

Constructivism in the **C**omputer Age

Edited by

George Forman

Peter B. Pufall



Constructivism in the Computer Age

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This volume is dedicated to the memory of Joachim F. Wohlwill, whose contributions to the Jean Piaget Society and to the field of developmental psychology extend far beyond his chapter in this book. Although he will live on in his published work and in our memories, we shall miss him deeply.

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Preface

In the Fall of 1983 the board of the Jean Piaget Society decided on the topic for the Fifteenth Annual Symposium to be held in June of 1985: Constructivism in the Computer Age. We stipulated, however, that this convention would be more than a computer fair to display the latest educational software. It was reasoned that computers will have a great effect on our research and our systems of education, and therefore needed to be evaluated in the light of developmental theory. Bill Damon (Clark University) helped draft a statement of purpose and the board recommended that it be sent to invited speakers. The following is a reprint of that statement of purpose for the 1985 symposium:

Intellectual development has always been interwoven with cultural progress. Breakthroughs in the science of knowledge representation and information processing, made possible by inspired individual advances, eventually transform the learning climate for all members of the culture. This dynamic interplay was apparent to Piaget in his studies of genetic epistemology. It was Piaget's cherished belief that cognitive achievements in society and in the individual go hand in hand, and should be studied in the light of one another.

At the present time we are witnessing a series of rapid cultural achievements resulting in an unusually sudden advance in our society's ability to process information. The source of this advance is the breakthrough in computer technology that has made powerful new computational skills and modes of representation available to wide sectors of the population. The miniaturization of memory storage devices, combined with inexpensive production techniques, has given the average person access to electronic tools for manipulating information and for representing events both physical and psychological. Just as paper and pencil make it possible to reason in ways that exceed the limits of our native short term memory, so too the microcomputer may allow us to extend our cognitive reach into further unexplored territories.

The computer revolution has occurred so quickly that we have not had time to examine some very basic issues related to the nature of computer-based intellectual activity. These issues are critical for an enlightened evaluation of the computer's proper use in education and knowledge construction. The following are issues that we believe need to be addressed at this time.

1. What is the nature of computer-based extensions of human intelligence? Is it mainly memory space that is being added when we use computers? Or does the computer enhance our symbolic facilities, allowing us to "see" our own thoughts in new modes of graphic representation? Could this cause us to understand self and world in different ways? In what sense does the computer externalize the functions of the human mind, and to what ultimate cognitive benefit?

2. What is the relation between natural language and artificial language? If we create a cultural network of intelligent machines that speak artificial languages like ADA or LISP, what will conversing with these machines do to our natural communication and problem-solving habits? What is the best level of abstraction for the building blocks of a computer language? Does making a language user-friendly place inherent constraints on the power of the computer language to improve our general problem-solving skills? Might we ourselves discover new communication skills from conversing with computers that inform us when and how we are not explicit?

3. What forms can the person-computer interface assume, and how can various forms be adapted to serve the educational needs of children at different developmental levels? Is the rush to teach children programming at the keyboard as misguided as our earlier rush to teach preschoolers reading? What are children learning when they learn to program in LOGO? At which developmental stages should digital systems, such as print, be introduced, given that kinetic icons are now possible as a viable alternative to print? Can computer applications be designed to foster the cross-modal integration of knowledge that young children need? Can computer techniques, such as hypertext, the simultaneous use of multiple modes of representation, increase the student's depth of understanding and range of application of subject matter?

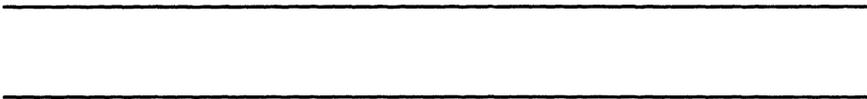
This statement of purpose was a general guide for our speakers and the panel discussion that occurred among our speakers one Friday evening in June 1985. The book that you now see has taken some of these questions to task and added others. It should be an interesting study in the evolution of this project to compare the preface of this book with the epilogue, which is a summary of the actual 1985 symposium.

Several people deserve special mention. Barbara Presseisen (Research for Better Schools, Inc.), a diligent board member, worked many hours in helping to fund this conference and to formulate its mission. She was instrumental in obtaining a grant from the Research for Better Schools, Inc., to whom we are most grateful. I would also like to give special mention to Don Nix of IBM who gave a special workshop on interactive video disks and his authoring system called "Handy." This was an extremely successful workshop. We were also

pleased that Alan Kay, then at Apple Computer, gave a plenary address on his pioneering work at the Xerox Palo Alto Research Center and his current ideas on computer enhancement of intuitive knowledge. While he was not able to write a chapter for the book, he certainly has influenced its content. Those of you who attended the symposium will also remember the fine contributions of James Levine (University of Illinois) and Roy Pea (New York University) who gave plenary addresses. Finally, our Series Editor, Lynn Liben did much to keep us on track and task as the book grew to full size and shape.

George Forman
Peter B. Pufall

Piaget in the Computer Age



The Conservation of Piaget: The Computer as Grist to the Constructivist Mill

Seymour Papert
Massachusetts Institute of Technology

INTRODUCTION

Piaget taught us to say that the child has conservation when something is recognized as unchanged in the midst of flux. When water is poured from one glass to another, the height, the depth, the apparent color all change. Yet the child staunchly maintains, “It’s the same.”

When Piaget is poured into a new decade, much will change. Whether one has conservation of Piaget will depend on what one perceives as most important in the thinking of the great master. My own view is that the essential aspects of his work have not fallen by the wayside. On the contrary, they are stronger and more relevant than ever.

One of the most striking changes in this past decade is that computational objects have become a new and very prominent part of the lives of children. They are understood by children in ways very different from how traditional objects are understood and therefore warrant special study. Piaget might have liked to study these new objects, but the most we can do is conjecture what he would have thought. If our own research produces results that seem to challenge Piaget’s thinking, then we might conclude that his ideas are wrong or obsolete. And in certain cases, what he actually said turns out not to be exactly true—but something better is true, something even more Piagetian.

Some of what Piaget believed will have to be changed. But whether one sees this as disproving Piagetian theory or as elevating it to its next stage of development depends on what one counts as most important in Piaget. Not everyone would agree with my perceptions. The Piaget I discuss here and find so relevant to the study of children and computers is not the same Piaget one usually

encounters in standard American psychology courses. In my Piaget, stages and even most senses of “active learning” are quite secondary. I focus instead on his constructivism and structuralism.

The “conservation of Piaget” metaphor has a second meaning as well. In the new and vigorous field of research on children and computers, people are writing as if Piaget never existed. For reasons that might be obvious to a sociologist, educators and psychologists entering this field look for theoretical inspiration from areas of cognitive science that have not connected with Piagetian ideas. The examples I discuss here might convince them that Piaget offers them much that is valuable.

Thus, this chapter has two messages. For those interested mainly in Piaget, it draws attention to children and computers as an interesting domain for study. For those primarily interested in children and computers, it serves as a reminder that Piaget is a rich mine of ideas.

PIAGET'S CONSTRUCTIVISM AND STRUCTURALISM

The title of Piaget's seminal book on number is a good example of the way in which translation of Piaget to America has subtly yet systematically undermined his emphasis on constructivism. Compare: *The Child's Conception of Number* and *La genèse du nombre chez l'enfant*.

To my ear, the English title suggests a static picture: there is a thing called number, and children have a particular conception of it. The French title suggests the dynamic, process-oriented way I read Piaget. Number is not something with an independent objective existence that children happen to have a particular conception of. Instead, the study of number is the study of something in evolution, something in the process of construction. Children don't conceive number, they make it. And they don't make it all at once or out of nothing. There is a long process of building intellectual structures that change and interact and combine.

These remarks give only the faintest flavor of Piaget's constructivism, but they certainly show the contrast with studies of computers and children. The intellectual frame for nearly all these studies is an objectively given computer interacting with a child. There is little hint of any thought that the child's conception of the computer might be important and different from that of the researcher—and no trace of any idea of the child actually constructing the computer.

A striking exception to these deficiencies is Sherry Turkle's (1984) *The Second Self*. Turkle carefully distinguishes between “the instrumental computer” and “the subjective computer.” The former is what exists out there objectively. The latter is what people construct in their minds. Her work on the issue of whether children believe that computers are alive is an excellent example.

Alive and Not Alive— Construction of the Psychological

Piaget studied children's opinions on what is alive and not alive. Stated in the simplest terms, he concluded that young children think that whatever moves is alive—and they only gradually come to separate living from moving.

This is quite understandable in the case of traditional objects. People and pets are the prototypical living things, and they are the prime movers. Stones and clouds also move—and are seen as lifelike even by adults in poetic moods. Children always view stones and clouds as alive until they begin to use categories of thinking that distinguish between the spontaneous moving of an animal and the imposed moving of a thrown rock or blown cloud. But when it comes to electronic games that talk and beat you at tic-tac-toe but don't move, it is obvious at once, even to the youngest child, that what is most lifelike about them is related to their mindlike characteristics rather than to their motions.

The issue is not whether children think these games are alive or not. It is the discourse they use in talking—and presumably in thinking—about whether these things are alive. They do not talk about whether or how these computational objects move. Instead, they ask if such games think and feel, do they create or simply do what they are programmed to do, and can they be angry. Turkle (1984) makes the pun: motion gives way to emotion as the criterion for what is alive.

One can take three attitudes in relating these observations to Piaget's discussion of childhood animism. One can say he was just plain wrong. One can say that he was right about animals and sticks and stones and rivers, but we now see that he had only a partial picture. Computers lie outside the scope of his discussion. Or one can say, as I wish to, that these new observations expand rather than undermine the sense in which he was right. They bring out more clearly the constructivist and structuralist aspects of his work.

When Piaget listens to a child talk about whether a cloud or a stone or a river is alive, what interests Piaget is certainly not the cloud or the stone or the river, and hardly even the child. Instead, the child's opinions about what is alive and not alive serve as a sort of peephole into a completely different realm. Like the shadows in Plato's cave, the child's judgment provides hints of a different kind of actor in the development of the child's intelligence. The true story is the construction in the child's mind of the physical—in the sense of physics—and the animistic.

Piaget sometimes calls these entities *groupements*, sometimes *structures*, but the play we are observing through the peephole of judgments about alive and not alive is a story told roughly as follows. The child is born into an undifferentiated world in which self and other, animate and inanimate, are all one. The major line of construction is the structuring of this world into two large parts: the animate and the inanimate.

This is not a classification—not a mere attaching of labels—but something far

more complex. For Piaget, such constructions are inextricably tied to the way in which the child makes sense of the world. At first, the child will say the stone *is* alive because you can throw it. Later the child will say it is *not* alive because you throw it. The process of changing from one opinion to the other is a process of making sense of the difference between spontaneous and impressed motion.

What we are looking at is the construction of understanding of the laws of motion. In short, we are looking at the construction of the physical in the sense of physics. When the child thinks that the stone is not alive because you have to throw it, but the river is alive, this opinion shows that the child's construction of the causality of motion has not reached the stage where the river can be seen as moving under the influence of external, impressed forces—in this case, gravity—so the river remains in the realm of the animate.

In summary, what Piaget looks at is the construction of large structures of thought—in this case, the construction of animate and inanimate around the criterion of motion. With this description in mind, let us rejoin the observations about the aliveness of computers.

Whether the computer is seen as alive or not alive has nothing to do with how it moves or what laws of physical causality are applied to it. So in this sense the computer is outside the scope of Piaget's particular analysis of structures. But when Turkle looks more closely, she notices that with increasing age, children's judgments about computers being alive or not alive parallel Piaget's observations about sticks and stones and clouds. Much as Piaget documented the development of physical sophistication, what Turkle observes is the development of psychological sophistication.

If we are to revise Piaget in Piaget's spirit, we do this by introducing another actor into the territory of structures. Besides the construction of the physical, we also take account of the construction of the psychological. And once more the judgment of alive and not alive is a window into something larger, into the child's construction of what it is to be a psychological being.

There is very striking similarity between this construction of the psychological and Piaget's observations on animism. Turkle reports that 5-year-old children say the tic-tac-toe game is alive because it cheats. These children do not yet make the distinction between spontaneous behavior that comes from itself and impressed behavior that comes from its program.

Computer-sophisticated 10-year-olds are quite unlikely to give cheating as a reason for the computer being alive. Their understanding of the "causality" of behavior is sufficient for them to make a clear distinction between doing it spontaneously and being put up to do it. In response to the question of computers being alive, a 10-year-old at the Hennigan School in Boston said, "Yes. They're more alive than trees, anyway—and everyone says that trees are alive." The way in which computers are more alive than trees is clearly psychological.

The issue of alive and not alive was certainly one of Piaget's interests and has become part of the social construction of Piaget. However, it is not on the main

line of his development and certainly is not the clearest case through which to see the issues of structure. The example of number that I touched on earlier is a much better candidate.

The Mother Structures of Number

What is most striking about Piaget and Szeminska's (1952) study of children's notion of number is how little of the book focuses on what happens in the classroom or on the popular version of number. There is not much there about how children add 3 and 4 to get 7, or how they get to know the multiplication tables. Instead, Piaget is looking at the larger actors whose shadows we see in the way the child learns to add. These entities are large structures that can be identified, named, and studied in their own right. At different periods in Piaget's life, they were referred to differently. The clearest and simplest is probably the term he used after his encounter with Bourbaki, namely, *mother structures*—fundamental structures out of which number and other mathematical thinking is created.

Piaget sees these intellectual structures as precursors of number. They are elements in a process that leads to the emergence, or, rather, the *construction*, of number, even though they are in themselves something else. The central point is that for him, when children think about questions that appear to be related to the numerical, they are not using numbers in an incompetent and inappropriate way but instead are using something else appropriately and competently. I see his demonstration of internal coherence in children's thinking as simple and strong support for this view.

The various structures that Piaget has identified (order, topology, and algebraic structures) are, let us say, the mother structures that underlie the school structures. Piaget might be right or wrong in his identification of particular mother structures or in the completeness of the set he proposed to us. But I think it is very essential to his view of things that what you ought to study is the mother structures. Almost all the discussion of how to use computers in education bears more or less directly on school structures: how to improve this or that particular school structure in mathematics, or writing, or communication, or whatever. Very little of such discussions try to expand our understanding of the old mother structures or to see whether there are any new mother structures.

This view of number as having large and looming structures is in very sharp contrast to the dominant model of thought for information-processing theories of psychology—particularly in the form taken by the Carnegie-Mellon School. There, the ideal would show numerical behavior emerging from the possession of many atomistic and highly specific production rules.

These contrasting points of view identify a major issue—perhaps *the* major issue—in the study of learning that is not being confronted by contemporary cognitive theorists. This is just one way in which Piaget sits rather uneasily in

the atmosphere of the decade after his death. Structuralism rings strangely for ears accustomed to the cognitive paradigm that came with the computer.

The Computer Challenge to Piaget: Phenomena and Theory

There are two methodologically very distinct ways in which the computer presence can affect Piagetian enterprise: explicative theory, and phenomena to be explained. Observations about what is judged to be alive or not alive show us phenomena which, on the face of it, do not fit Piaget's explanatory theory. As I have shown, there are ways of looking at the theory from another angle, ways that see these phenomena as strengthening rather than undermining his thinking. But regardless of which view you take, we are talking here about the computer presence throwing up phenomena to be explained. The question is: can Piaget's theory explain them?

We see something very different when we look at the discordance between Piaget's kind of theorizing and, say, Newell and Simon's (1972). The difference now focuses not on what phenomena are to be explained, but on the kind of explanation being given. In this case, the question is: which kind of explanation best fits the spirit and paradigm of these times?

The conflict between Piaget and Newell and Simon is not between modern computer models and old-fashioned structuralist models. One cannot identify Newell and Simon with the computer, and there are ways of thinking in computational terms that are closer to structuralism. For example, the *Society of Mind* (Minsky, 1986) approach to psychological theorizing allows one to postulate active entities with different degrees of complexity and of different sizes, so to speak, in the models being built. It encourages one to analyze the way of the mind in terms of active entities of all sizes. In contrast, the Piagetian view is that such active entities are large, encompassing structures.

Numbers of people (for example, David Klahr, 1984, Gary Drescher, Marvin Minsky, 1975, and myself) have developed computation models as alternative theoretical frameworks to Piaget's, and I see this kind of rethinking of Piagetian theory as a valuable pursuit to which I continue to devote some energy. My focus in this paper, however, is not on the kind of theory, but on the phenomena to be explained.

The Computer and New Mother Structures

When I was looking for ways of using the computer to enrich the development of mathematical thinking, I asked whether there might be other mother structures that Piaget had not recognized merely because they didn't appear clearly in the contexts that were familiar to him. The concept of the turtle arose from such strivings and speculations.

I was touched and impressed by being introduced at the 1985 Piaget Society Symposium not as the father of LOGO but as the father of the turtle, because the turtle is vastly more important than LOGO. From the wisdom of hindsight, the turtle captures a mother structure that has been fully as important to the historical development of mathematics as the mother structures identified in Piaget. This mother structure of the turtle is differential geometry—which is central to the construction of mathematical physics from Newton’s time up to today.

One sees this structure most clearly when thinking about the motion of a particle. This motion can be represented by a differential vector that has a position, magnitude, and direction. So the turtle can be thought of as a mother structure to the motion of the particle. The turtle is logically simpler: its state has position and direction, but no magnitude. So this “turtle structure” has a family resemblance to many of the things that Piaget dealt with, but does not, in fact, fall cleanly under any of his structures.

Why is the turtle such an important mother structure? First of all, using the kind of terms that are very dear to Piaget, I got excited about it and began to think it was a mother structure when it first began to emerge from the crossing of two lines. Piaget told us over and over again to look for the intersection between the historical development of science—what has been important epistemologically in the development of any science of knowledge—and the psychogenesis of children.

The turtle captures that intersection because it is a mathematical concept that can be anthropomorphized. Euclid’s point has position—but no other properties. When you are taught this definition in school, it usually evokes a laugh or a giggle of embarrassment, because you don’t quite understand. What can that mean? A point has position but no magnitude or no color? This is the only example you have ever had of a formal object with very reduced properties, so it does not mean very much. When something has two properties, it makes more sense. A turtle has only two: position and heading—and in its mathematical definition, that is what a turtle is. It is akin not to biological things, but to Euclid’s concept of a point.

Yet the turtle is also different from the point, especially in two ways that belong to the two intersecting lines of development I mentioned earlier. From the perspective of science, the point is not really the natural way to do geometry. From Galileo on, especially in the hands of Newton and all later development of mathematical physics, we came to understand that the natural element for geometry is the differential vector, an entity tangent to the curve, having both position and heading. So the turtle really does capture an epistemologically key element in the evolution of mathematical science—mathematical physics especially, but mathematical economics no less.

Looked at from the other side, by giving Euclid’s point a heading as well, the turtle gains in anthropomorphizability. You can’t really identify with a point because it is very difficult to imagine having a position and nothing else. But

having a position *and* looking somewhere, facing a direction you can walk toward, the turtle becomes much easier to identify with. So the turtle has a psychological dimension as well as a mathematical one. The fact that these two dimensions intersect in the turtle makes me think that it is a good thing. It touches on something important and powerful.

One can talk about anthropomorphizability in other Piagetian-like ways. This affinity between yourself and this mathematical entity allows you to assimilate the mathematical situation to schemas of personal knowledge. Without such a pipeline into personal knowledge, these mathematics would otherwise be abstract. But with this bridge between mathematics and your own bodily action schemas, sensorimotor experiences, and self-image, the mathematics becomes as tangible, real, and concrete as mud pies. I think that introducing this turtle gives a new facet and new perception to a fundamental theme of Piaget.

Why is the presence of computers so important to this mother structure? Well, the turtle can be introduced without computers, but I doubt that one can introduce it to children without computers. The two together—the turtle and the computer—make something that becomes very accessible to young children. They can take it up and make what they will of it. And you don't have to tell them to anthropomorphize it. You don't even have to call it a turtle, which suggests a kind of anthropomorphizability. Children anthropomorphize this thing quite spontaneously.

So we are looking at a new kind of structure and assimilation-accommodation process. Maybe if we had Piaget's taste for giving structures their "real mathematical names," we'd call this a *differential vector structure*. It would go side by side with structures of order, topology, and algebra. Piaget had not recognized this new one because he was in a different mathematical tradition. So he could not see the differential vector structure as sufficiently distinct—or in a form that appeared in the activities and thought processes of children. The computer's active nature enables us to introduce objects like the turtle that are more dynamic and anthropomorphizable than the kinds that existed before.

In summary, this account of the turtle shows how Piaget's constructivist and structuralist framework can be used as an heuristic for research. And certainly the idea that there might be a field of research called *La genese de l'ordinateur chez l'enfant* must—in everyone's view of things—be seen as reinforcement of the Piagetian approach.

A CRITIQUE OF THE FORMAL AND OF PIAGET'S STAGE THEORY

I have already stated at some length that what I find to be strong and essential in Piaget is his constructivism and structuralism. What I find least powerful in Piaget is the stage theory. Here again, my focus is on phenomena to be

explained—and the phenomena I present are differences in intellectual style that become evident when children are allowed to “construct the computer” in whatever ways are natural to them. But to make clear how these phenomena impact on Piaget’s stage theory, I’ll take a digression that has little to do with computers as such.

Gilligan and Kohlberg: Stages of Moral Development

This digression challenges the judgment that the formal and analytic is a superior and “ultimate” style of thinking. Its relevance here is that the formal stage may be the most troubled question in the exegesis of Piaget.

Larry Kohlberg’s theory of moral stages (Kohlberg, 1969) is similar to Piaget’s in some obvious ways. At the beginning, there is no differentiation of the self. Moral judgment is entirely egocentric. It gradually becomes externalized and takes into account other people. This externalization goes through various phases. The earliest is still very self-centered. That is, it is good for me to do something for you because you will do something good for me afterwards. Then beyond that, it is good to do something for you because that is in itself a justification. This progressive detachment of moral judgment from the self winds up at a stage where, detached even from other people, moral judgment is made in terms of general principles. It becomes a formal and abstract intellectual endeavor. And that is the last stage.

Carol Gilligan (1982) challenges Kohlberg in a number of ways. Her book, *In a Different Voice*, observes that this final, “abstract principles” stage of moral judgment is more often found among men than among women. She notes that many women who in every way are highly developed and sophisticated people—morally, personally, socially, intellectually—nonetheless always want to know the context in making moral judgments. Instead of being based on abstract principles, these women’s moral judgments are made in terms of other people. Carol Gilligan says that perhaps these women do not “fall short” of the final stage of moral development described by Kohlberg. Perhaps they have taken a different direction altogether.

My purpose is not to enter into this debate. I mention it here as a model for asking a more general question about Piaget’s stages of development. In essence, Gilligan challenges the idea that seems so straightforward, obvious, and natural to Kohlberg, that the ultimate development of human thought should be in the direction of abstract, detached, decontextualized thinking. This favoring of the formal and abstract is shared by Piaget.

A Different Voice for Thinking

For most people who have grown up in our Western tradition, it might be

acceptable in the area of moral judgment to reject this analytic mode as being superior to the contextual; such a rejection in more logical and mathematical areas of thought is much harder to accept. The nature of the differences in intellectual style that are emerging from our research with children and computers, however, provides strong evidence for a different voice in this area as well.

For some children, it is not that they haven't reached a formal, analytic stage of reasoning. Their work certainly becomes more and more complex, sensitive, and sophisticated, yet it does not become more and more analytic. Computers are a domain where everyone expects the analytic to reign supreme, yet this situation makes it especially clear that for certain children, the development of intelligence and programming expertise can reach high levels without becoming highly analytic as well.

In observing children who are programming computers, a substantial number do hold to a path of development that seems in spirit to be like what Piaget and Kohlberg would say is the norm. By the time they are 10 and 11, that is to say, just about when Piagetians would expect to see them moving into the formal stage, these children do show a style of programming that fits the model of "the logical." Faced with a problem, they subdivide it, modularize it, deal with the parts one at a time, put them together and make a program that is clearly logically structured.

But other children demonstrate a different style—one in which a program emerges not through planning and subdivision of a problem but through something closer to the way in which a sculptor or painter makes a work of art—a process in which the plan of what is to be made emerges and is refined at the same time as the created object takes form. One might call it more of a negotiation between the creator and the material than an imposition of logical order.

This situation would not challenge the stage theory but for an observation that parallels Gilligan's. On any criteria other than an *a priori* commitment to the superiority of the analytic, children who follow a negotiational style are performing at an intellectual level that is fully as excellent and of high quality as the other children. Like the women Gilligan studied, these children are just as sophisticated, intelligent, well-educated, capable, and mature as the other children.

So, just as Gilligan describes another voice for moral discourse, perhaps we are seeing another voice for mathematical discourse—indeed, for the whole spectrum of intellectual endeavor.

Whether this theory will stand up is a matter for extensive research. But if it does stand up, what does this tell us about Piaget? Has the computer created an opportunity for a more Piagetian way of thinking in Piaget's favorite areas, logic and mathematics? Or does it mean that this voice has always been there, but the advent of computers made it clearer? My own opinion is the latter.

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Function in Piaget's System: Some Notes for Constructors of Microworlds

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The growing disenchantment with structuralism in general and the formal structuralism that marked the middle segment of Piaget's theoretical work has fostered a shift away from Piaget's genetic epistemology. Piaget aided and abetted his detractors by emphasizing structural over functional characteristics of mind. Statements as, "genesis emanates from a structure and culminates in a structure" (Piaget, 1967) left no doubt that Piaget conceived of mind as continuously developing, but did little to placate critics looking for precise theoretical statements about the processes by which one structural form is transformed into another. His final elaboration of equilibration was oriented toward a structural analysis of change differentiating types of equilibration in terms of the structures reorganized. (See Furth, 1981, for a clear presentation of equilibration.)

This leads easily to the conclusion that Piaget has little to offer any serious examination of "constructivism in the computer age." This is especially true if the computer age is conceived of as creating environments, "microworlds," that serve as incubators of "powerful ideas" (Papert, 1980). Both of these ideas are discussed fully later. However, it seems useful to lay out in general the meaning of *microworlds* in this chapter. A microworld, as the real world, embodies principles rather than didactically presenting them. The principles have been identified by other humans as important, and in many cases they embody a theory shared by experts about a physical or social phenomenon. In short, the heart of microworlds is that they are conceptual systems. In addition, they are fleshed out in contexts that, presumably, will make it easier for us to construct the principles through our transactions with that world.

The present chapter has two purposes. One is to look at constructivism in Piaget's theory by exploring his writings about functional aspects of mind. The