the content of the curriculum is also a matter of some concern. After hours of teaching, many children have little understanding of the simplest of mathematical concepts (4) and after hours of practice, many children are unable to carry out successfully the simplest of computational algorithms (5). It has even been found that the ability of children to undertake computations correctly sometimes actually declines with age (6). Finally, even if pupils are able to carry out computational algorithms successfully, they usually are quite unable to decide the appropriate algorithm to use in any given situation (7).

Another feature of the school system in countries like the UK (which touches upon the affective issues already mentioned, together with factors concerned with teacher belief and expectation) is the existence of consistent and widespread gender related differences in attainment and attitude to mathematics and the widespread underachievement of ethnic minorities (8). This is an extremely complex phenomenon and cannot be discussed in any depth here. However, it is of interest to note that the type of environment in which school mathematics generally takes place at present is not only particularly alienating for girls in terms of subject presentation and organization, but also seems particularly unlikely to encourage girls to move away from a linear step-by-step approach to mathematics. Girls, therefore, tend to fail to develop the global, intuitive, and autonomous problem solving strategies which are so crucial for future work in the subject (9).

The above brief survey serves to illustrate the extent of the failure of school mathematics at the present time. It also shows how "piecemeal rule following" and "obedience to authority" are encouraged at the expense of independence of thought and creativity. Mathematics educators now recognize, however, that pupils do in fact try to make sense of the mathematics presented to them and make responses which are rarely random and illogical (although perhaps "wrong" from the perspective of the teacher). Pupil answers are now believed to be based on quite rational and consistent abstractions from their learning experience (10). It is also now known that these "alternative mathematical frameworks" are not overturned simply by verbal exposition or counter-demonstration by the teacher, and if future mathematical activity is not to be perceived as illogical or dogmatic (or both), these pupil interpretations must first be recognized by the teacher and then worked with by teacher and pupil together (11). Finally, research has also shown that performance on a problem can be quite dramatically affected by the context in which the problem is embedded, the way it is posed, and the method of assessment used (12). It is therefore reasonable to hypothesize that in different circumstances with different priorities and ways of working, pupils would not only be more successful in their mathematical work, but also develop a more positive and productive attitude to it. What is needed, therefore, is a powerful new intervention strategy which enables teachers and pupils to "break out of the mold" in terms of how the mathematics curriculum is perceived and how it is transacted -- and this is where Logo has a crucial role.

LOGO IN THE MATHEMATICS CURRICULUM

With this background in mind, the following three priorities for a school mathematical environment of the future can be identified:

* The environment should generate extended pupil projects;

* The environment should encourage discussion and reflective experimentation;

* The environment should illuminate pupil meanings and interpretations.

This paper will seek to show that Logo in the mathematics curriculum has a significant part to play within each of these priorities.

1) <u>Logo as an environment for extended pupil projects</u>

A powerful means of moving pupils away from routine exercises and non-purposeful tasks in mathematics is to set up "situations to investigate" rather than "problems to solve". If these situations catch the imagination, pupils can be provoked to take on challenging pieces of work and tackle them creatively and independently (often to the surprise of the teacher!). By this means, pupils not only learn new techniques in a meaningful way (that is within a context in which they are required), but also obtain the experience of taking on the role of "expert" with responsibility for the successful completion and dissemination of the project (13). If, in addition, these projects are undertaken collaboratively, pupils also learn skills of explanation and communication. Logo in the math classroom provides just such a situational environment, and has proved to be both a rich and flexible source of pupil problem posing and project work. In the Logo Maths Project (Hoyles, Sutherland and Evans, 1985a), pupil pairs have spontaneously come up with and explored, with quite amazing persistence, a wide variety of projects of a mathematical nature, frequently returning to their work in order to refine and extend it.

There are three points to be made about these pupil projects:

* Firstly, their significance in terms of motivation and the building up of self-esteem;

* Secondly, the crucial role of the discussion between pupil pairs in deciding upon the project; keeping it going; negotiating extensions; and finally "finding ways round" obstacles which seem likely to impede successful completion;

* Thirdly (which relates most specifically to the computer context), the importance of the opportunity afforded by the computer to provide a "reasonable" graphical outcome at an early stage which can be refined later as pupils become more sophisticated in their control over the programming language.

The following is an example of one such pupil project taken from the Logo Maths Project:

Beryl and Tracy, as case study in the Logo Maths Project, worked on a project of their own choosing over a period of six months. During this time, they learned to use a wide variety of mathematical techniques and also started to experiment with modular program design. Before starting the project, the pair had restricted themselves to using a double identical digit input to distance and turn commands (e.g.,FD 22 and RT 55) (14). *They therefore were unable to draw a right-angled figure (because 88 was used instead of 90). The pair came to their eighth session with the well-defined plan shown in Figure 2. At the time, it was thought (by the class teacher and the researchers) to be far too difficult for them. The pair were not, however, to be discouraged from their goal and eventually, many weeks later, completed it to their own satisfaction. Measuring the angles in the design with a protractor provoked the link to be made between turtle turn and angle in degrees and the "move away" from the double digit strategy. The discussions and procedures used also showed the pair's perception and use of the modular nature of the design* (Reference Figure 2). *Having completed this project, Beryl and Tracy decided to extend it as shown in Figure 3. Their construction of this design, however, provoked the introduction of a new technique, the absolute coordinate system, which they then used to make a more accurate representation (their original design was not quite mathematically correct). This project was perceived by the girls themselves as important, challenging and enjoyable. It was also the vehicle for considerable progress in both programming and mathematical ideas.* (Hoyles, Sutherland and Evans, 1985a, pp.180-82)

2) <u>Logo as an environment for discussion and reflective experimentation</u>

Mental models of the world are generally developed through experimentation, and learners of all ages need to build up concrete metaphors for their mathematical concepts if their learning is to be meaningful and applicable. Experimental activity allows ideas and concepts to be viewed from a variety of standpoints. It therefore aids in the development and coordination of schema or "frames" by focusing attention on relevant characteristics and relationships which can then be reflected upon and discussed (15). Investigative work has affective as well as cognitive consequences. It helps to build up feelings of control and self-confidence and a less authoritarian perception of mathematics. The school environment in which mathematical activity takes place should foster exploration and encourage pupils to develop a healthy sense of questioning and inquiry.

Programming in Logo seems quite naturally to provoke pupils to become involved in experimental activity while they try to understand a new idea, process or procedure. This has been noted by many researchers (16). In the Logo Maths Project, a rather general categorization of pupil activity was made, called "Making Sense of" activity (17). This encompasses all types of investigative activity during which mathematical and/or computational concepts or processes are "tried out" in a reflective and experimental manner. This "Making Sense of" activity is regarded as a key element in pupils' Logo work. It appears to be influential in developing an understanding of the intrinsic nature of turtle geometry, i.e., that a procedure can be used in different contexts (18), of the processes involved in Logo programming, and of the mathematical ideas that arise within Logo projects. Discussion during the "Making Sense of" activity is crucial for both coming up with "things to try" and for developing a meta-language to describe the features of the activity. In learning to communicate with their partner, pupils also learn to articulate and elaborate their thoughts and strategies; to listen to and work upon their partner's suggestions; to make and challenge conjectures; and attempt to clarify incompatible explanations and problem solving strategies. It is also hypothesized that discussion helps pupils understand the formality and syntax requirements of a programming language, and helps them "see" the merits of alternative ways of representing a given situation (19).

The following extract serves to illustrate the three-way interactions between a pupil pair and the computer during a period of experimental activity with a new command:

John and Panos were working on a "moving man project" and were using the WAIT command within their ARM procedure (so that the arm waved). Initially they used WAIT 1 but decided it was too slow. Panos changed the input to 0.35, but John was confused thinking that a smaller input to the WAIT command would mean that the arm moved more slowly. They made sense of WAIT by trying out more inputs and discussing what was happening.

> *John: "That was a bit too slow."*

and changed WAIT 0.35 to WAIT 0.45. (He was, in fact, increasing the wait between arm movement and therefore slowing down the movement of the arm.)

> *Panos: "If it was slow you need to halve it...that's even longer now.*
>
> *John: Let's just try it.*
>
> *Panos: That's nearly half a second.*
>
> *John: So.*
>
> *Panos: Bent fish...I don't know how I let you talk me into this."*

Later, they returned to this exploration when Panos wanted to change WAIT 0.55 to WAIT 0.1, but John thought that it would become slower.

> *Panos: "How can 0.1 be slower than 0.5?*
>
> *John: 'Cos it is.*
>
> *Panos: Well, the computer's wonky.*
>
> *John: It ain't...you just think about it."*

They enter the command and the visual image convinced John that it was not slower, but he still wanted to work out why this had happened.

> *John: "How come it was going slower when I put 55 than it was going at 45? (He means .55 and .45)*
>
> *Panos: 'Cos that's how many seconds it waits...get it?...it's not how many seconds it takes to wait...it's how many seconds it waits.*
>
> *John: Oohhhh.*
>
> *Panos: So that's why 5 seconds is longer than 1 second...ain't it... true or false....*
>
> *John: Yeah, but look, when it was quite quick, when it was 25 it was*

quicker...so when it was 45, it would be even quicker.

Panos: No, you don't get it...we added on another 0...and so its got to be 0.045 to make it quicker."

Finally, after some more experimental activity, John understands.

John: (with excitement in his voice) "OK...I know...I know... I just realized." (Hoyles, Sutherland and Evans, 1985a)

Experimental activity while programming in Logo occurs quite spontaneously in a wide variety of contexts. Different **levels** of understanding, however, are sought by the pupils according to their needs at the time and according to the demands of their particular investigation. Often the focus of activity (at least at the initial stages) is on **product**, that is, on the visual image on the screen. Pupils tend to use their turtle graphics procedures in ways that are simply a natural extension of the manipulation of actual objects or shapes and are just concerned with the outcome when, for example, a procedure is tried out in different positions, is fitted together with others to form patterns or is used with different combinations of inputs. This "outcome" tends then to be discussed and assessed by the pupils according to whether it is visually pleasurable, whether it matches up to a preconceived design or whether it fits neatly into the new context. However, even at this early stage, the immediacy of response during the "Making Sense of" activity frequently leads to pattern recognition and generalization -- both important aspects of mathematical thinking (20). **In addition, however, pupils are frequently provoked by the needs of the context of their investigation to shift the focus of attention from product to process.** For example, Beryl and Tracy, in the project described above, having made a procedure for one quadrant spent some considerable time looking back over how it had been built up in order to work out how it could be used for the other quadrants. New contexts also often provoke pupils to think about not only the **effects of different inputs**, but also **what the inputs actually stand for** and how they can be developed and used more flexibly.

Sally and Janet, for example, "took time out" from their goal-directed activity (which was to draw a clown's face) in order to experiment with a procedure, look inside it, and find out how it could be applied within their project. This is described in the following episode:

Sally and Janet had already "made sense of" a procedure for POLYGON, with one input for the number of sides.

```
POLYGON "NUMBER
REPEAT :NUMBER FD 20 AND LT DIV 360 :NUMBER
```

They used this to draw a round face for their clown (using POLYGON 13). They then place the turtle in the correct position for the nose.

Janet: "What type of nose are we going to do?

Sally: Round?

Janet: Round!"

Sally initiated the idea of extending the already written POLYGON procedure so that it would draw a variable sized regular polygon.

Sally: "Miss, could we...that program...do you always have to do 20?"

Janet elaborated Sally's suggestion indicating that she also understood the idea of making the side length variable.

Janet: "Miss, you know the POLYGON...the one we did...could we just change it?...say leave a space...so whenever we want to, we could put something in, Miss?"

We showed them how to edit their polygon procedure to:

```
POLYGON "NUMBER "LENGTH
REPEAT :NUMBER FD :LENGTH AND LT DIV 360 :NUMBER
```

and after "making sense of" different sized inputs for number and length, the pair then decided that POLYGON 20 3 would be right for their nose, and completed their clown's face. (Hoyles, Sutherland and Evans, 1985a, pp. 36-8).

3) Logo as an environment for illuminating pupil meanings and interpretations

Mathematical activity in the classroom should be organized so that the intuitive mathematical conjectures and strategies made and used by pupils are more accessible to teachers. It is now well established that pupils are "active in the construction of their own knowledge, with bugs as by-products in attempts to perceive regularities in the world around them" (Schoenfield, 1983). It is also known that despite exposure to formal methods children tend to solve mathematical problems in the informal ways which have worked for them within their limited experience (Booth, 1984). Thus, it is important for the teacher to try to gain access to a pupil's interpretation of any situation, try to work with pupil conceptualizations, and then reflect upon them together with the pupil concerned. "We all have the pre-mathematical frames and if we can bring them to bear on a mathematical problem we can probably solve it. Hence good mathematical instruction should build on this capability" (Davis, 1984, p. 160). In this way, pupils will be encouraged to hold their mathematical activity at a distance and become more aware of the mathematical processes they are in fact undertaking (von Glaserfeld, 1982; Kilpatrick, 1984). Learners will then be better able to relate new knowledge to existing mental structures and widen the contexts in which their mathematical processes can be applied.

In mathematics, the problem for the teacher is that generally only the **product** of pupil work is available for inspection, and the **process of solution** is not necessarily clear. Propositions and verbal descriptions offered by the pupil provide the teacher with some clues, but these are often incomplete and difficult to comprehend. However, "[o]bservation of children's responses in computer based environments can make their thinking more accessible than it would otherwise be" (Weir, 1984, p. 63). In addition, a pupil's planning, rough work, methods of recording, and construction of Logo programs all help to provide a powerful means of illuminating both how the problem has been perceived and how it is to be solved. Thus, the programming activity helps the teacher in the task of negotiating meaning with the pupil.

The transcript data collected in the Logo Maths Project (which includes pupil discussion as well as the record of Logo work) contains a wealth of insights into pupil conceptions and associations, some of which are summarized below.

- **The way a pupil "feels about" a particular mathematical concept or operation can be revealed in the way it is approached in the Logo work over a period of time.**

For example, Janet feels that decimals are "peculiar" numbers and is loathe to use them in her Logo work. In her fourth Logo session, Sally, her partner, had calculated that 32.8 was the turning angle needed to draw an eleven-sided regular polygon, but Janet wanted to change the goal:

> *Janet: "Why don't we do the 12?...it won't have a point."*

Later, when drawing their clown's face, the pair wanted to place the nose in the middle of the face which required a move of "half 15".

> *Sally: "Now do backwards 7.5.*
>
> *Janet: Forget about the .5...it's silly."* (Hoyles, Sutherland and Evans, 1985a, p. 53)

* **The pervasive influence on the learner of the first experience of a new idea or process can be clearly observed.** This illustrates a general characteristic of learning, that is, that discrimination in terms of the characteristics of a new concept are made according to the demands of the context in which it is experienced (21).

For example, Sally and Janet happened to be introduced to the REPEAT command in the context of building a procedure in the editor. It became apparent several months later that Janet believed that she could only use the REPEAT command within a procedure definition and not in direct drive. (Hoyles, Sutherland and Evans, 1985a, p. 56).

* **The difficulty of counteracting well-established relationships that have "worked" in the past and have been built up over a period of time becomes quite obvious to the teacher.**

For example, Panos spent many weeks "discovering" 360 degrees in a variety of contexts. He then drew a great many regular polygons, confidently calculating the exterior angle by division of the number of sides into 360. However, when he came to draw an equilateral triangle, he suddenly behaved differently, saying:

> *Panos: "REPEAT 3 times...60 60 it's 60 I'm sure...'cos remember equilateral triangles have 60 degree angles."*

The strong connection between equilateral triangles and 60 degrees was still very much in evidence. (Hoyles, Sutherland and Evans, 1985a, p. 150)

* **The overall pupil perception of the nature and context of a task in the Logo context becomes more open to inspection, as does the relationship of the task to the problem solving strategies used.**

How a task is viewed depends on the systems of representations available to the pupil, but also on the meaning embodied in the situational context in which the task takes place, which includes the totality of feelings and emotions that are "called up" by the situation - whether the task is perceived as "play" or "work", "doing maths", "drawing a picture", or even "hard" or "easy" (22). Within the period of study of the Logo Maths Project (this may, of course, change with time), pupils appeared more likely to write structured programs when pursuing abstract mathematical goals (as in the case of Beryl and Tracy above) than picture goals. They also tended to be resistant to using subprocedures and the

REPEAT command in classroom contexts where "high status" is attached to long procedures (Hoyles, Sutherland and Evans, 1985a, pp. 170-72).

In order to give a more coherent flavor of the way children's work with Logo can illuminate how they might be conceptualizing and learning mathematical ideas, a brief illustrative episode is described below.

On a visit to a classroom which is part of the Chiltern Logo Project (Noss, 1983, 1984), I came across David who was in the middle of a project to draw three "men" of similar shape in decreasing order of magnitude (Reference Figure 4). David had already written a procedure MAN :B :N :A :SIZE, in which B was a measure of the length of the body, N the neck, A the arms and legs, and SIZE the triangular head. David had typed a procedure as follows:

```
TO MEN
MOVE1
MAN 55 30 40 35
MOVE2
MAN 45 25 30 25
MOVE3
MAN 35 20 20 15
```

in which MOVE1, 2 and 3 were simple sequences of commands used for the interfaces between the three men.

Several observations can be made by a consideration of this one short procedure. Firstly, David was using subtraction as an operator to produce his "similar" shapes even though when asked about scale factors he happily talked about multiplying and dividing. This illustrates very clearly how knowledge tends to be "fragmented" (Papert, 1984), and how every experience tends to be "domain specific", i.e., specific to the situation in which it was experienced and not automatically transferable to different contexts. In particular, it shows clearly the "gap" between formal rule following (i.e., verbal reproduction or paper and pencil exercise) and mental representation of knowledge, and between awareness of what is known and the ability to apply knowledge in practice (23).

In order to investigate further, I intervened to provoke what I hoped would be a cognitive and perceptual "conflict":

> *Researcher: "How about if you made them smaller more quickly? Why don't you take 10 from each input?"*

David happily carried out my suggestion. He actually typed 0 for the input to the neck of the smallest man and then stopped:

> *David: Oh, he cannot have no neck! I had better make the largest man 32!"*

He then went back and added two to all the inputs to the largest man.

This episode illustrates beautifully the difficulty of shifting conceptions, and how anomaly and contradiction are necessary but not sufficient to cause change in any conceptual perspective.

I was also interested in the fact that David had not written a general superprocedure for his three men. It could be argued that the context did not demand this as his self-imposed task was, after all, to draw just three men, so there was no incentive to generalize further. It could also be that David did not understand how control is passed from procedure to subprocedure in Logo. However, from the perspective of a mathematics educator, it could serve as indication of the strong resistance on the part of many children to the assimilation of the idea of an unknown as generalized number, which can be accounted for by reference to Piagetian research in mathematics education (Collis in Booth, 1984, p.88). Collis, for example, suggests that the distinction drawn by Piaget between concrete and formal operational thinking in terms of a child's degree of reliance on reality is probably reflected in a child's perception of the nature of algebraic elements (Collis, 1973). While the "concrete operational thinker" is able to deal with the notion of letters representing particular unique, if currently unknown, values, it is not until formal operational thinking is attained that the generalized nature of the values represented by the letters can be fully appreciated (24).

To continue the story of David, the suggestion that he write a superprocedure with variable inputs for his three men created no problem, indicating that "flow of control" was not his problem. It was perhaps rather surprising, however, that he used recursion immediately and typed the following:

```
TO MEN :B :N :L :SIZE
MOVE:MOVE
MAN :B :N :L :SIZE
MEN :B-10 :N-10 :L-10 :SIZE-10
```

(where MOVE:MOVE was used as a way of "generalizing" MOVE1, MOVE2 and MOVE3.)

Once again, many conjectures are generated from these few lines of program. (It also led to an exciting exploration of negative numbers!) However, the one point that stands out for me as a mathematics educator is the confusion evident in the second line between different linguistic levels, i.e., between referent and symbol or name and value (Adda, 1982). This confusion is difficult to resolve and was observed later in this session when David tried to insert a stop condition in his program by typing, IF :MOVE = 4 [STOP].

THE FUTURE

From the above analysis, it is evident that Logo can play an important role in developing a more productive environment for the learning of mathematics. Although not the subject of this paper, it must be mentioned that Logo also has a role in relation to the **learning of specific mathematical concepts.** It is possible to build numerous links between the mathematics pupils spontaneously use or want to use in their Logo projects and the "traditional" mathematics curriculum (25). In addition, an almost endless variety of structures, which add some facilities and possibly curtail others, may be superimposed upon Logo in order to focus the learning experience around specific mathematical concepts. An exciting possibility, which it is hoped will be investigated at the Institute of Education in London (in collaboration with Richard Noss), is to try to link process and product in mathematics in a dynamic way through Logo programming and, in particular, to enhance the awareness of processes through structured exploration of content. It is important, however, that we guard against building ever more complicated microworlds "for the sake of it." Considerable work still needs to be done to decide exactly which curricular topics would be enriched by work in Logo (26).

Change ultimately depends, however, on teachers, their interpretation of the value of Logo for their teaching, and how they incorporate the Logo activity into their classrooms. Logo may help us solve some of our problems in mathematics education, but we must be aware that it will certainly not solve all of them. Some children do work in an instrumental way with Logo (see Hoyles, Sutherland and

Evans, 1985a, pp. 217-226) and do not always understand what they are programming. Also, sometimes they are competitive, as indicated in the following extract:

> *Panos: "Holy smoke...put draw...then quickly put...what was it...KITT (a previous procedure they had made)...because people will come and watch now, won't they!"* (Hoyles, Sutherland and Evans, 1985a, p. 134)

These occasional incidents are no reason to doubt the benefits that can accrue from working with Logo in our mathematics classrooms. However, for any real change to take place an atmosphere has to be created within the classroom that allows pupils to experiment and collaborate through a flexible management of the curriculum and encourages the interchange of ideas and methods between Logo and non-Logo activity. This implies, however, a shift in the social relations in the classroom from a teacher to a more pupil-centered approach which is not necessarily compatible with the beliefs held by teachers about the way mathematics should be taught. A teacher's beliefs about the nature of mathematics and mathematics education play a significant role in both shaping classroom practice and in defining what mathematics is and who is good at it. At the ends of a continuum, two perspectives of mathematics held by teachers can be identified - a knowledge-centered perspective and a problem-solving perspective (Lerman, 1983). These perspectives are communicated to the pupils in a variety of ways: for example, through the metaphors chosen for exposition or explanation. Teachers with a knowledge-centered view may see mathematical investigation as a reasonable pedagogic strategy in order to motivate pupils, but their beliefs must always tend to compel a resistance to the dynamics of interaction, especially if it seems likely to lead to uncharted territory.

Using Logo to promote mathematics investigation must therefore be seen not just as a reasonable and efficient pedagogic strategy, but also as a way of challenging the authoritarianism of the deductivist pattern of teaching mathematics by trying to move away from a rather sterile and static formalism to one that is more dynamic and learnable. The position is summarized succinctly by Hersh (in Lerman, 1983, p. 63) when he evaluates criticisms of formalism in the high school which are based merely on pedagogical considerations. "...[A]ll such arguments are inconclusive if they leave unquestioned the dogma that real mathematics is precisely formal derivations from stated axioms. If this philosophical dogma goes unchallenged, the critic of formalism in the school appears to be advocating a compromise in quality: he is a sort of pedagogic opportunist who wants to offer the student less than the 'real thing.' The issue, then, is not what is the best way to teach, but what is mathematics really all about....controversies about high school teaching cannot be resolved without confronting problems about the nature of mathematics."

A challenge of the 1980s within mathematics education is to use the power of Logo to shift the focus of mathematical activity in schools away from learning the formal properties of symbolic codes and syntax to the discovery of their semantic meaning and, in so doing, to allow the pupil's interpretation of the curriculum to become both more visible and more influential on the way learning is organized. Researchers and teachers must take on this challenge together. The time is ripe since discussion of the role of microcomputers in mathematics education has revitalized educational debate, and many "taken for granted" views and assumptions are being looked at afresh (Cuffaro, 1984). These discussions must confront and try to resolve practical as well as theoretical questions about using Logo in the mathematics classroom.

Our aims (if we are concerned with mathematics education) must remain clear, i.e., to achieve a more "appropriate mathematics" (Papert, 1980), within classroom environments which incorporate a variety of goals, styles of working, and methods of assessment and in which teachers are able to adopt a more "ideographic" or individualistic view of their pupils (Hoyles and Bishop, 1982). One would hope all this would be to the advantage of all pupils, but perhaps, in particular, to the advantage of girls (who tend to prefer a collaborative rather than a competitive atmosphere and who are often defined as lacking in initiative or problem solving ability). Most children love working with Logo in their mathematics lessons, but it must be remembered that they also enjoy other things as well -- provided that they are excited by and involved in the activity. As Panos said when asked about his mathematics lessons over the last year:

"I really like Logo and Maths - it's the only time that you work by yourself without the teacher telling you, 'stop what question you are on!'...We (John and Panos) were making a super robot and we managed to get a moving picture. That was such a good time because it took us ages and a lot of brain power. But the best time in maths though was when we all measured Mr Ratcliffe's flares (27)...*I mean..they were a foot long!!"*

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NOTES

1. The Logo Maths Project (Hoyles, Sutherland and Evans, 1985a) is a three year longitudinal study which started in London in September, 1983 with children aged 11/12 years. It is monitoring and evaluating how Logo can be used within mathematics classrooms which have adopted a "pupil-centered" approach to learning. Since one of the objectives of the research is to monitor the effects of collaborative learning, the pupils work in pairs at the computer. The researchers act as participant observers of the case study children in one mathematics classroom into which Logo work is being integrated. This enables influences of classroom context and management to be monitored together with the spread of ideas between Logo and non-Logo work. More fundamentally, working continually in the school (together with administering occasional structured tasks) allows the researchers to experience the dynamics of the pupils' learning, and thus more able to interpret it. "Failure to observe children's constructive processes first-hand denies the researcher the experiential base so crucial in formulating an explanation of those processes" (Cobb and Steffe, 1983, p.85). Systematic data is collected for four pairs of pupils (one "boy" pair, one "girl" pair and two mixed pairs) throughout the three years of the research project. (During the first year of the project, four additional case study pairs were "followed" in a second school.) This data includes recordings of the pupils' Logo work, all the spoken language of the pupils while working with Logo, the researchers' interventions, a record of all the "other" mathematical work undertaken by the pupils, and teacher and pupil interview data. In addition to the case study work, since September, 1984, the research has been extended into ten further schools where data is being collected by questionnaire, teacher and pupil interviews, structured task and task-based interviews. Specific hypotheses concerning teacher and pupil attitudinal and perceptual factors and pupil understanding of variable are being evaluated within this extended network.

2. This style of interaction has also been found in more recent classroom-based studies in the UK; for example, in the Mathematics Teacher Education Project (Hoyles, Armstrong, Scott-Hodgetts and Taylor, 1984).

3. See, for example, Hoyles (1982); Buxton (1981); Tobias (1978).

4. For example, 33% of 15-year olds in the national monitoring undertaken by the APU in the UK were unable to write down the percentage of the square that had been shaded in (Reference Figure 1) (APU, 1985).

5. For example, 56% of pupils in the same survey (Note 4) were unable to give a correct answer to 785/25.

6. Kerslake (1981) found that the ability of children to add and subtract fractions declined between the ages of 11 and 15 years.

7. For example, only 38% of 12-year olds picked multiplication as the operation to be used in the following question: "You can choose from 3 sorts of bread and 6 sorts of filling. How do you work out how many different sandwiches you could choose?" (Hart, 1981, p. 25).

8. As far as gender differences are concerned, see, for example, APU (1985) and Cockcroft (1982) for results from UK, and Fennama (1974, in press) for results from US. Differences in mathematics attainment (as separate from overall attainment) due to ethnic background are less well researched at present, but some work has been done by Grieb and Easley (1984).

9. See, for example, the work of Walkerdine and Waldon (1983).

10. See, for example, Davis (1984); Erlwanger (1973); Resnik (1976); and Easley (1984).

11. See, for example, Clement et al. (1981) and diSessa (1982).

12. See, for example, APU (1985); Walkerdine (1982); Lave et al. (1985); and Wolf (1984).

13. See, for example, Higginson (1973); Bird (1983); Walters and Brown (1977); and Steiner (1983).

14. The importance of working in this restricted environment should not be underestimated. It was simple enough to allow the pair of pupils to build up their confidence and feelings of "control", yet flexible enough to enable a considerable amount of creative exploration (of circles, in this case, because of the actual nature of this restricted environment).

15. The terminology will depend on one's underlying theoretical framework. See, for example, Dienes (1973); Skemp (1971); Bruner (1959); Davis (1984); and Dorfler (1985).

16. Exploratory activity evident at the initial stages of Logo work has been described as activity "for which goals are at best vague and for which plans are not elaborated but constructed a step at a time, contingent on feedback" (Hillel, 1984, p. 12). Noss suggests that this type of activity is "based on the utilization of programming ideas as a means of extending the power of the language...and such strategies [are] used by children as a means of making new concepts their own, of extending their control over their learning environment" (Noss, 1985). This type of activity has also been considered as a programming "style" of pupils who prefer to "negotiate" and interact with the computer in a creative manner rather than carry out a pre-worked plan (see Turkle (1984, p. 108) for a description of "soft masters" and of "tinkerers" as described in the Brookline Report (Papert et al., 1979)). It should be noted that in the Logo Maths Project it has been difficult to distinguish the consistent working style described elsewhere (Turkle, 1984; Solomon, 1982). The extent of planning and pupil programming style appeared to be context-specific and dependent on the goal undertaken and how it was presented (Hoyles, Sutherland and Evans, 1985a). The readiness of children to switch between different modes of activity was also observed by Noss (1985). Collaborative work in pupil pairs in the Logo context has also been investigated by Hawkins et al. (1984).

17. In coming to this classification, the dangers of imposing <u>our</u> representations of problem solving strategies on the data and of confusing application of problem solving strategies from awareness of their use is recognized. Attempts are being made at present to elicit the <u>pupils'</u> interpretation of their problem solving behavior.

18. Pupils at the initial stages of Logo work do not necessarily "see", for example, a square used in a drawing for a face <u>as</u> a square, but actually as a face!

19. This conjecture is to be investigated in a structured group task to be carried out within the Logo Maths Project in June, 1985.

20. For an example of this, see Hoyles, Sutherland and Evans (1985c).

21. See also Davis (1984, p. 363).

22. For related research in mathematics education, see Bauersfeld (1984); Brousseau (1980); and Rouchier and Samurcay (1985).

23. See also Lawler (1981); Bauersfeld (1984); diSessa (1982); Clement et al. (1982); and Hoyles, Sutherland and Evans (1985b). Children need, therefore, to re-experience and re-learn a concept in a variety of contexts.

24. This phenomenon has also been noticed in another Logo environment where children were quite happy to build simple procedures with one input (for example, HOUSE :SIZE), leaving the value of the input to be decided later, but found it difficult to cope with generalized relationships between numbers (Goldstein, 1985).

25. In London, a Curriculum Development Project funded by the Microelectronics Project is developing materials to support these "links." Uri Leron has also undertaken considerable work towards developing a Logo/Mathematics course. See, for example, Leron (1985).

26. This question was addressed at the Logo and Mathematics Education Conference held in London, March, 1985 (Hoyles and Noss, eds., 1985).

27. Flares are wide-bottomed trousers which are very old-fashioned!

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SOME THOUGHTS ON LOGO 85

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NOTES ON THE LOGO COMMUNITY

I. Introduction

The thoughts expressed here are based on my personal experience in teaching and studying Logo, augmented by conversations with many colleagues around the world and observation of some of their work (though I do not claim consensus.) Thus, they are offered here not as definite "findings", but as issues for further discussion. If these informal and incomplete thoughts will help stir a more vigorous discussion of the issues raised, the paper will have achieved its purpose.

II. Learners, Not Researchers

Our work in Logo touches on many themes of great intellectual depth and complexity, but I do not consider it "scientific" work. Therefore, I believe, we have a great deal to gain from thinking about ourselves not as researchers, but as learners: learning about Logo-learning (I call this learning-squared). In particular, we could then benefit from all the learning principles promoted by the Logo community in its work with children.

III. Learning-squared and Logo's Principles of Learning

In our Logo work with children, we encourage exploration, experimentation, playing with half-baked ideas, making mistakes and learning through debugging. Socially, we encourage a free and open discussion and exchange of ideas, including ones which are only partially understood. While the spirit of this kind of learning can be seen everywhere in our reports of children's learning, I believe the Logo community has largely denied itself the benefits of these principles in its own learning (learning-squared). I also believe this has had an inhibiting effect on the intellectual growth of the Logo community since 1980.

IV. A Lull

I am struck by the observation that nearly all the fundamental thinking on Logo was done within the MIT Logo Group until 1980. At that time, the first microcomputer implementations of Logo were released for public use, together with the publication of the enormously influential *Mindstorms* (Papert, 1980). Also, at about the same time, the two other influential MIT-based books were nearly finished: *Turtle Geometry: The Computer as a Medium for Exploring Mathematics* (Abelson and diSessa, 1981) and *Logo for the Apple II* (Abelson, 1982). For other important Logo-related developments at that time, see Sylvia Weir on special needs, Jeanne Bamberger on music, and Andrea diSessa on physics. (See e.g., Weir, *BYTE*, September 1982, Bamberger and diSessa and White, *BYTE*, August 1982. For an extensive bibliography of Logo literature, see the 1985 Logo Conference Pre-proceedings.)

In contrast, consider the next four years (the period 1980-1984). To me it seems that while the Logo movement has grown impressively in volume, it has nearly ceased to grow in depth. (Note that I am not talking about undercurrents or the state of certain individuals. I am talking about the community as it appears from, say, the published works on Logo.) In the large crop of books, entire journal issues, and single articles on Logo, it is hard to find new ideas and insights not contained in the original Logo literature from MIT. In fact, much of the literature seems to range from the rehashing of Papert's (or Abelson and diSessa's, etc.) ideas to trivial reporting of plain anecdotes or outright unrealistic and misleading "romanticized" reporting.

During the last two years, one can discern signs of unrest from within the Logo community. See, for example, "Creating Logo Cultures" (Watt, 1984), "Expectation is Part of the Environment" (Goldenberg, 1984), "Some Problems in Children's Learning Logo" (Leron, 1983), and "Problem Spaces in a Project-Oriented Logo Environment (Bull and Tipps, 1984). (I am not concerned here with criticism from without.) I believe this signifies the desire of some Logo workers to break away from this self-imposed "freeze" and hold a more open and critical discussion of our present knowledge and achievements. In other words, in order to renew the growth of the Logo movement, we should encourage in it the same sort of learning processes and atmosphere as we do in our Logo work with children.

V. Logo Culture and the World: A Conditional Acceptance

In the period I have described as a "lull", Logo does seem to have been very successful in spreading its culture to more and more schools and individuals. It seems that the world has given Logo an enthusiastic albeit conditional acceptance, based more on the promise of Logo than on actual demonstration of its accomplishments. We therefore face the danger that in the long run, if we cannot deliver what we have promised, there might be a backlash, perhaps even a return-to-BASICs movement. Inasmuch as there are still unsolved problems in the theory and practice of Logo (and of course there are many), it had better be the Logo community that should first address these problems. In this connection, I think we should take seriously the editorial "Logo Frightens Me", in the second special Logo issue of *The Computing Teacher* (Moursund, 1984).

VI. Clean Vision and Messy Reality

Papert's theory is wonderful in giving us a coherent and wide-ranging vision of what education and learning in the computer age could look like under ideal conditions. *Mindstorms* is a book of vision and as such it is justified in creating an idealized model of the learning process (just as mathematical models of reality must assume idealized conditions to be able to develop a reasonably elegant theory). Can this vision be fully realized? It can, but mostly with an ideal learner (a bright and intellectually alert child), ideal teacher (knowledgeable, caring and sensitive), and ideal interaction (mostly one or two children to one computer to one teacher or, at least, a very supportive and constructive group work). Thus, besides the model itself, we must study its goodness-of-fit and work hard on its interface with reality. Education is an applied discipline, and even models that give us an extremely good approximation may fail to work satisfactorily because of the small error. We cannot hope for "elegant" solutions here. We can have elegant descriptions at "top level", and this is how I view *Mindstorms*. It lays down the Grand Scheme, but it must be elaborated and debugged to become operational, to better fit the real world.

DIRECTIONS FOR GROWTH

VII. Moderation

> "I have often been amused by the vulgar tendency of the human mind to take complex issues, with solutions at neither extreme of a continuum of possibilities, and break them into dichotomies, assigning one group to one pole and the other to an opposite end, with no acknowledgment of subtleties and intermediate positions - and nearly always with moral opprobrium attached to opponents."[1]

Consider the following opposing pairs:

* Piagetian learning (as defined in *Mindstorms*) vs. conservative classroom teaching.

* Child-centered approach vs. subject-matter-centered approach.

* Generalities vs. anecdotes in reporting Logo work.

* Rigorous, formal research vs. "anecdotal", informal reporting.

(The reader can add to the list many more examples from his or her own experience.)

Each of these pairs represents two opposing extremist positions that one can adopt (in fact, many do). However, it seems more useful to adopt a position somewhere in between. The most fruitful direction is, in my opinion, to study various such intermediate positions with an attempt to find a "golden middle" or, at least, to approximate it.

VIII. Debugging

Some people have found what I say too critical. (Apparently they agree, at least partially, with the content, but believe I should not be saying it aloud.) I find amazing the thought that the Logo community, of all people, should not be open to the "growing through debugging" philosophy when applied towards itself. Surely, the Logo movement is robust enough to allow experimentation and variation with its assumptions and ideas. This is not an ideological battle; it is an open discussion, in the academic spirit, of how to improve our understanding of and work in Logo. We all consider it natural enough that the implementation of the Logo language should go through many cycles of running and debugging. Just as well, I believe, should the Logo theory of learning be subjected to the same treatment, now that we have "run" it long enough. (For more specific "debugging" remarks on Logo, see my "Logo Today: Vision and Reality", 1985).

Incidentally, the only real criticism I have is the Logo community itself not being open enough to criticism-as-debugging. From many conversations with Logo workers around the world, I know that

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[1]Stephen Jay Gould, "Just in the Middle", *Natural History*, January 1984; quoted in "In Praise of Fingertips" (Allen and Davis, 1984

individual members of the Logo community possess much more wisdom and knowledge than the "official" knowledge of the community as it is reflected in Logo articles in books and journals. This is probably the main reason for the "lull" that occurred in the intellectual progress of Logo in the last four years: the Logo community has denied itself the very same conditions it has been advocating for children's learning, the very same conditions that seem to have nurtured the original MIT Logo Group. These conditions are mainly an open and supportive atmosphere for exploration and experimentation, encouraging the expression of criticism and "3/4-baked" ideas.

IX. Stages of Partial Understanding

A central feature of Logo learning that has recently begun to come to the fore is the importance (indeed, inevitability) of going through many stages of partial and vague knowledge before coming to "really understanding" a complex issue. (I call this "3/4-baked" knowledge, hoping to give it the respectability that "half-baked" knowledge seems to lack.) Thus, it may often happen that after you have worked with "normal" 12-year olds for several months and you ask "have they learned the effective use of sub-procedures?" (one of the outstanding powerful ideas in Logo), the answer is not clear. If you try to formally test their knowledge, you may conclude that they have learned very little. On the other hand, if you spend much time observing their work during those months, you clearly feel they have learned a lot. So what is really happening? I believe they are in an intermediate stage of vague understanding, which is partially workable (it enables them to achieve some of their goals in programming), is extremely important in learning any complex topic, and is very hard to be made explicit (hence much of the "no results" literature on learning Logo, or any other complex educational endeavor).

Now this phenomenon has a strong parallel in our learning of learning Logo (learning-squared Logo). I feel our current understanding of the Logo world is precisely at this imprecise stage. (This is certainly true about my own personal knowledge and, judging from the literature, the Logo community's knowledge as well.) Thus, I claim only a very modest status for what I am saying. Not only can I not prove my claims experimentally and objectively, not only can I not convince you that they are correct (if, for instance, my claims do not invoke in you any feelings of familiarity from your experience), I am not even absolutely sure about it myself and am likely to modify (debug) my ideas as my understanding evolves. This may not be a very scientific thing to do (talking and writing about matters one doesn't quite understand), but I believe this is about as much as we can do right now. Moreover, as the Logo-learning parallel suggests, this is probably the only way to come to a better understanding: expose our 3/4-baked ideas and findings, then try to improve upon (debug) them gradually. On the other hand, this does not mean allowing any kind of nonsense. I do believe that what I am saying is at least partially true or has at least some grain of truth in it -- after all, it is already a product of many cycles of debugging.

X. Unpacking

While it is important to have an integrated overview of the Logo world, it becomes crucial at a certain stage to scrutinize the individual components separately. Much of the heated discussion about Logo, by supporters and opponents alike, is rendered almost meaningless by treating "Logo" as a one-piece package: is "Logo" good or bad? Does "Logo" teach thinking (problem solving, planning, math, etc.)? Can children who fail in math in school succeed in "Logo"?

Here are some examples of issues that are often treated in the Logo literature as one piece, but that may be profitably unpacked. We then may experiment with the separate components and with various ways of recombining them in our actual work.

* Content ("powerful ideas") vs. mode ("Piagetian learning") in Logo. It is worthwhile, for instance, to experiment with variations on pure Piagetian learning and see how acquisition of some powerful ideas is affected. In a different vein, it is important to explicate as much as possible the mathematics that can be found in Logo (or in turtle geometry, or in programming in general), even though we may not know at the moment how this mathematics may be learned.

* Teaching in general vs. bad teaching. We seem to have overreacted to the situation often found in schools by equating teaching with bad teaching. As a result, there has been little discussion of the crucial question of what good teaching might be like and, in particular, what is the teacher's role in Logo.

* Curriculum in general vs. rigid and oppressive curriculum. This is similar to the case of teaching. By equating curriculum with bad curriculum, we miss the opportunity to discuss what a good curriculum might be like. In particular, because of the nature of the interaction with the computer, having a curriculum need not conflict with the child's freedom, control, and discovery learning. It also need not lead to tests and grades.

* Writing "socially" (to spread the Logo culture) vs. writing "scientifically" (to advance our knowledge and understanding of Logo). As I have said in the beginning, I do not consider our Logo work "scientific." Thus to me, writing "scientifically" simply means writing insightfully and responsibly. It does not mean formally or quantitatively.

SOME OUTSTANDING ISSUES

This section lists in a telegraphic style some fundamental issues pertaining to the Logo learning environment. The list represents a personal choice and is not meant to be comprehensive. However, its items all share the following two attributes: on the one hand, they are important to the cause of realizing more of the educational potential of Logo; but, on the other hand, our knowledge of them is not satisfactory. They are raised primarily as problems for further discussion -- no answers are supplied. Some brief remarks on some of the issues are made here, and some are elaborated further in "Logo Today: Vision and Reality" (Leron, 1985).

1. The teacher's role: how much intervention and what kind?

2. Curriculum and written materials: microworlds for specific topics.

Remarks on 1 and 2: My everyday experience in teaching Logo, as well as some specific studies undertaken at Haifa University, have convinced me that Piagetian learning alone (as described in *Mindstorms*) is not enough for the acquisition of many of the powerful ideas that are potentially learnable through Logo (see "Logo Today: Vision and Reality" 1985). To deal with this problem, we have devised a modified style of interaction, called quasi-Piagetian learning (QPL), in which there is a more active role given to teachers and learning materials, but the atmosphere of exploratory and meaningful learning is maintained. It is hoped that by experimenting with various such styles of teaching/learning, we may retain the benefits of Papert's Piagetian learning while, at the same time, increasing the amount of children's learning of important ideas from mathematics, computer science, and the art of problem posing and solving.

3.

The social factor: working individually, in pairs or in groups.

Remarks: In addition to the more obvious social and emotional factors, two more (cognitive) benefits from socializing are sometimes observed. One, verbalizing as a means to reflecting on the programming activities; two, new kinds of projects that help make the introduction of some powerful ideas more natural (e.g., using group projects to introduce state-transparent procedures, and other interface issues). However, the question of how to promote constructive (rather than competitive) interaction must be dealt with.

4. 3/4-baked knowledge in the context of programming.

Remarks: I see 3/4-baked knowledge as a necessary means to achieving a more complete understanding of complex ideas. However, this presents a serious practical problem: how should we deal with debugging difficulties faced by the children in the meantime? In order to maintain their autonomy, we would like children to debug their programs with only minimal help from the teacher. But in many cases, this requires a more complete understanding than they possess at that moment. The problem is that gaining mastery of a powerful idea is a long-term process, whereas successful debugging is an immediate need if the programming project is to continue. Another fundamental issue is how to define 3/4-baked knowledge in positive terms. In other words, what is it that the children do learn in the intermediate stages? What is the incremental entity in the process? How can we assess it?

5. How can we study (research) and report Logo learning?

Remarks: This is similar to the preceding issue -- one level up: once again it is the problem of working in a state of 3/4-baked knowledge; this time, our own knowledge. This seems to impose a severe limit on the amount of rigor, formality, and quantitativeness that is desired in our research. Whatever the research method, we eventually have to report our findings and insights. To improve the quality and usefulness of our reporting, it seems to me that the following ""don't"s" should be observed more strictly than they have been in the past.

* Do not mix "spreading the Logo culture" (a political/social issue) with "studying Logo learning" (an intellectual/educational issue). In particular, assume your readers are well acquainted with *Mindstorms*, so that there is no need to repeat the ideas found therein. (If they are not, refer them to it. You are not likely to say it better than Papert.)

* Do not mix the mathematics (or physics, or any powerful idea) you see in the children's work with the mathematics they have actually learned.

* Similarly, do not confuse the mathematics implicit in their activities with the mathematics they have actually required. (The turtle may be a "math-speaking creature", but we cannot automatically assume that the children always listen to

what it says.)

* Do not claim to solve the child's problems by giving the teacher more tools. For instance, do not call your article "learning recursion made easy" if all it does is give some more examples of recursive procedures. In contrast, the "little people" metaphor (see *Learning with Logo*, Chapter 7, (Watt, 1983), where they are called "Logo helpers") does seem to offer a genuine tool for the learner.

* Do not promote the creation of myths by reporting idealized or even just "favorably selected" anecdotes.

6. Psychological issues: children's conceptions and misconceptions.

7. Towards creating a unified computer science and mathematics curriculum.

   Remarks: Trying to get the best of both worlds: a procedural, experimental, activity-based aspect of math from computer science; a logical, deductive, declarative aspect from mathematics. A sample topic: functions and variables. By investigating various procedures with input and output, one can get an intuitive grasp of the mathematical notion of a function. Various other mathematical benefits follow. For example, having discovered experimentally (by checking many input values) that two procedures compute the same function, how can you be sure that this is true for all input values? This question leads naturally to studying the equivalence of algebraic expressions. The domain of definition of a function is encountered naturally and concretely as the set of those input values that trigger an error message of the type "PENCOLOR DOES NOT LIKE 7 AS INPUT." However, these topics are further removed from children's immediate interests and are not likely to be "picked up" spontaneously by the children. Again, a somewhat more structured approach seems to be needed.

8. The theory of Logo.

   Remarks: See "Theories of Logo" (Groen, 1984) and, in a different vein, "Putting Computers in Their Proper Place: Analysis versus Intuition in the Classroom" (Dreyfus and Dreyfus, 1984).

9. Developments in technology: hardware and software.

   Remarks: Some examples that seem to hold high educational promise are sprites, the creation of new microworlds, and the new language "Boxer" now being developed by the Educational Computing Group at MIT (see "A Principled Design for an Integrated Computational Environment", diSessa, 1985).

10. Super-issue: Logo and the educational system -- teachers and schools.

    Remarks: The success of Logo depends a great deal on the quality of Logo teachers, but we are not equipped to deal with teacher preparation on a large scale. Good books and other learning materials may give some help, but are not likely to solve the problem. A related problem here is how does one develop a "Logo culture" in a school?

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COMPUTER CRITICISM VS. TECHNOCENTRIC THINKING

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Critic (from Greek *kritikos* able to discern or judge)

1 : one who expresses a reasoned opinion on any matter involving a judgment of its truth, value or righteousness, an appreciation of its beauty or technique, or an interpretation . . . .

2 : one given to harsh or captious judgment.

-- Webster

. . . the critic may on occasion be called upon to condemn the second rate and expose the fraudulent: though that duty is secondary to the duty of discriminating praise of what is praiseworthy.

--T.S.Eliot

In the beginning, criticism is simple. Do I like it? My judgment is personal and intuitive. I answer to myself alone, and consider only the immediate object of my attention. Soon, however, something more is needed; taste must be justified. Others challenge our opinions and counter with their own, and even personal development eventually requires us to grapple with our reasons.

The Logo community faces the challenge of finding a voice for public dialogue. Where do we look? There is no shortage of models. The education establishment offers the notion of evaluation. Educational psychologists offer the notion of controlled experiment. The computer magazines have developed the idiom of product review. Philosophical tradition suggests inquiry into the essential nature of computation.

Each of these has intellectual value in its proper place. I shall argue that this proper place is a conservative context where change is small, slow and superficial. The crucial experiment, to take one example, is based on a concept of changing a single factor in a complex situation while keeping everything else the same. I shall argue that this is radically incompatible with the enterprise of rebuilding an education system in which nothing shall be the same.

Today, I am sharing with you the result of looking at a very different model for thinking about the dialogue between Logo and the world. This model is a department of thought that adopts the adjective "critical" in Webster's first sense. I am proposing a genre of writing one could call "computer criticism" by analogy with such disciplines as literary criticism and social criticism. The name does not imply that such writing would condemn computers any more than literary criticism condemns literature or social criticism condemns society. The purpose of computer criticism is not to condemn but to understand, to explicate, to place in perspective. Of course, understanding does not exclude harsh (perhaps even captious) judgment. The result of understanding may well be to debunk. But critical judgment may also open our eyes to previously unnoticed virtue. And in the end, the critical and the creative processes need each other.

> *. . . the large part of the labor of an author in composing his work is critical labor; the labor of sifting, combining, constructing, expunging, correcting, testing; this frightful toil is as much critical as creative . . . .*
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> --- T.S. Eliot

Computer criticism is in its infancy compared with the sister disciplines I imagine it emulating. Many would argue that it must always remain at best a lesser sibling since the objects, computational ones, on which it brings to bear its critical powers will never, in their opinion, have the stature of Shakespeare or the depth and complexity of social structure. I think history will gainsay this attitude. The computer is a medium of human expression and if it has not yet had its Shakespeares, its Michelangelos or its Einsteins, it will. Besides, the complexity and subtlety of the computer presence already make it a challenging topic for critical analysis. We have scarcely begun to grasp its human and social implications.

In this lecture, I shall be concerned with issues closer to earth: not with the highest reaches that computer criticism may someday attain, but with its daily practice here and now: with how people talk about computers when they argue such practical matters as policies for using computers in schools or the value of a new piece of software. Within this already restricted purpose, I shall concentrate on just one proposition: I believe that computer criticism is blocked at a stage that I think is properly called technocentric -- a term that captures an analogy with the egocentric stage in Piaget's model of the young child.

Egocentrism for Piaget does not, of course, mean "selfishness" -- it means that the child has difficulty understanding anything independently of the self. Technocentrism refers to the tendency to give a similar centrality to a technical object -- for example computers or Logo. This tendency shows up in questions like "what is THE effect of THE computer on cognitive development?" or "does Logo work?" Of course such questions might be used innocently as shorthand for more complex assertions, so the diagnosis of technocentrism must be confirmed by careful examination of the arguments in which they are embedded. However, such turns of phrase often betray a tendency to think of "computers" and of "Logo" as agents that act directly on thinking and learning; they betray a tendency to reduce what are really the most important components of educational situations -- people and cultures -- to a secondary, facilitating role.[1] The context for human development is always a culture, never an isolated technology. In the presence of computers, cultures might change and with them people's ways of learning and thinking. But if you want to understand (or influence) the change, you have to center your attention on the culture -- not on the computer.

One might imagine that "technologists" would be most likely to fall into the technocentric trap and that "humanists" would have a better understanding of the role of culture in the so-called "effects of

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[1]For example, an article from *Psychology Today*, cited below, grants that even the best software can be ruined by poor teachers. This is technocentrism.

the computer." But things are not so simple. People from the humanities are often the most vulnerable to the technocentric trap. Insecurity sometimes makes a technical object loom too large in their thinking. Particularly in the case of computers, their intimidation and limited technical understanding often blind them to the fact that what they see as a property of "the computer" is often a cultural construct.

I am not talking about simple misunderstandings that could be dispelled by a course on "how computers really work." You should rather think of the way sexist or racist stereotypes are rooted in, and supported by, the cultures in which we grew up. Computer stereotypes are as much cultural constructs as are stereotypes of women or blacks, and will be as hard to extirpate.

The struggle against sexism went far deeper than correcting erroneous beliefs about women. It has led to a re-examination of fundamental assumptions about human nature and about society. Combating technocentrism involves more than thinking about technology. It leads to fundamental re-examination of assumptions about the area of application of technology with which one is concerned: if we are interested in eliminating technocentrism from thinking about computers in education, we may find ourselves having to re-examine assumptions about education that were made long before the advent of computers. (One could even argue that the principal contribution to education made thus far by the computer presence has been to force us to think through issues that themselves have nothing to do with computers.)

1. What Logo Practitioners Need to Know

If you ask "what does a Logo practitioner need to know?" the answer goes beyond the ability to use and teach Logo. The practitioner needs to be able to talk about Logo, to criticise it, and to discuss other people's criticisms.

Talking about Logo has a political side: how do you reply when an administrator says he read in *Psychology Today* that "Logo doesn't work"?

It has a pedagogical side: Logo is at a stage where one very high priority is to talk critically about a first implementation in order to decide where to go next.

And talking about Logo has a culture-building side. The way a teacher talks to parents about Logo feeds back into the attitudes the child brings to class, and the way the teacher talks in class influences the talk about computers in the living room. The popular interest in computers gives every teacher the opportunity to influence the development of the "computer culture" not only in the school but also in the society at large. Taking that opportunity is part of teaching -- or at least of what teaching ought to be. Developing a discourse is at the heart of developing a culture, and a more textured and knowledgeable discourse about Logo contributes to the "Logo culture," the "computer culture," and to the "learning culture" in its broadest sense. It sets the cultural context for personal learning.

Finally, a more self-conscious discourse will help the Logo community become increasingly self-critical; not, by any means, to put itself down, but because, like Eliot writing poetry, we need well-honed critical thinking to carry out the "frightful toil" of responsible educational creativity. I don't think any of us is safe from falling into occasional technocentrisms. What is important is having a set of concepts that allow one to correct oneself -- and then having the sense and humility to do so.

2. Logo Didn't Deliver What it Promised

The following discussion of a "poor way" to talk about Logo will sharpen these remarks by making my point about the pitfalls of "technocentrism" more concrete.

The September 1984 issue of *Psychology Today* featured articles on computers and education. In one of these (by Dr. James Hassett), we read:

> *"In several studies comparing children who learned LOGO with control groups who did not, researchers at Bank Street College's Center for Children and Technology have been surprised to find that, as Jan Hawkins put it, 'Logo promises more than it has delivered.' . . . Bank Street researcher Roy Pea found no evidence of intellectual benefits on two planning tasks designed to measure the higher levels of thinking skill supposedly produced by LOGO learning."*

It would be frivolous to dwell on what the reference to promises and delivery evokes for me: the image of a "technological fix" -- the image of Logo driving a delivery truck loaded with crates of promises. But it is far from frivolous to examine what is presupposed and implied by treating "Logo" as an entity that can "produce" changes in thinking (or anything else!). "Does Logo work?" "Is Logo good for learning this or that?" All these turns of speech are signs of the technocentric stage of computer discourse.

Consider for a moment some questions that are "obviously" absurd. Does wood produce good houses? If I built a house out of wood and it fell down, would this show that wood does not produce good houses? Do hammers and saws produce good furniture? These betray themselves as technocentric questions by ignoring people and the elements only people can introduce: skill, design, aesthetics. Of course these examples are caricatures. In practice, hardly anyone carries technocentrism that far. Everyone realizes that it is carpenters who use wood, hammers and saws to produce houses and furniture, and the quality of the product depends on the quality of their work. But when it comes to computers and Logo, critics (and some practitioners as well) seem to move into abstractions and ask "is the computer good for the cognitive development of the child?" and even "does the computer (or Logo or whatever) produce thinking skills?"

As I already said: such language suggests a diagnosis of technocentrism. To confirm it, one has to look more closely at what lies behind the language. This I shall do from several perspectives in the following discussion. For the moment I note one. Technocentrism is often supported by a certain model of what a "rigorous" experiment in educational psychology consists of. I'll call this "the treatment model."

You take two groups of children. One group, the experimental group, is given a certain "treatment." (For example, these students are taught Logo.) The other group, the control group, is not given the treatment. Everything else is kept constant. After a suitable lapse of time you come back and apply a test to see whether the particular thinking skill that interests you is better developed in the experimental group than in the control group.

There is nothing wrong in principle with this "treatment" model. Some very good science is based on it. It is the standard model for testing medical treatment by drugs -- hence its name -- and, indeed, some very good support for Logo has come from it. For example, Clement and Gullo at Kent State University used it skillfully to show that certain cognitive and metacognitive skills developed significantly better in a group of children who worked at Logo than in a control group who worked at CAI. But the use of the model requires care, and technocentrism places unskilled users at risk.

The risk is greatest in the interpretation of negative results. If you need to know whether drug X reduces blood-pressure, you may fairly safely draw a negative conclusion from a "treatment model" experiment in which hospitalized patients were given X and no change in blood-pressure was observed. On the other hand, you would not deduce that drug Y does not increase fertility from the simple fact that hospitalized patients who received it had no babies. You would want to know more about other conditions that are known to be necessary. Nor would you deduce that ice is a bad material for building dwellings if you heard that I tried to build an igloo in Boston in mid-summer and failed. The right environment and, I presume, a high degree of special skill are necessary. Such a failed experiment would say much more about me than about whether "igloos deliver what they promise."

It is quite surprising that Dr. Hassett thinks that Dr. Pea's finding says more about Logo than about Dr. Pea. The experiment was based on a treatment model with negative results: children given Logo failed to show significant improvement on a particular test for cognitive change. Thus we know the experiment is at risk. Enter technocentrism. Pea's negative result is moderately compelling if you believe that Logo is a well defined entity (like drug X) that either has an effect or does not have an effect (the technocentric vision). However, the finding as stated has no force whatsoever if you see Logo not as a treatment but as a cultural element -- something that can be powerful when it is integrated into a culture but is simply isolated technical knowledge when it is not.

My analysis of Dr. Hassett's technocentric language illustrates the value of the idea of technocentrism, for it can explain, at least partially, the quite extraordinary fact that Dr. Hassett, and many others as well, seem willing to make so much of a very slim experiment on the effects of learning Logo. But to pursue the point, I have to develop the contrasting idea of Logo as a cultural element.

3. An Example of Logo as a Cultural Building Material

I choose a simple example of Logo being used as a "cultural building material" by a teacher trying to create a particular educational culture in his science classes at the Computer School, an alternative public junior high school in New York City's School District Three. George Franz, one of the school's two science teachers, has intellectual roots in the tradition of "open education" represented by such people as Lillian Webber (under whom he studied directly) and David Hawkins. The spirit of this tradition is captured in a paper by Hawkins marvelously entitled "Messing About With Science," in which he describes how he and Eleanor Duckworth introduced children to the study of pendulums by encouraging them to "mess about" with pendulums for a number of class hours that would horrify teachers who measure the efficiency of education by how quickly students get to "know" the "right" answers. But Hawkins was interested in more than right answers. He had realized that the pendulum is a brilliant choice of an "object to think with" (to use the language of *Mindstorms*) for building a sense of science *as inquiry* rather than as answers.

A mechanical (and to my mind trivial) way to meld the computer into Hawkins' kind of learning experience would be to provide computer simulations of pendulums. Franz did something much more subtle.

His idea was to get his classes engaged in "messing about with clocks" by challenging them to build devices to measure time more accurately than such spontaneous methods as counting "one chimpanzee, two chimpanzees . . . ." The students were encouraged to form small teams, each of which would build a clock -- defined for this purpose as anything that could measure time.

One enabling cultural factor here is that the science room at the Computer School is a good "messing place." It is like an old fashioned science lab in being well stocked with string and sealing wax -- and bits of plastic and wire and hamsters and snakes -- as well as being like a modern one in being well supplied with computers. So when the students let their imaginations go, they could find the odds and ends to make many kinds of clocks. One group worked with sand running out of a plastic container, several constructed some kind of pendulum device . . . and some made "clocks" in the form of Logo programs. It is good to contemplate this coexistence of clocks made of ancient materials and modern ones: wood and plastic and computers. The computer was "just one more material." I think that David Hawkins would have liked what happened.

One does not "need" a computer to mess about with making simple clocks. But the students' clock experience was made very much richer (as you can imagine for yourselves or read in a forthcoming Computer School publication) by the fact that everyone in the class, students and teachers, knew enough Logo and had enough access to computers to make computer clocks as well as clocks of sand and wood. Each different material extends the range of what the students can do, and the computer does so somewhat more than the others do. For example, it gave rise to more concern with calibration and more interest in concepts like calibrating by averaging over many cycles. It is more adaptable to using the same principles to measure very short intervals (human reaction times, for example) or very long ones. A computer clock could be adapted to measure the speed of model cars the students were building out of Lego. In short, the presence of this additional material never took over the project -- the traditional materials retained their interest -- but greatly enriched the clock culture that grew up in the science room of that school without changing its nature. Since everyone knew some Logo, even those who did not make their own computer clocks could understand those made by their classmates.

If Logo contributed to the growth of the classroom culture, this clock culture contributed simultaneously to Logo. Several students came to understand technical aspects of Logo they had not learned before. For example, some who had resisted using variables asked "what was that thing with dots?" when they needed the idea to go from analog to digital clocks. I think all of them took another step towards appreciating Logo and the computer in a way that seems to be beyond the comprehension of many educational psychologists: using the computer not as a "thing in itself" that may or may not deliver benefits, but as a material that can be appropriated to do better whatever you are doing (and which will not do anything if you are not!).[2]

4. Two Educational Cultures

In School A (which I leave unnamed since I am neither personally in sympathy with its culture nor interested here in arguing against it), the students meet Logo in a computer room (misnamed "lab") where each sits down in front of a machine and are taught what the school system's educational objectives describe as introductory programming: turtle commands, subprocedures, variables, recursion . . . and so on. The sequence is planned and orderly.

School A uses Logo as part of a conservative educational policy. But it is innovative in how it does this. One local innovation, typical in spirit and ingenuity of several that have been invented or

[2] This incident gives a glimpse of a use of Logo that will become more prominent as the computer culture matures. Up to now, one usually sees two kinds of work with Logo in schools: exercises and projects. An exercise is a task set by a teacher or a textbook as a teaching strategy; a project is a longer term enterprise, ideally undertaken by a student out of personal interest. The initial work with clocks fell into the project category. But when the clock programs were adapted to measure the speed of the model cars, the computer was being programmed by the students as a tool that served another task rather than as a project in its own right. The students had truly appropriated the computer.

re-invented at this school, is the theory that computers should be so arranged that the students sit with their backs to the teacher's station. That way, when the teacher calls for their attention, they are forced to turn around -- away from any temptation to see their screen or fiddle with their keyboards. School A is innovative, but at a heading of 180 degrees to the kind of innovation we saw Mr. Franz making.

The absurdity of the technocentric question "what is THE effect of Logo?" becomes plain when one tries to imagine what is common to these two Logo experiences. Both involve Logo, both involve computers, and I am sure that one could devise tests to show that they share some very generalized educational consequences. That would satisfy the technocentric kind of education evaluator. Yet it would be sadly missing the point of Logo. For the two educational enterprises have different goals and have used Logo for quite different purposes. What is most important to each is *not* shared: they use Logo not to become more alike, but rather to develop their individuality. In the end, each becomes more purely itself and so more distinctly different from the other.

5. The Right To Be Me

The principle that Logo can be used by two schools to become more distinctly different has a counterpart on the level of the individual. In *Mindstorms* and in the Brookline Report, there are examples of students who use very different styles in their work with Logo. But the idea of students appropriating Logo in very different ways did not mature until we reached a point where children could have sufficient access to computers that their individual styles developed in more strikingly divergent ways than was possible in the more confined conditions of the early experiments. I became aware of something deeper than we had seen in early work while collaborating with Sherry Turkle on observations that are reported most "thickly" in her book *The Second Self: Computers and the Human Spirit*.

It will be recalled that what Dr. Pea's experiment failed to find was evidence "on two planning tasks" for the thinking skills "supposedly produced by Logo." Dr. Hassett quotes this finding without asking who supposes that the thinking skills produced by Logo would show up particularly well on "planning tasks." But the answer to the question he does not ask is easy to find: "everyone" knows that computer programming uses the kind of thinking one needs for planning -- precise, abstract, analytic descriptions.

The point is that this is the way our culture represents programming. But when we studied what children do with Logo, we see a very different picture. Some do indeed fit the cultural stereotype. For them, work with Logo is an occasion for the exercise of planning. But many do not. Many find in Logo their first opportunity to work with mathematical ideas in the kind of broad-brush intuitive style that comes naturally to them. They are not led by Logo into conforming to the planning style even more closely than school already tries to make them do. On the contrary, in Logo they find a liberation from a style that distorts their natural way of being as surely as forcing left-handed children to use their right hands.

Dr. Pea's criterion for how Logo is supposed to improve thinking skills implies that we should be disappointed to see these students find a different voice[3] for learning. This is a good example of the conservatism inherent in traditional experimental methodology.

[3] I intentionally use the phrase Carol Gilligan invented for a similar phenomenon in the area of moral judgment.

6. Do Not Ask What Logo Can Do To People, But What People Can Do With Logo

These two questions lead to quite different models for how to do research. Technocentric thinking favors the "treatment" methodology. This is appropriate for investigating the effect of a drug. And if you have read Inhelder and Piaget on formal stage thinking, or if you were taught "the scientific method" at school, you probably know that the way to do an experiment is to change one variable at a time while keeping all other things the same.

This works well for certain kinds of school science experiments, such as finding out how a pendulum's weight, length and amplitude affect its period. But does it work for education? How do you apply this methodology if you are Geraldine Kozberg of the St. Paul Public Schools and want to use Logo as an instrument for change?

Ms. Kozberg's initial interest in Logo came from an intuition that introducing Logo into the schools could be used as an occasion to bring about other changes -- not only in the way teachers did their work in the classroom but also in the relationship of the community to the school. The initial excitement about computers in the classroom could be used to bring parents to workshops; discussions would start off dealing with computers, but then move on to education as a collaborative endeavor.

This is the methodology of an educational activist. Instead of introducing Logo and keeping down other change (which appears to the activist as subverting the very thing one is hoping to do), here one introduces Logo and then works as hard as possible to make all other things as different as possible (which can appear to experimentalists as subverting as science).

The Computer School in New York's School District Three (Upper West Side including West Harlem) gives us another example. This new, alternative public school is attended by about 150 students, many of whom come from severely disadvantaged backgrounds; during the school year, the computer presence grew in numbers from about 20 to 60 machines. The school's policy is that all students learn Logo and the use of a word processor, but beyond this, the teachers adapt their styles of work very differently. Some have looked for ways to adapt method and content in their subject areas to take advantage of the computers. Others believe that advantages will come less directly and more gradually.

This is not a controlled experiment on "the effects" of Logo. It is an attempt to create a working educational environment in which 60 computers and Logo are important elements -- but so are nine teachers with nine personal approaches to education who are trying very hard by all possible means to make the school a success.

The methodological issue comes into clear focus when we look at successes in areas having the least direct connection with "computer work." For example, the Computer School was significantly ahead of other schools with children from similar backgrounds on reading and attendance scores.

Psychologists trained in the "treatment" methodology have been taught to ask questions like: "how can we measure the extent to which Logo contributed to these scores?" These psychologists repine for controlled experiments that will distinguish between the contributions of each of many possible factors. What experiment would tell us whether factors such as the teachers' enthusiasm (or attention from visitors, or the students' sense of getting something special) contributed to the high scores? But there is no need to wait for experiments: of course such factors play a significant role.

This does not mean that the computers were not important; rather, it reminds us that the importance of each element in a cultural process can show up in many ways. These teachers came together in the first place to create a school that would use computers in a Logo spirit. Without the computers, the school would not have existed at all. Discussing, sometimes even fighting, about what to do with Logo created a relationship between the teachers that colored the atmosphere of the school. So, I am sure, did the fact that everyone in the school knew that student X was, until this year, considered to be "learning disabled" but is now an ace with the computer -- this particularly dramatic example of someone who went beyond what seemed possible surely contributes to the atmosphere of the school. One could continue almost indefinitely to list ways in which the computer presence could be woven into the consciousness of the people in the school -- and so make a difference to how students learn and whether they want to come to school.

There is a radical incompatibility between studying phenomena of this sort and using the "treatment" method of research. A simple argument for this point is the incredible number of experiments one would have to do in order to isolate these factors one by one. But there is a deeper argument. Factors of this kind simply don't work one by one; they work as a web of mutually supporting, interacting processes. The illusion that more than a tiny fraction of the educational benefits could be demonstrated by experiments on the treatment model is simply another form of technocratic fallacy.

Let me express the same idea in a different way. It is a self-defeating parody of scientism to suppose that one could keep everything else, including the culture, constant while adding a serious computer presence to a learning environment. If the role of the computer is so slight that the rest can be kept constant, it will also be too slight for much to come of it. The "treatment" methodology leads to a danger that all experiments with computers and learning will be seen as failures: either they are trivial because very little happened, or they are "unscientific" because something real *did* happen and too many factors changed at once.

7. Bank Street vs. Kent State

My purpose here is not to survey good reports about Logo. But I shall discuss one. One often hears that reports of good Logo environments are "anecdotal." This word is used as a derogatory form of the adjective "ethnographic" and in contrast to a more "scientific method." I do not agree with the derogation of the case study approach, but even if one's taste runs to methodologies which emphasize statistical rigor, there are other studies than that of Dr. Pea. For example, Clement and Gullo of Kent State University conclude from a careful and statistically orthodox study that a group of children who worked with Logo showed significant improvement on a battery of tests designed to measure a range of cognitive skills.

Pea and Kurland are negative, Clement and Gullo positive about what happens when children learn Logo. One can look at the difference from two sides -- analogous to the supply and demand sides of economic theory. The experimenters demand a certain performance from the students as a condition for success; and certain educational conditions are supplied to the students for the purpose of achieving this performance.

On the demand side, that is to say on the tests used, the experimenters are fairly explicit about their differences. Pea and Kurland approach their experiment with a very specific idea of what cognitive effect to look for: they are checking for an improvement in a very narrow and specific form of planning activity, so they use a focused ad hoc test. The Kent State workers approach the problem with a relatively open mind about what the cognitive effects of doing Logo might be: they apply a broad spectrum of well known, standard tests of cognitive function (amongst many others: divergence, reflectivity-impulsivity, operational competence, right-left orientation, Matching Familiar Figures, and following directions). Even before one sees the results, it is obvious that the Kent State experiment stands a much higher chance of coming out positive as, indeed, it does.

The supply side is more subtle. What are the children given? Stated abstractly, the two studies have the same explicit intention: the children are to be given "programming" -- and the purpose of the experiments is to see what happens. But there is no such thing as "programming-in-general." These children are not given "programming." They are given Logo. But there is no such thing as "Logo-in-general" either. The children encounter Logo in a particular way, in a particular relationship to other people, teachers, peer mentors, and friends.[4] They don't encounter a thing, they encounter a culture.

Both studies are flawed, though to very different extents, by inadequate recognition of the fact that what they are looking at, and therefore making discoveries about, is not programming but cultures that happen to have in common the presence of a computer and the Logo language. But the flaw is fatal only in the Bank Street case. I would be rather surprised (though pleasantly so) if the cognitive changes measured by Clement and Gullo turned out to be repeatable for all children in all encounters with Logo. However, their study *has* added to the collection of serious reports about phenomena occurring in some Logo environment. Perhaps it will lead to recommendations about how to design Logo environments so that most children would experience the developments it reports. I cannot see how anything useful can be derived from the Bank Street finding that the children did not meet Dr. Pea's criteria of planning.

8. ExperLogo: Designing a New Logo

In the near future, Logo practitioners will have a new kind of challenge in choosing among varied forms of Logo. Up to now, the differences among the versions of Logo available for the major educational computers strike many people as being able to choose any color as long as it is black. I believe that this is a mistaken view; some of the seemingly very small differences between versions can make a difference. But these are inconsequential compared with larger choices that will be presented as Logo implementers take advantage of greater machine power.

In this context, I do not mean to speculate about what new directions Logo will or should take. There certainly is no single "right direction" -- Logos will be varied and flexible. What I want to discuss here is how to discuss the choices that will be offered. And, once more, I shall concentrate on just one issue: the difference between technocentric thinking and a style of computer criticism that has learned to think in terms of cultural phenomena. As I used an article in *Psychology Today* as a springboard for an earlier part of my talk, my springboard here will be a product review in *InfoWorld* of a new version of Logo for the Macintosh known as ExperLogo.

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[4] Logo environments differ in many relevant ways that are not mentioned in the reports of either study. I have become impressed with the fact that diagrams on the walls can influence what projects the students want to do and how they think about Logo. Several of my colleagues and students have been probing the diversity of factors that make a difference. Aaron Falbel has pointed out that it makes a possibly important difference whether the children see adults programming in Logo for themselves. Do the children think of Logo as a "schoolish" activity for children, or a "real-world" activity for grown-ups as well? Steve Ocko and Mitchell Resnick have built microworlds in which the active object differs only in appearance: as a turtle, a car, an insect, a ferris wheel, etc. This allows them to see boys and girls engaging differently with what is formally the same microworld. Sylvia Weir associates certain Logo styles with spatially oriented children and Sherry Turkle associates Logo styles with personality. In both cases, one must expect quite radically different relationships with Logo depending on whether each individual's development of a particular style is (tacitly or explicitly) actively encouraged, simply permitted, or discouraged. Robert Lawler has documented in dramatic abundance how personal one child's appropriation of Logo turns out to be when you look at it in its fine detail.

This product review (*InfoWorld* of May 13, 1985) is perfectly technocentric, and I assume that its author would take this as praise rather than negative criticism. This is what product reviews are. They consist of lists of features and faults of a technical object. Their strength is efficiency in passing information when they are written and read within a culture. For example, professional programmers looking at Logo are likely to be interested in such questions as:

* Is it fast? (since Logo is notoriously slow compared with their languages)

* Does it compile? (since the idea of a Logo compiler has been around for a while as an obvious technical challenge) and

* How does it move data? (since Logo is seen as a language for "toy" programs that may use interesting ideas but do not do useful work).

The review asks questions like these and gives ExperLogo a decent rating (one *excellent*, one *fair*, and the rest *good* on its standard report card). But a very different kind of discussion is needed if the purpose is not giving grades but placing the object in a cultural context. This is especially important since ExperLogo is the first serious[5] Logo to be produced by a team which, in my view, has a different set of cultural values from those represented by Standard Logo. The job of serious criticism is to recognize such cultural discrepancies and explore their consequences.

ExperLogo is, according to the blurb on its packaging, "a powerful adaptation of the Logo computer language . . . loaded with innovative features. In addition to standard Turtle graphics, Experlogo introduces Bunny Graphics where bunnies frolic on the surfaces of spheres and race through 3-D space. Incidentally, we call them bunnies because they move incredibly fast, at speeds up to 100 times that of the turtle in other Logos."

I have a certain family feeling for people who are trying to design an implementation of Logo since I have been involved in designing many. But for readers who have not lived through anything like it, I preface my discussion of ExperLogo by talking a little about the experience of designing so complex a system as a programming language. The experience is itself complex: both exhilarating and painful. What is exhilarating is inventing the features of a cognitive space where people will work, live for a while, and move around. What is painful is choosing among them; there is only so much that can be included; most "bright ideas" have to go. The ever present question is: "what will we give up?"

Among the decision rules I personally use for this job, two principles have come to be most important: "effects" are in the service of syntonicity, and syntonicity is in the service of intellectual depth. To show you how this works, I will use an especially familiar example in Logo: the turtle and the power of the turtle circle.

Everybody who has worked with Logo knows the joy a child can get from the surprising discovery that turtles can draw circles. For me, the mathematician watching the child, there is another joy: anticipation of the development of something that the child cannot yet know. From a beginning such as REPEAT 1000 [FD 1 RT 1], the child will be moving on a significant mathematical track -- passing through REPEAT 360 [FD 1 RT 1] -- to a procedure whose input is the radius of the circle it will draw. At the mathematical heart of this procedure is the use of a variable in the instruction

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[5] I count versions of Logo as "not serious" when they reduce the power of Logo (to Turtle Graphics for example), or when they are implemented on a machine that does not reach significant numbers of people, or when they are so eclectic as not to show any consistent set of values in their technical choices.

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REPEAT 360 [FD :stepsize RT 1]
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and the safe feeling (which we shall see in a moment is undermined by ExperLogo) that you don't have to think about what :stepsize will be. Whatever it is, the turtle will draw a circle.

What is important here is that the "holding power of the turtle" -- in my view based on the user's ability to identify with it physically (everyone, whether child or adult, learns to draw the circle by "playing turtle") -- fits so smoothly into the development of powerful mathematical ideas. This is *my* aesthetic. This, for me, is what makes something beautiful. This, for me, is what has cultural importance. The designers of ExperLogo have another aesthetic. Contrasting the two provides a lesson in computer criticism.

What is beautiful for the designers of ExperLogo is the speed of their bunny. I, too, would like speed -- and an ideal implementation of Logo would allow you to choose between, let's call it a hare, that would outstrip even the bunny and, let us say, a tortoise that moves slow enough for you to think about what it is doing as you watch it. But in the real world there is no such thing as an "ideal" implementation of a computer language. At the core of the process of design is the art of trade-off. If you want more speed, you have to take less of something else. Observing what a design team finds worth giving up is a window into its aesthetics and its intellectual values.

The bunny gains speed at the cost of a kind of intellectual power that may be of no consequence to a professional programmer working on expert systems, but could be highly consequential in shaping a child's computer culture. Since this choice is made consistently in ExperLogo, I could give many examples, but shall select one: the way Bunny commands deal with their inputs.

In standard Logo, REPEAT 100 [FD 0.1] has the same effect as FD 10. For me, this is very important. When a child is manipulating Logo, it is important that this child also be able to gain a personal sense of manipulating fractions and to follow intuitions of natural expectations -- for example, seeing that what is "on the computer" follows the rules of multiplication that apply in the world outside the computer. In ExperLogo, bunny speed was bought (in part) at the cost of making FD treat its input as an integer. So, 0.1 is simply treated as 0. REPEAT 100 [FD 0.1] is the same as FD 0. Thus the relationship between Logo and mathematical intuition is impaired, and the passage into mathematics through the turtle circle is impeded. In ExperLogo, the instruction

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REPEAT 360 [FD :stepsize RT 1]
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will sometimes draw a circle. But if :stepsize happens to be less than one, it will draw nothing.

What kind of decision did the ExperLogo team make in choosing speed over mathematical transparency? The point is not whether the choice is right or wrong but what it tells us about the decider. There is no obligation to be interested in fostering early development of mathematical values or nurturing a "mathematical aesthetic" in novice computer users. The designers of ExperLogo have the right to give higher priority to speed. But this *is* a choice. And each choice is a reflection of cultural affiliation.

For the computer critic, what is at stake goes beyond whether children use ExperLogo to develop programs for turtle circles -- or even whether their Logo experience undermines their sense of mathematical values. Also at stake is the discourse about computing -- the way teachers, parents, and children think and talk about it, the way that talking about computers is integrated into talking about other topics such as mathematics. The crux of my own ideas about computers and learning is that their deepest role is cultural rather than instrumental. What is important about the turtle circle is not that the child drew a circle, or how fast the bunny frolicked, but that this way of working into the drawing of circles provides new ways to think about circles, and through them, new ways to think about mathematics more generally.

At the risk of belaboring what will be obvious to those who have grasped the point, I end this section by describing two imaginary classrooms.

In teacher X's room, the culture that has grown up around Logo is more than usually focused on the "spectaculars." X happens not to have thought much about Logo's mathematical values, and has not encouraged the children to adopt ways of thinking that might be offended by violating those values. Thus X is creating a different culture around Logo than teacher Y, who has worked at encouraging the children to feel continuity between REPEAT and multiplication and to feel safe with variables by understanding *stepsize* as "just a name."

9. Logo: The "Cabbage Patch Kid" of Computation?

I began by announcing that my intellectual source for this lecture was literary criticism. This source might not have been visible throughout, but its influence was there. For the individual and historically, literary criticism begins with one person and one poem: with one person's taste for a particular piece of writing. Its development is a process of *decentering*: it rises above the individual reader and above the individual work. In its maturity, it never leaves the intimate experience of reading the poem -- which becomes part of a much larger one: the individual's taste is never purely individual but a reflection of culture, and the poem is not an isolated entity but a moment in a literary movement. In a parallel way, I have sought to decenter the perception of the Logo experience. We are not looking at the effect of a technological object on an individual child, we are looking at the workings of a cultural process.

In the previous paragraph, I talked about microcultures on the level of a school or classroom. I would like to conclude by talking about some aspects of Logo in the larger macroculture, and as a first example, I will discuss a relatively superficial cultural process.

Over the past few years, there has been a change in the media's perspective on computers in education. Until sometime in 1984, most writing about computers and children had an upbeat, almost "gee-whiz" tone. One could scarcely open a magazine without being reminded that journalists had discovered that one of the most photogenic scenes of our age was a child in front of a computer screen. The light from the screen catches in the eyes and you get a really marvelous effect, just a beautiful picture.

I have suggested elsewhere that backlash was inherent in this situation: there had to arrive a point when no one could stomach the picture one more time nor the euphoric hype that often went with it. But since the media must find something to say, the next thing that was newsworthy was that computers are bad. Thus followed a spate of such negative articles. This shift has little to do with anything new that has been discovered about children and computers. We are looking at a pendulum swing. Indeed, we may predict a new phase of euphoria a few years down the line.

One might find it annoying that events of this order affect our "serious" work. But they are part of the reality of education. I don't simply mean that the mood of the press influences how easy it is to get a budget approved. More importantly, it is part of the social perception of the computer. It doesn't merely influence the educational process, it is an essential part of it.

Recall the analysis in *Mindstorms* of the new Math and how it differs on a social dimension from what we are trying to do today with Logo. In my view, one important root of difficulties in mathematics education is the social construction of mathematics in our culture as an alienated thing. This social construction is a dominant aspect of any non-technocentric view of mathematics education. Yet in the discussions that led to the New Math, the focus was not on concepts like alienation and culture, but on concepts like logical parity and what was fashionable in the mathematics community at the time. The result was an even more alienated form of mathematics. I don't say that this was the only reason for the minimal effects of the New Math movement -- it had other flaws as well -- but this one would have been sufficient.

We are in a very different place today. Using the computer as a carrier of mathematical learning means that we can channel the social attitudes surrounding computation to energize the way that mathematics and other subjects are learned. Again, I do not say that such social phenomena are the whole story. The relationship between the individual and the computer in the microculture of the classroom (or other learning environment) is obviously central, but the larger social movement is a very significant force. Logo practitioners must learn to integrate it into their thinking.

The first step is to pay attention to the individual manifestations of cultural movement around computers: the pendulum swing of the media attitude, the rise and fall of debates about video games, the place of computers in movies and television, and the often more pretentious and occasionally more significant discussion in books and professional journals. For example, the summer 1984 issue of the *Teachers College Record* (published by Columbia University) was devoted to a "critical look" at computers in education. The message: computers are bad for children; Logo in particular is a serious threat to their mental health.

A second step is to use the interest they might arouse. One can look at the *T.C.R.* in many ways. One can dismiss it as drivel. One can become angry. One can take it seriously and launch a King Canute-like campaign against computers. Or, and this is what I think we ought to do, one can treat it as a cultural event to be understood, and perhaps even made the occasion for discussion in a school, a P.T.A., or a community. The centerpiece of such a discussion could be the view of the computer as a cultural element. Many of the features of the computer that the *T.C.R.* authors found objectionable are not features of the computer but of the ways in which computers are constructed, used, and represented.

For example, Douglas Sloan (then editor of the *T.C.R.*), in a public debate with me at the 1985 American Orthopsychiatric Meeting, was angry about the difference between color on a computer screen and the watercolors used by children in "real painting." He felt that working with the computer screen had far worse effects than undermining artistic development: it fundamentally changed the child's relationship with reality. We all know that the colors on school computers are less than ideal, but why is his reaction so intense? My interpretation of his position is that the difference between watercolors that run and shade into one another and computer colors as Professor Sloan understood them captures the feature of the computer that figures most prominently in a common anti-technological construction. The computer is digital, binary, all-or-none; the real world is an ultimately ambiguous continuum. I would share his anger if I felt that the minds of children were being molded to inflexible patterns. Indeed, I have expressed similar outrage at what I see as the two major influences in this direction in our society: school and the misuse of the computer. Nothing is more digital than school math, nor more guilty of sensory impoverishment.

The easy reply to Professor Sloan is to say that we have made Logo quite explicitly to provide a glimpse of how learning need not be "digital." We are entitled to claim some credit for warning that school as it is exposes children to the very risks which Professor Sloan fears in the context of computer learning. But this reply slips too easily into technocentrism. The challenge to school, in its traditional forms, cannot be made by simply dumping computers and computer languages, however well designed, into classrooms. The schools will assimilate the computer to their traditional culture, and Professor Sloan will be proved right. A more effective answer to Professor Sloan would consist of extending computer criticism beyond technocentrism: it would call into question social structures and cultures that existed before the computer. By describing the beginnings of a new computer culture, it would give us glimpses of possible alternatives. It would show, paradoxically, the "humanists" of the *Teachers College Record* as victims of technocentrism no less than the technologists themselves. It would pose sharply the problem of education as requiring a new alliance of intellectual trends in which the Logo community would have a proud position.

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THEORETICAL PAPERS

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