THE QUARTERLY NEWSLETTER OF THE

LABORATORY OF COMPARATIVE HUMAN COGNITION

Center for Human Information Processing
University of California, San Diego

Volume 10, Number 1 — January 1988

TABLE OF CONTENTS

Introduction

Although the articles included in this issue were all submitted by different people, you will easily find among them many common themes reflecting the Newsletter's tradition. The first article by Schliemann examines the kind of mathematical understanding that is acquired through the work activity or from formal schooling by applying procedures repeatedly. Her results reveal that neither "the functional everyday experience of the bookies" nor school instruction relying "exclusively on symbols and formulas" was sufficient to promote mathematical understanding of permutation. One had to have both, and coordinate them.

This article implicitly raises an important methodological issue: It suggests that in order to examine what is acquired in detail, an investigator must ask questions which are "unfamiliar" to subjects. The bookies were all very competent when asked about familiar problems often posed in their work, and there were no differences according to their years of schooling. Schooling made a difference only when novel types of questions were posed. How can we reconcile this suggestion with our continuous emphasis of ecological validity? A related question is how we should conceptualize the observed difference due to schooling. Did it facilitate "generalizations," i.e., help the bookies construct knowledge more readily applicable to other contexts? Or, did it only enable them to answer "odd" questions posed by an experimenter more elegantly? We have to establish more adequate criteria for distinguishing "odd" and "unfamiliar but meaningful" questions. As recent cognitive studies have suggested, human knowledge is not tied rigidly to the situation in which it was acquired, but more or less flexibly applied as far as contexts suggest to use that knowledge.

The second article, by Farrell, sheds light on the issue of interaction of various experiences from a different angle. It presents three interesting instances of misconceptions which were so strongly established that the students did not trust visual input contradicting them. I do not think his claims that (a) formal operational ability (if it exists at all) is not enough for inducing correct solution to physics and mathematics problems, and (b) experience with the real apparatus is needed even for formal thinkers surprise readers of the Newsletter. However, we do not know much about the why of these claims. Farrell seems to believe that a formal operation must be constrained properly by concrete knowledge about the object in order for it to lead to the correct solution. Another likely interpretation is that people tend to solve these problems not by propositional reasoning but by running a simulation with mental models, and the construction of the mental models must be based upon manipulation of the real apparatus.

The next two articles approach computers from different perspectives. The article by Totsuka and Miyake, like Farrell's, presents three impressive examples, but theirs are about the brighter side of school instruction. A computer can be very powerful when it is used as a tool for representing aptly what children have observed and thus enabling them to examine the data more carefully to discover hidden laws. After reading the article, you will become optimistic about the possibility of exploration and the acquisition of culturally valued scientific knowledge.

The article by Pulos and Fisher demonstrates that children may build mental models of a computer as they interact with it, and when they do so, they may use their prior knowledge about a human. I fully agree with them that children may transfer analogically their knowledge about a human being to a computer, even when they distinguish the two clearly. (See Inagaki and Hatano in the October 1987 issue of this Newsletter for the basis of this expectation.

The final article by Engeström is not easy to understand on first reading, because most of the implications of his claims for empirical research remain implicit. Let me try to make explicit one of them. Although the number of cognitive studies on the activity of work has been increasing, especially in relation to everyday cognition, expertise, and cognitive engineering (or person-tool interface), many cognitive and developmental psychologists are still hesitant to do research on work, probably because, whereas school and play activities look universal, there are so many different kinds of work activities that it is difficult to choose one. Research may produce a detailed monograph of the selected work activity, but the findings may not be generalized to other work activities. Engeström gives valuable suggestions as to this issue of choice of work activities to study: in addition to conventional cognitive considerations, such as whether the activity is in a knowledge-rich domain, an ill-structured domain, etc., the selection must be based on historical considerations, that is, what is happening in work in our industrialized society. More specifically, our priority should be given to the type of work activity that best exemplifies the current trends in work. I believe that this argument can be applied to research on play and schooling as well.

Giyoo Hatano

Understanding the Combinatorial System: Development, School Learning, and Everyday Experience

Analúcia Dias Schliemann
Universidade Federal de Pernambuco
Recife, Brazil

Mathematics can be viewed within a rationalist framework as a discipline in which conclusions are rigorously obtained from clearly stated premises. When considered in this light, mathematics has little relationship to everyday practice. However, there are psychologists, mathematicians, and educators (viz., Piaget, 1986; Kitcher, 1984; and D'Ambrosio, 1986) who put forth a different view about the nature of mathematical knowledge. Despite differences in their views, mathematical knowledge is treated by these authors as knowledge which must be grounded both upon experience and rigorous thinking. Piaget (1965) proposed that this interaction between experience and reflection is so important that he expected children to be able to develop the understanding of quite a few mathematical models rather independently of instruction, going so far as to treat the success of education more as a consequence than as a cause of this development when he states that, instead of receiving the mathematical notions from school instruction, children only choose from the world the aspects that their levels of development allow them to integrate.

Research work by anthropologists and psychologists has shown that, differently from what would be expected from a rationalist point of view, everyday experiences provide opportunities for mathematical learning, at least in the area of elementary arithmetic (see Lave, 1977; Scribner, 1984; Carraher, Carraher, & Schliemann, 1985). However, the scant research on more elaborated mathematical models suggests that without schooling the generalization of the models is somewhat restricted (see Carraher, 1986; Carraher & Schliemann, in press; Acioly, 1985; Schliemann & Acioly, in press).

A mathematical model which is taught at school but also used in everyday life is the combinatorial system. Piaget and Inhelder (1951) have suggested that the understanding of combinatorial operations such as combinations and permutations is the result of a developmental process through stages and that adolescents after the age of 12 or 13 would be able to systematically find out the permutations for any number of objects. However, Fishbein, Pampu & Minzat (1970) showed that through specific instruction on how to find all the possible permutations among the elements in a given set, it is possible to improve children's performance in combinatorial tasks.

According to Piaget's model, independently from specific school instruction on the combinatorial system, adolescents would be able to discover a systematic approach to deal with permutations. According to Fishbein's results one should expect that school instruction on the combinatorial system should also have an impact on performance on combinatorial tasks. However, previous work in the area of arithmetic operations revealed that school teaching turns most often to the transmission of procedures than to problem analysis. Non-systematic observations reveal that school instruction on combinatorial operations is often limited to training on the use of algorithms to find out the number of permutations or arrangements and not on working them out. Would such an approach promote understanding of the relations involved in permutation tasks? If one adopts the view that mathematics is a purely deductive discipline, school teaching on the symbolic aspects of the combinatorial system should be enough to promote understanding.

Acioly (1985) and Schliemann & Acioly (in press), in their study on mathematical knowledge among lottery bookies in Brazil, described the combinatorial system as part of the everyday experiences of people who deal with a special kind of game, the Animal Lottery. To process a bet from a customer, a lottery bookie has to find out how many permutations exist with the digits in a number. Bookies do not have to work out permutations but only to look up in printed tables the number of permutations for each kind of number. At the end of the day, when the winning number is drawn, if they want to find out whether some given bet won the prize, they only have to check whether the digits in the drawn number are the same that were in the bet, regardless of their order.

The procedure used by the bookies to determine the number of permutations, as is the case for students, can be seen as a rule or an algorithm which can be performed regardless of their understanding of permutations as a system. However, differences in experience do exist. For bookies, use of the algorithms occurs in order to solve real problems that appear at work. When they have to find the number of permutations, problem solving does not end by finding the answer, instead, this answer is a means to an end, namely, to calculate the price of a bet. For students the algorithms are used as school problems--problems that terminate when the number of permutations is obtained. In this case the result is not a means to an end. Another difference is that, in the lottery game, the number of permutations is restricted to only one type of content, namely, numbers in the game. At school, the contents of the problems is varied and not restricted to numbers.

Would experience in the use of algorithms help understanding the relationships involved in a mathematical model such as the combinatorial system? If so, what sort of experience is more profitable? Everyday functional experience in a well defined situation or the more general and symbol oriented school experience?

This study evaluates how algorithmic knowledge contributes to the understanding of the combinatorial system or, to adopt the terms used by Resnick & Omanson (in press), how procedural learning helps the acquisition of conceptual knowledge. We will compare the performance of lottery bookies to that of people who had learned about permutations at school but did not work in the lottery game. The permutation tasks involve letters and numbers. A third group with no formal or informal regular experience on the combinatorial system also participated in the study as a control group.

Method

Subjects. Three groups of subjects were examined. The first group was formed by 20 lottery bookies who deal with the combinatorial system as part of their work.

The second was a group of 20 students who had just passed the University entrance examination which included topics on the combinatorial system. Half of the students were from social science programs and half from exact sciences.

Finally, the third was a control group consisting of 20 workers belonging to the same socio-economic group as the bookies and with similar school experiences, but who worked at different jobs, none of them requiring experience with the combinatorial system.

Procedure. Each subject in the three groups was individually asked to work out permutations in the following problems:

> **Problem 1.** Let us suppose that you have cloth of three colors, Red, Blue, and Black, and you want to make shirts for different soccer teams. Each team has to have a different kind of shirt made with the three colors. You can make different shirts arranging the colors like this: For one team you may use Red on the top, Blue in the middle, and Black on the bottom. For another team, Black on the top, Red in the middle, Blue on the bottom. How many different shirts can you make in that way? Show me the different ways you can find.
>
> **Problem 2.** I want you to find out how many different ways you can order the letters in the word CASA, without adding or removing any letter. Try to find out all the possible ways to arrange the letters.

If, while trying to solve Problems 1 and 2, they did not spontaneously relate the solution to the lottery game, bookies were further asked whether the same number of permutations found for numbers in the game would be found for the colors or letters in the problems. Similarly, if students did not spontaneously mention the relationship between the problems and their knowledge of the combinatorial system, they were asked whether the problems were related to permutations or the combinatorial system.

Results

Results in the Permutations Task.

Performance on the permutations task was analyzed at first in terms of the standard Piagetian stages (Piaget & Inhelder, 1951) and, accordingly, subjects were classified into the following levels:

Stage IA. The subject does not find all the possible three-element permutations even by trial and error and has difficulty understanding that the same elements can be arranged in several different ways.

Stage IB. In this stage, the subject may find by trial and error the six possible permutations for three elements, but he is not certain that other permutations cannot be found.

Stage IIA. Here the subject is able to find by trial and error the six permutations among three elements, and knows that no others are possible. However, no success is observed when the problem includes four elements.

Stage IIB. In this stage the empirical discovery of the permutation system for three elements is generalized to four elements.

Stage III. All possible permutations of three and four elements are generated systematically from the beginning.

Table 1 compares the performance of the three groups. As a whole, the students performed better than the others and the difference between them and the bookies group, considering the five stages as an ordinal scale, was significant (Mann-Whitney $U = 137.5$, $n_1 = 20$, $n_2 = 20$, $p. < .05$ for one-tailed test). However, it has to be pointed out that, although the students group had 12 years of school experience, nine of them were classified at stages IA or IB. In the other groups, only bookies and members of the control group with less than nine years of schooling were classified at these levels.

For each level of schooling, at least some bookies attained levels that none of the members of the control group reached. The difference between the bookies and the members of the control group was also significant (Mann-Whitney $U = 136$, $n_1 = 20$, $n_2 = 20$, $p. < .05$ for one-tailed test).

The fact that some students were classified at levels IA or IB while no members of the control group with nine or more years of schooling presented such a low level of performance may also reflect an influence of the lottery game. The students belonged to a socio-economic group where it is unusual to bet in this kind of lottery game. The members of the control group belonged to the same socio-economic level as the bookies and some used to bet in the Animal's Game.

Table 1

Distribution of Subjects: Group X Schooling X Performance Level

Group	Level of Schooling	Piagetian Level IA	IB	IIA	IIB	III
Students	12 years	3	6	3	3	5
BOOKIES	None	2	2	-	-	-
	1 to 4 yrs	4	2	-	1	-
	5 to 8 yrs	1	1	1	1	1
	9 to 11 yrs	-	-	-	2	2
CONTROLS	None	4	-	-	-	-
	1 to 4 yrs	4	3	-	-	-
	5 to 8 yrs	1	3	1	-	-
	9 to 11 yrs	-	-	2	2	-

There were also significant associations between level of schooling and performance in the permutation tasks among the bookies and members of the control group. (Kendall's tau = .58, $z = 3.51$, $p. < .001$; and tau = .74, $z = 3.84$, $p. < .001$, respectively).

How Subjects Relate the Problems to their Experiences.

Results for the bookies were also categorized as to whether or not the problem was seen, spontaneously or after prompts, as related to the lottery game procedures. For the students a similar categorization was made regarding the relationship between the problems and their knowledge of the combinatorial system for math classes. These results are shown in Table 2 (see next page).

For both samples, most of the subjects acknowledged the relationship between the problem and the original situation in which they had worked with the combinatorial system. The four bookies who did not admit the relationship between the problem and the game belonged to the groups with less than five years of schooling. They tended to think that the number of permutations to be found among numbers was different from that to be found among letters or colors.

Table 2

Subjects' Relation of Problems to Game (Bookies) or Combinatorials (Students)

Group	Do not relate	Relate after prompts	Relate spontaneously
Bookies	4	3	13
Students	7	8	5

The six students who could not relate the problems to studies on the combinatorial system appear to have never studied the topic or to have forgotten completely what they were taught at school.

The fact that 13 bookies, compared to only 5 students, spontaneously related the problems with their previous experience may suggest that transfer of the model was easier for bookies than for students. However, one has to be cautious about this conclusion. Bookies were asked to solve the two problems analyzed in this study among a series of other problems related to the lottery game, a fact which may have helped them to realize that a relationship between these problems and the use of permutations in the game could be drawn.

School Knowledge and Performance on Permutations Task.

In the group of students no relationship was found between level of performance and acknowledgement of the relation between the problems and the combinatorial system as taught at school. Among the 13 students who related the problems to the combinatorial system, only 3 were able to find the permutations in the two problems using a systematic method.

Only five of the students who identified the problems as combinatorial problems tried to use formulas to find out the number of permutations to be worked out. Of these, only three knew the right formula. Knowledge of the formula also did not help in finding out the actual permutations. One of the students was able to correctly compute the number of permutations to be found for three and for four elements, with one element repeated, but could not find all six permutations for the three colors in Problem 1, nor the 12 permutations on the letters C, A, S, A in Problem 2.

Discussion

It appears that everyday experience of the sort provided by the lottery game improves skills at working out permutations. On the other hand, general school experience also seems to promote better understanding of how the permutations can be systematically generated. However, specific school instruction on the combinatorial system does not appear to be crucial. The overall superior better performance of the students seems to result more from their length of schooling than from specific instruction on the combinatorial system. School instruction on algorithms to find out the number of permutations among different sorts of elements does not guarantee at all that understanding of the mathematical model occurs. Even when they knew how to compute the number of permutations to be generated, some students were unable to work out the permutations among the elements in the problem.

These results show that the rationalist model that relies exclusively on symbols and formulas to express mathematical relationships is not the best suited to promote mathematical understanding. Also, the functional everyday experience of the bookies is not sufficient by itself to promote a systematic approach to permutations tasks. However, when everyday experience on the lottery game is joined with general school experience the best results are obtained. An interesting point is that the school experience does not have to include specific instruction on the combinatorial system to promote better understanding and transfer. This does not mean that algorithms and symbolic models should be banished from mathematical education but rather that they should be taught at school in relation to functional experiences that would provide a meaning for the formal models.

References

Acioly, N. (1985). *A lógica matemática no jogo do bicho: Compreensao ou utilizacao de regras?* Masters dissertation, Universidade Federal de Pernambuco, Recife, Brazil.

Carraher, T. (1986). From drawings to buildings: Working with mathematical scales. *International Journal of Behavioral Development, 9*, 527-544.

Carraher, T., Carraher, D., & Schliemann, A. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*, 21-29.

Carraher, T., Carraher, D., & Schliemann, A. (1987). Written and oral mathematics. *Journal for Research in Mathematics Education, 18*, 83-97.

Carraher, T., & Schliemann, A. (in press). Culture, arithmetic and mathematical models. *Cultural Dynamics.*

D'Ambrosio, U. (1986). *Da realidade a acao: Reflexoes sobre Educacao e Matemática.* Sao Paulo, Summus Editorial.

Fishbein, E., Pampu, I., & Minzat, I. (1970). Effects of age and instruction on combinatory ability in children. *The British Journal of Educational Psychology*, 40.

Kitcher, P. (1984). *The nature of mathematical knowledge.* New York: Oxford University Press.

Lave, J. (1977). Cognitive consequences of traditional apprenticeship training in West Africa. *Anthropology and Educational Quarterly, 7*, 177-180.

Piaget, J. (1965). *Etudes sociologiques.* Paris: Librairie Droz.

Piaget, J., & Inhelder, B. (1951). *La genese de l'idee de hasard chez l'enfant.* Paris: Presses Universitaires de France.

Resnick, L. & Omanson, S. (in press). Learning to understand arithmetic. In R. Glaser (Ed.), *Advances in instructional psychology: Vol. 3.* Hillsdale, NJ: Erlbaum.

Schliemann, A., & Acioly, N. (in press). Mathematical knowledge developed at work: The contribution of practice versus the contribution of schooling. *Cognition and Instruction.*

Scribner, S. (1984). Studying working intelligence. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 4-40). Cambridge, MA: Harvard University Press.

∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞

In order to transmit an experience or content of consciousness to another person, there is no other path than to ascribe the content to a known class, to a known group of phenomena, and as we know this necessarily requires *generalization.* Thus it turns out that *social interaction necessarily presupposes generalization and the development of word meaning.*

L.S. Vygotsky, 1955

The Formal Thinkers Among Us

Edwin Farrell
The City College
City University of New York

Colleagues of mine at an urban university sometimes complain that our students are not formal operational thinkers. Kohlberg and Gilligan's much cited paper, *The Adolescent as a Philosopher* (1971), draws from the work of Kuhn, Langer, Kohlberg, and Haan (1977), to suggest that half of the high school and college age population has not attained the stage of formal operations and that many adults never do. To accept such complaints and suggestions would confront me with a dilemma; how do I teach my students if they are incapable of combinatorial thought and proportional reasoning, the factors which Piaget and Inhelder (1969) maintain permit access to what they call "the spontaneous development of an experimental spirit?" (p. 123).

Genetic epistemologists, of course, see the formal operational stage as a natural extension of the preceding ones. I would find it very hard to accept that many of my students have not attained it and, therefore, somehow lack the experimental spirit. But an examination of their "wrong" answers to certain well-known problems that measure cognitive development leads me to believe that they are virtually all formal thinkers. These answers are not, I believe, the result of a generally lower ability level than other college students, but rather, I suggest, of a lack of exposure to mathematics and science. My suggestion is based not on curriculum research or educational case histories but on the hearing of wonderful (albeit wrong) answers from both minority students from a public urban school of education and liberal arts students from a prestigious university.

The Parallelogram

In attempting to show the difference between "teaching" a computer vs. a human being in one of my psychology classes I drew a parallelogram on the blackboard and wrote a program for finding its area on my computer screen. Next I questioned a student, Brenda, who claimed not to have any familiarity with the problem and asked her to speculate on how to solve it. She pondered and then suggested that I multiply the base times the side. When I asked her how she arrived at that solution she responded that if I straightened the parallelogram up it would be a rectangle and that area could be found by multiplying the sides.

It appeared that the difference between teaching Brenda and teaching the computer lay in unteaching her first. But most of the class was taken with the elegance of her answer which, although empirically wrong, seemed to them to be an intuitive proof. Furthermore, her thinking appeared to be on the formal level in that she was making Piagetian transformations. Her version of the relationship of the sides of the parallelogram to the sides of the rectangle can be expressed in the inverse proportion, base[p]/base[r] = side[r]/side[p] and it is empirically correct. If the area of the rectangle is equal to the products of its sides, it may not seem unreasonable to assume that the product of equivalent factors is the area of the parallelogram. Indeed, when the angle from the vertical of the rectangle is not great (<45 degrees) the difference in the areas of the two figures is not readily apparent to the eye. When the angle is 30 degrees, the area of the parallelogram is approximately 85% of the area of the rectangle. (Neither is it readily apparent to the eye that Colorado is smaller than New Mexico, for example, when, in fact, it is 85% of its area.)

Brenda had achieved an equilibrium which was not upset by her perceptions of the parallelograms she was likely to see. To upset this equilibrium I demonstrated Euclid's proof that the area of a parallelogram was the base times the height. Like many of my students, Brenda never had a course in Euclidian geometry. Many of those who did had either forgotten the proofs or never learned them in the first place. Whereas most geometry teachers demonstrate the proofs of the theorems, they do not always require them on examinations. At any rate, Euclid's proof neither convinced the class nor did it upset Brenda's equilibrium.

Werthheimer's (1945) proof fared better. Moving a right triangle from one end of the parallelogram and fitting it to the other, making the figure a rectangle, is an intuitive proof that does not jar anyone's perceptions. Brenda, however, clung to her primary eidetic image of the original parallelogram being straightened to a rectangle. She was easily able to follow Werthheimer's proof, thereby demonstrating the ability to reason about a proposition she did not believe, but because the dimensions of the sides of the figure did not change she did not see why the area should change. I pointed out that the height decreased as the rectangle became a parallelogram but she countered that the area of the triangle created in the process increased, or so it appeared. In fact, the area of the triangle does increase until the angle from the vertical reaches 45 degrees at which time it begins to decrease.

The only way I could think to prove this decrease was to use trigonometry. Using the Pythagorium theorem I showed her what the areas of the triangles would be at different angles from the vertical. Brenda did have knowledge of the Pythagorium theorem and seemed to follow my proof in spite of the fact that much of the class lost interest. She accepted the reasoning that the area of the figure, whatever its shape, was the product of the sides but varied with the angle from the vertical. The product of the sides and the cosine of the angle from the vertical determined the area. Even though she, along with many college students, had never been taught what a cosine was, she was capable of performing operations on operations.

Yet in spite of this, Brenda asked, "If the area decreases where does it go?" What she was assuming was that area here was a real rather than an abstract concept. She was taking the traditional view that the axioms of geometry, even though she had either not been taught them or did not remember them, are true of space. But the axioms of geometry can only be assumed on a flat surface; they do not work, for instance, on the curved surface of the earth. Godel (1931), moreover, proved that such a set of axioms are not even internally consistent. The area that seemed to disappear for Brenda was only imaginary in the first place.

Not until I made a movable model of a rectangle that could be changed into a parallelogram was Brenda willing to trade in her old equilibrium for a new one. Once she actually saw that when the angle from the vertical was increased beyond 45 degrees the parallelogram began to be flattened to an area of zero, did she fully accept the premise. Although the definition of the achievement of formal operations requires that a subject be able to perform operations upon operations I wondered if reality, for formals as well as non-formals, had to be constructed from the "bottom up" rather than the "top down"; operations that require the construction of a new equilibrium may have to be operations that are performed on objects first. I could use Euclid, Werthheimer, and Pythagorus, and, although Brenda was capable, in my opinion, of following them she did not create a new schema until she viewed the object and experienced it in all its permutations. How typical Brenda was, I cannot tell. Do all college students need to construct their reality from the bottom up or is this phenomenon restricted to the type of student who majors in education? To investigate this, let us look at a "superior" liberal arts student's solution to a pendulum problem.

The Pendulum

Working on a research project which employed numbers of undergraduates from a prestigious university as research assistants I was able to poll them informally on a version of the pendulum problem. I would ask them how to regulate a grandfather's clock. Do you move the ball of the pendulum up or down to make the clock run faster? From approximately 50 students polled over the course of an academic year, only about half thought that moving it up achieved the desired result. The answers my students in an urban college consistently follow the same pattern. Myron, a dean's list philosophy major from the prestigious school, was one of those who wrongly sought to speed up the clock by moving the ball on the pendulum down.

Phrasing the pendulum problem in a grandfather's clock isolates the variables for the students. It excludes the weight factor (the weight of the ball remains the same). It also excludes the amplitude of oscillation factor (the pendulum can only swing within the casing of the clock). All the subject has to do is concentrate on the length of the pendulum. Without an actual clock, however, and a great deal of time, the solution of the problem is restricted to operations on operations. Myron's reasoning was top down.

His explanation showed that he correctly saw there was a moment of force involved. The weight of the ball times its distance from the clock gives the force involved, F = Wxd. Myron realized that when the W remains the same and the d is increased, the F must increase. To translate force into speed, he cited Newton's major contribution, force equals mass times acceleration or <u>F</u> = <u>ma</u>, and equated <u>ma</u> to his now increased F. If the force is increased (by moving the ball down and increasing the d) and the mass remains the same (the weight of the ball does not change), then the <u>a</u> must increase in order to keep the equation in balance. Increased acceleration, he maintained, speeds up the clock.

Myron's answer, to me, was as wonderful as Brenda's and he was certainly a formal operational thinker. He was capable of operations on operations, had studied syllogistic logic, and could deal with a number of different variables in his explanation. That his answer was wrong is no reflection on his formal reasoning ability; even formals can arrive at wrong answers. After polling my classes on the grandfather's clock and getting my usual 50-50 responses as to whether the ball of the pendulum should be moved up or down to speed up the clock, I can give Myron's explanation and several of my students will change their answers to agree with his. His explanation is, obviously, compelling and might convince anyone save physicists, genetic epistemologists, and others whose experience includes grandfather clocks or pendulums.

To unteach Myron I decided to use bottom up reasoning and demonstrate an empirical proof. With a string and a weight I swung my own pendulum with a long length and with a short length of string asking Myron which length produced a faster swing. Myron said although it appeared that the shorter length did, in reality the longer length did. As proof he pointed out that the Rockette on the outer edge of the "wheel" that the dancers make at New York's Radio City Music Hall had to move much faster to keep the "spoke" of dancers on line. If that Rockette moved to the inner parts of the circle she would not have to move so fast. My pendulum, he pointed out, was a case of the real vs. the perceived with a perceptual error which was caused by an illusion, optical or otherwise, accounting for the apparent speed up of the weight.

I referred Myron to a physics major with no great expectation that he would be dissuaded from his view. However, I have full confidence that if Myron had a grandfather's clock and a few days to experiment with it that he would arrive at a new schema. The equilibrium he had achieved, like that of Brenda, was not upset by the perceptions of the "pendulums" he was likely to see in his everyday life. Myron had to experience the grandfather's clock as the object it is; he had to experience a real clock and not the imaginary clock of my problem. To see if experiencing the real vs. the imaginary object was a prerequisite for formal operations let us look at how both liberal arts and education students deal with the balance beam.

The Balance Beam

In a graduate research seminar at the prestigious university I was presenting my research which had to do with learning how to solve problems, including the balance beam. I had to stop and explain the problem that covered the balance beam because 4 of the 12 participants had forgotten how to solve it. No one would suggest that the third of the class that could not solve it were not in formal operations. I was once in a calculus class where the majority had forgotten long division simply because long division is rarely required in high school and college math and almost never in the everyday life of most people. So too the balance beam; few people ever see one more than a few times in their lives.

Fewer students actually learn the balance beam than many educators might like to admit. One finds the apparatus in many elementary schools but few elementary students have achieved formal operations and are unable to fully understand the problem. In many states there is an eighth grade physical science curriculum but, for whatever the reasons, the formal operational solution to the problem is not often taught. Perhaps publishers are aware of the research that suggests that a majority of the 10-15 year-old population (Kuhn, et al., 1977) has not achieved the final Piagetian stage. At any rate, the eighth grade physical science texts of four of what I consider to be the six leading textbook publishers, mention the problem but do not teach the full solution that requires proportional reasoning.

The next opportunity for most students to experience the problem is in high school physics which is often not taken until the senior year and a majority of American students never opt for the course. Very few of the college students I teach have had high school physics. From what they tell me, I assume that either they thought it was too hard, too dull, or were never encouraged to take it and the balance beam has not found its way into many other high school courses. Without casting blame, it might be argued that they have had a poor education in math and science.

How do my students then solve balance beam problems when they meet them in courses in human learning? As a means of demonstrating what error analysis is I usually draw a balance beam on the blackboard. One of my examples was a balance beam with an unknown weight three units to the left of the fulcrum and a weight given as 2, six units to the right of the fulcrum. Eight of the 31 students present on the day I gave this example offered 4 as their solution when I asked them to find the missing weight; seven thought the answer was 9; eight thought it was 5; five thought 7; two, 2; and one student gave 1 as the answer.

Although the correct answer is, of course, 4, I am not willing to believe that only eight of my students had achieved formal operations. The two students who said the answer was 2 seemed to be working from the schema, Weight[left] = Weight[right]. The student who said 1 might have been working from the proportional schema, Weight[left]/Weight [right] = distance[left]/distance[right]. The former would appear to involve no formal operational thinking but the latter indicates proportional reasoning which is, at least, one requirement of formal thought. Both answers, however, defy the reality of riding on a seesaw, one experience which all of my students have had; when you move back on the seat you increase your moment of force. For this reason I have little basis for arguing that these three students had achieved formal operations.

I would argue, however, that those who gave 9 as their answer exhibit at least two criteria of formal thinking. To arrive at this answer you might either use the proportional schema W[left]/distance[left] = distance[right]/Weight[right] or guess, and I find it unlikely that seven students guessed the same wrong answer. In addition to using proportional reasoning these students were able to deal with two variables, weight and distance from the fulcrum. Moreover, seeing the heavier weight as being closer to the fulcrum is not a denial of reality. For those who have never been taught the balance beam, 9 is a wonderful answer. Without the actual apparatus of the balance beam my students were not able to make transformations. They were performing operations on operations and their answer was not as elegant as that of Brenda and not as complex as that of Myron, but it was no less wonderful.

Those whose answer was 5 also seemed to be able to deal with the variables of weight and distance. Their schema appeared to be W + d = W + d. This schema will even yield the correct answer at times, for instance when Weight[left] = distance[right] and vice versa. Those with 7 as their answer might have been using W - d = d - W, an inversion of sorts that may have been prompted by previous experience on seesaws or whatever. With no apparatus and no prior learning of the concept these are perfectly reasonable answers. That the students were able to deal with two variables leads me to believe they are meeting at least one requirement of formal thought. By not trying to use proportions they sought a simpler answer and they should not be judged inadequate for that.

But with only 8 correct answers among 31 students I ended the lesson after the error analysis telling them we would come back to it. Before the next week I made a real balance beam, rather than the symbol of one on the blackboard, and, in the ensuing weeks, asked the class to experiment individually and try to derive a formula for the correct solution as I watched while giving no directions. Eventually, every student, even the three who demonstrated no formal thinking, came up with the correct proportional solution, in every case, however, stating it in its multiplicative rather than its fractional form, W[left] x distance[left] = Weight[right] x distance[right]. This is actually the only form that works when you use more than one weight on each side.

My data were not, of course, collected in an experiment and, even with a semi-clinical interview method, were tainted. Students may have passed information to each other, a very good way to learn, however. But what I am sure of is that it would be very difficult to ascertain whether an individual had achieved formal operations from a paper and pencil test or from answers given in response to a professor's questions in the course of a lecture. Moreover, to expect correct solutions to problems that students have never seen before is unrealistic unless they are able to experiment with the *real* apparatus.

When Brenda had an actual rectangle that she could change to a parallelogram and see the area decrease to zero, when Myron, I trust, is willing to experiment with a real grandfather's clock, and when my 31 students had an actual balance beam to experiment on, they were (and will be) able to solve the problems. If one of my students was unable to arrive at a solution after being able to experiment on real and not imaginary apparatus, only then would I be willing to admit that she had not achieved formal operations.

For any number of reasons, not all of them bad, we can no longer rely on all students admitted to college to be familiar with physics, Euclidian geometry, or trigonometry. However, most of my students, I believe, are formals and are capable of the "spontaneous development of the experimental spirit." To suggest they have not achieved formal operations is to blame them for high school curricula and lack of required courses. If we feel that our students should have a grounding in basic science we will have to create minimum requirements of our own for our undergraduates. What those requirements might be are beyond the scope of this paper but not beyond the capabilities of my students.

References

Godel, K. (1931). Uber formal unentscheidbare satze der principia mathematica aund verwandter systeme I. *Monatschefte fur Mathematik und Physik, 38,* 173-198. Cited in E. Nagel & J. Newman, *Godel's Proof.* New York: New York University Press, 1958.

Kohlberg, L., & Gilligen, C. (1971). The adolescent as a philosopher: The discovery of the self in a postconventional world. *Daedalus, 100, 4,* 1051-1086.

Kuhn, D., Langer, J., & Kohlberg, L., & Haan, N. (1977). The development of formal operations in logical and moral judgement. *Genetic Psychology Monographs, 95,* 97-188.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child.* New York: Basic Books.

Werthheimer, M. (1945). *Productive thinking.* New York: Harper & Brothers.

∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞

Socrates, he who does not write--Nietzche

However the topic is considered, the *problem of language* has never been simply one problem among others. But never as much as at present has it invaded, *as such*, the global horizon of the most diverse researchers and the most heterogeneous discourses, diverse and heterogeneous in their intention, method, and ideology. The devaluation of the word "language" itself, and how, in the very hold it has upon us, it betrays a loose vocabulary, the temptation of a cheap seduction, the passive yielding to fashion, the consciousness of the avant-garde, in other words--ignorance--are evidences of this effect. This inflation of the sign "language" is the inflation of the sign itself, absolute inflation, inflation itself. Yet, by one of its aspects or shadows, it is itself still a sign: this crisis is also a symptom. It indicates, as if in spite of itself, that a historico- metaphysical epoch *must* finally determine as language the totality of its problematic horizon. It must do so not only because all that desire had wished to wrest from the play of the language finds itself recaptured within that play but also because, for the same reason, language itself is menaced in its very life, helpless, adrift in the threat of limitlessness, brought back to its own finitude at the very moment when its limits seem to disappear, when it ceases to be self-assured, contained, and *guaranteed* by the infinite signified which seemed to exceed it.

Nietzsche, 1903

Computer as a Tool for Children's Exploration of Nature

Takito Totsuka
Konan Elementary School

Naomi Miyake
Aoyama Gakuin Women's College

It has been repeatedly said in educational practices that letting children explore nature on their own is beneficial. It is also true, however, that children on their own rarely come to understand the laws of nature, the knowledge human beings have gradually gained through their sincere scientific struggle for long centuries. One of the reasons for this gap can be that tools for representing the results of exploration are hard to use, or just not available for children.

Computers have been claimed to be a new tool created to fill this gap, that is, a tool for children to represent the results of their exploration, to explore the represented "microworlds," and to derive laws from them (e.g., Papert, 1980). The usefulness of the tool, however, can only be decided by actually using it for some specific purpose. For the above claim to be substantiated, concrete and content-rich examples are needed.

Computers can be regarded as a tool for representation when the users can program them to simulate what they have observed for further exploration. However, teaching a programming language, at least any of the ones currently available for school use, tends to be tedious and time consuming. Many teachers would feel frustrated by this, particularly when they want children to be involved not in exploring programming but in exploring nature. For a programming language to be a useful tool for children in school, it has to be powerful from the very early stage of its programming. What we need to know is again concrete examples of how simple programming could still help children fulfill the role of an explorer in nature with a scientific outlook.

In this article, we report three such examples. These are the activities carried out by the first author in his classrooms from 1983 to 1987. In the first example, children used LOGO to make maps and came to grasp why units are needed in measurement. In the second example, children simulated the growth of sunflower leaves with simple LOGO procedures. This simulation led to a child's discovery of "a law of the shapes of leaves." In the last case, children simulated the movement of the four moons of Jupiter, and "discovered" the periods of Io and Europa. Through this experience the children learned that natural phenomena, however complex they may appear, are controlled by laws that they would be able to describe.

The Setting

During 1983 to 1985, Totsuka taught at Hokone Elementary School, where the first example we report below took place. Forerunners of the other two activities were also done here. It was a remote detached-class for a thinly populated, isolated area in the mountains of Toyama Prefecture, which faces the Japan Sea and is some 200 miles northwest of Tokyo. The school was very small, with Totsuka as an only teacher and two to six children depending on the year.

After that, he taught fifth grade classes at Konan Elementary School, located in Himi city. This was in 1986 and 1987. Himi is a small city also in Toyama Prefecture. Out of its population of 60,000, two-thirds are farmers and fishermen.

Konan Elementary School is a small, typical Japanese elementary school. There are 300 children and 11 teachers there. Children who participated in the second and third activities were fifth graders. They replicated and expanded what Totsuka had started with a smaller number of children at his previous school.

Taking advantage of the naturally rich environment of the schools, Totsuka's curricula have aimed at having children explore their surroundings and discover natural laws on their own as much as possible. Children are encouraged to "teach," or represent on computers, what they observed in terms of LOGO procedures.

Finding the Importance of Units in Map-Making

Two of Hokone Elementary School's children, a second and a third grader, made a "town" on the floor of their classroom. Buildings were carton boxes; roads were pieces of tape glued onto the floor. The town was big enough for them to walk through. They used this town to learn about lots of different topics. They put "telephone wires" among the buildings to study about the transmission of sound over a string. When they supplied electricity, they learned about battery connections in series and in parallel.

They also decided to run a bus. There were three routes for the bus to run. To decide the fares, they needed to measure the length of each route. They took turns in walking through each of the routes to measure the length in terms of the number of steps, and the angles of the roads at turnings in terms of the numbers of degrees. The records of these lengths and angles were directly turned into LOGO procedures to represent the routes on a computer screen. This provided a partial map of the town. However, the map they drew on the screen did not correspond with the actual formation of the roads of their town. They were surprised, but soon they realized, on their own, why the screen map was not correct. One of the children said, "This route is wrong because you measured it with your own paces. The length of our paces are different, and those differences caused this discrepancy. When we measure the length, either you or I have to do it for all the routes."

This girl discovered the concept of units, which has been known to be hard to understand, particularly for the lower grades. LOGO helped her compare her representation of the routes with that of the other girl's, in an abstracted form of numbers. LOGO required that abstraction, but showed the children the results of such formalization in a visible form of graphics.

Encouraged by this "finding," they walked all over their village with a protractor. This time one girl did all the counting of her paces. The map that the children had thus created did not look correct to anybody in the village, but Totsuka found an old aerial photo. It matched the map. This experience gave them a new perspective of their village.

Simulating the Growth of Sunflower Leaves

In agriculture, marks are put on products and measured while they grow to provide useful information on their growth. This method is often recommended as a theme for a "summer vacation project" for elementary school children in Japan.

While Totsuka was still at Hokone Elementary School, he observed a child measure the growth of a sunflower stalk. She followed an orthodox method, measuring the width of the intervals originally put at every one centimeter on the stalk. These observations lasted for three months.

As the stalk grew the marks faded, requiring darkening them every week or so. Using the pen for this activity, the girl drew a face on one of the leaves. This inspired Totsuka with the idea of having children measure the growth of leaves by drawing shapes on them and following their changes.

Another child took up this idea and accumulated drawings of the deformation of shapes put on the surfaces of the leaves. At this point, Totsuka realized that children could use LOGO as a tool to represent and store the daily data collected in this way.

After moving to Konan Elementary School, in May, Totsuka had children sow the sunflower seeds in the school garden. Since the sunflower grows very rapidly, two weeks later they had already grown several inches high and started to have tiny young leaves. Totsuka suggested to the class, as their summer projects, this "sunflower experiment." Four weeks later, when the young leaves of sunflowers became big enough for the experiment (about 5 to 6 centimeters wide in diameter), eight children started the experiment.

They drew various strange marks on the surface of young leaves with a felt pen. Because sunflower leaves grow very rapidly, it is difficult to track down on how the whole shape of the leaves changes. By putting marks on the surface of young leaves, they expected to detect even slight changes of the shapes of marks. By watching carefully how the shapes of the marks change everyday, they hoped to pin down the growth pattern of sunflower leaves more precisely than usually done.

The children became quite excited with this idea and very much enjoyed these activities. Totsuka gave them small protractors and rulers so that they could record any slight changes of the shapes by measuring the length of the lines and angles between the lines.

These observations lasted for two weeks. Every morning children measured the marks and brought back the data to their classroom so that they could compare the results of the day with those of the previous day. The changes children observed of their leaf marks were turned into a series of LOGO commands and numbers to draw the shape onto the screen, representing direction and amount of movement to recreate the observed shapes; LOGO acted as a medium between the childrens' observations and their formal representations.

A day's observation, in terms of LOGO commands, was stored in the computer memory as a LOGO procedure. One of the children measured his mark shown in Figure 1 on August 2nd. The form of the data he put in the computer is shown in Table 1. This program was named AUGUST2ND, which actually is a LOGO procedure name.

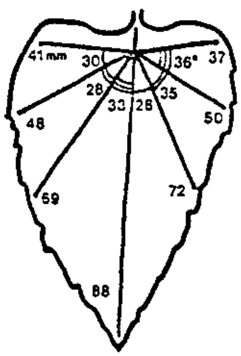

Figure 1: Observed data on a sunflower leaf on August 2nd.

Table 1

A LOGO Procedure for the Observation on August 2nd

```
TO AUGUST 2ND
  FORWARD 88
  BACK 88
  RIGHT 33
  FORWARD 69
  BACK 69
  RIGHT 28
  FORWARD 48
  BACK 48
  RIGHT 30
  FORWARD 41
  BACK 41
  LEFT 119
  FORWARD 72
  BACK 72
  LEFT 35
  FORWARD 50
  BACK 50
  LEFT 36
  FORWARD 37
  BACK 37
END
```

As children kept track of the changes of the sunflower leaves every day, they also kept up the LOGO procedures. As the activities went on, the data of the sunflower leaves' growth and their LOGO procedural representations gradually increased.

In two weeks, the sunflower ceased to grow. The growth of the sunflower leaves also stopped. Each child had saved 14 procedures in the LOGO database during the previous two weeks of activities. Totsuka and the children then tried an experiment. They ran the 14 procedures all together in a sequence, let's say from JULY25TH to AUGUST7TH, one after another, one on top of the previous one. They made up a higher order procedure just by sequentially listing the accumulated data. Running this higher order procedure resulted in a vivid computer graphic image, or a computer animation of the growth of a sunflower leaf.

The images that appeared on the computer screen were beautiful. The children and Totsuka report that they could hardly believe their eyes. They were very excited by the animation.

Totally fascinated as they looked at the computer animation again and again, one child suddenly noticed a strange pattern in this growth animation. He realized that inside the growth movements of the leaves, there were some mysterious sequences of motions, whose mechanisms were unknown. The growth movement first heads towards the points of the leaf, along the axes. Then that movement suddenly stops. After that comes another growth movement, this time towards the edges of the leaf, vertically away from the axes.

One of the children described what he observed in this computer animated graphics in more detail. It seems that the growing process of the leaves consists of two growing stages.

(1) One stage of growth occurs in a direction of the points of the leaf, thus, the growth occurs in a parallel movement along the axes of the leaf.

After this growing stage stops, there comes the next growing stage.

(2) This time, the growth occurs in a different direction, towards the direction of the leaf's edges, thus growth occurs in a vertical movement away from the axis of the leaf.

But why should the leaves grow in these two separate stages independently in one long growing process? Where does this strange rhythm come from?

One child gave a unique but bright idea. He deduced, "Suppose there is some unknown power, we may call it "the growth power," in the leaf, and let's also suppose it is generated from the axes of the leaf. The power first works along the axes, and then away from them. That could determine the two stage growth patterns."

And then, suddenly, he found a solution to this puzzle. "Aha, I now understand the reason why the sunflower leaves must have such shapes like they do now. You know, the answer is very simple. It's only an addition, an addition of three single normal leaves, because a sunflower leaf has three axes!"

He named this the "Addition Model," which he described as,

In the case of sunflower leaves:
There are three axes on the surface and they are crossed over each other. If the growing process would go on independently along each single axis, then we could get the shape of the sunflower leaf.

To Totsuka's great surprise, he realized by himself that his "Addition Model" could be generalized, to be more powerful. Not only does it explain the shape of the sunflower leaf, but it also could explain the shapes in general, of other leaves.

In the case of leaves in general:
The shape of a leaf in Nature is decided by the number of its axes and their crossing angles.

Figure 2 depicts this model. Both Totsuka and the other children of the group were very doubtful about this thesis. To prove whether his model was right or wrong, they decided to go out in the field and test it on real leaves.

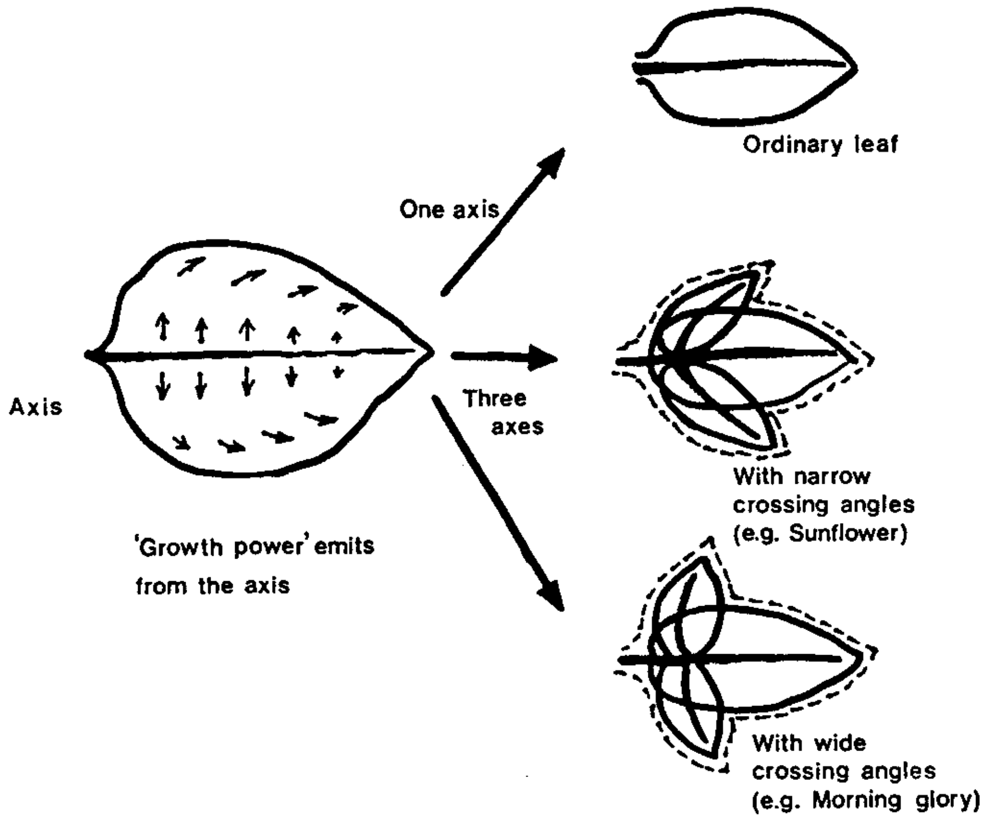

Figure 2: The "Addition model."

On the following day, the children with Totsuka went out for a walk to the mountains and searched and kept inspecting lots of leaves one by one, as many as possible to see if his thesis was right. To their great surprise, his "Additional Model" was mostly right. His model turned out to be more powerful and useful than he first imagined. In a sense, he discovered a "hidden law" of Nature, which had been hidden in the children's observations. The children discovered it with the aid off computer animated graphics; without computers, it would have been almost impossible for them to reach this abstraction.

This experience gave the child who discovered the addition model great confidence. He mentioned, "It was really exciting. I felt as if I had become the only person who solved one deep difficult question, whose answer was hidden behind Nature. I am truly satisfied."

Finding the Periods of the Moons of Jupiter

Jupiter has many moons, four of which are large and bright enough to be easily observed with a telescope. Galileo found them, named them, and wanted to find out their periods to use this knowledge as a piece of supporting evidence for his heliocentric theory. He did this with great difficulty. At least he had to invent a tool to simulate the movement of the moons from scratch, on his own.

One sixth grader at Hokone Elementary School and two fifth graders at Konan Elementary School, in different years, all tried the same as Galileo, and they had a helpful tool at hand to do that.

They first observed the four moons of Jupiter to determine their relative locations at a scheduled time for about a month. Then they focussed on the two fast moving moons and followed the change of their locations day by day.

In LOGO, a circle is drawn by making a turtle go around the circumference. A typical LOGO procedure to draw a circle would look like: REPEAT :N [FORWARD 1 LEFT 360/:N] where :N stands for a variable which decides the size of the circle. In an analogy, the turtle can be taken as a moon. In this analogy, the above :N can be regarded as a number corresponding with the period of the moon, measured in appropriate units. The children who participated in this activity took hours as their unit of time.

A three dimensional version of LOGO allows its users to take different perspectives in three dimensional space. With this capability, children could relate the circular movement of a moon, or its top view (Figure 3A), to its horizontal, oscillating movement which they observed through the telescope, or its side view (Figure 3B). To help the children better understand this relationship, at Konan Elementary School, Totsuka also had one of the children locate a small clay ball at various points on the circumference of a circle drawn on a table, and then had the other child look at the movement of the "moon" with his eye at the edge of the table.

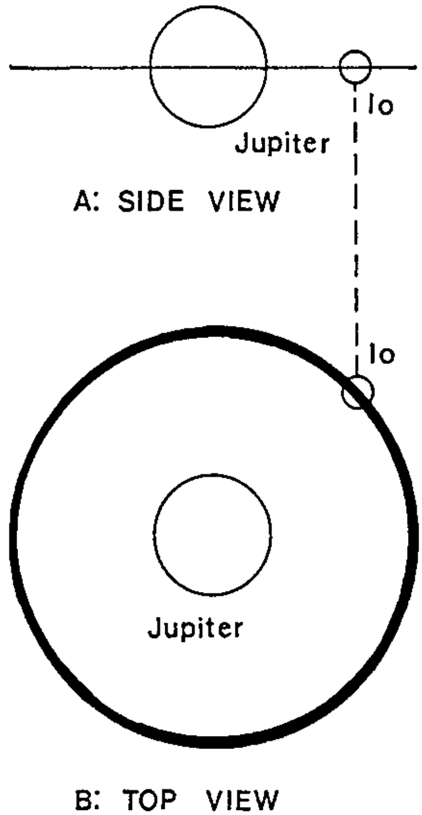

Figure 3: Correspondence between the side view (A) and top view (B) of Io moving around Jupiter.

With all these settings, children first made hypotheses about the periods of Io, the fastest moving moon of Jupiter. According to different hypotheses, they put different numbers in terms of hours in 360/:N to draw circles of various sizes on the screen. Then they ran the procedure with 24 repetitions with a set :N, that is; REPEAT 24 [FORWARD 1 LEFT 360/:N] to yield the day's movement. Then they had the

LOGO produce its side view, to test whether the day's movement on the hypothesized circle corresponded with their observation. With this method, they first determined the period of Io. Then, they scratched out Io's positions from their original data, leaving what should be the trace of changing locations of the other moon, Europa. On this set of data, they repeated the method to determine Europa's period.

The children at Konan Elementary School estimated that the periods were 48 and 89 hours for Io and Europa, respectively. The Science Almanac for 1987 gives 1.77 and 3.55 days (that is, 42.48 and 85.2 hours) as their periods. Considering the age and the experience of these "scientists" these numbers appear to be quite acceptable.

Totsuka did not tell them these numerical facts given in the almanac. To test their hypotheses, the children predicted the next day's locations of these two moons of Jupiter. On the next day, they appeared very close to the points they had predicted. This satisfied them. One of them commented, "Galileo should have had a computer at hand, as we did."

Through all three examples we reported here, computers seem to have given the children a method to turn their "raw" data into concrete objects on the screen. The objects were presented in terms of programming commands and numbers, that is, in abstracted forms of representation. On the one hand, because the children could relate them both to what they had observed in nature and to what they could identify on the screen, the abstraction continued to be meaningful to the children. On the other hand, because the commands and numbers were abstract, they could easily be manipulated by the children. We'd like to hypothesize that this combination helped them to grasp the meaning of abstract concepts like "units," and to deduce laws from their observations of nature.

We are trying to accumulate more cases with the same characteristics. By analyzing these, we hope to find out conditions for creating environments in which children could learn from their own observations. By analyzing this type of learning, we hope to gain some understanding of how formalization helps structure our knowledge.

Reference

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* Basic Books, New York.

The Child's Understanding of Computers

Steven Pulos
Sarah Fisher
University of California, Berkeley

For the first time in history children are faced with a machine that "thinks." Understanding how children reconcile the idea of the computer as a machine and as an entity able to think may provide insight into how children interact with computers, and how they develop an understanding of cognition in general.

In one of the few studies relevant to this issue, Turkle (1984) found that children's concepts of computers differ from their concepts of other inanimate objects. She asked children whether or not computers were alive and found that they progressed through stages in which their explanations of computers became increasingly psychological. While Turkle's work clearly suggests that children think that computers are something between people and machines, her work does not address how children understand computer cognition. This was the goal of the current study.

Methodology

Subjects and Site

The subjects consisted of 140 children in the 3rd through 7th grade, with 28 students (14 boys and 14 girls) at each grade level. The children were selected from typical classes in a middle-class elementary or middle school, and were chosen by the teachers to represent typical children in their class.

All students in the 4th grade and above had experience with computers in school. The computer curriculum consisted of weekly to biweekly visits to the computer lab where each child spends 20-30 minutes with the computer, working alone or in groups. Those who were interested could also work with computers, during lunch, recess or after school.

The computer experience included computer assisted instruction, computer literacy course work explaining how computers function, rudimentary experience with word processing and programming in BASIC. The computer curriculum in these schools is considered one of the best in the area, and serves as a model for other schools. In general, the curriculum is fairly typical of elementary and middle school programs in this country (Becker, 1985).

Procedures

Children were interviewed by trained examiners using a semi-structured interview. Questions were rephrased as needed to insure that the children understood the question. Each answer was probed until the interviewer felt the child's answer was as explicit as he or she could make it. Such probing was necessary because the meanings of many of the terms used by the children did not correspond to those of adults, e.g., many children used the word "programming" to refer to the act of putting a diskette into the disk drive.

Children were asked two categories of questions: one about their relevant experience with computers, and the other about their understanding of computers. The questions about relevant experience included: (1) Where have they used computers; (2) How often have they used them; (3) What did they do with them; 4) Where have they played video-games; (5) How often have they played them; (6) Who do they know that use computers, and (7) How do they use them.

The questions about the children's conception of computers included: (1) How do computers and video games differ; (2) How do computers work; (3) Do computers think the same way as people do, and why; and (4) Who is smarter, people or computers, and why.

Results

Background variables of the sample are presented in Table 1. It is important to note that for many of these variables, e.g., siblings who use computers, the variability is very small. Thus the correlates of the meanings of computers will tend to be much lower in magnitude than if there was greater variability.

Because children's concepts were tapped by different questions, our model of a child's understanding of how computers work was drawn from the total interview. One child, for example, gave a more sophisticated response about how a computer works when describing the difference between how people and computers think, while another child was more explicit when asked how computers actually worked.

The responses fell naturally into five categories. Originally it was planned to examine separately the child's conception of the relative intelligence of people and computers, and the concept of how computers work. But when we found a consistent relationship between these two variables, we combined them into a single classification system.

Table 1

Percent of Children with Computer Contacts Outside of School

Type of Computer Contact	Percent
Computer in the home	28
Sibling uses a computer	06
Father uses a computer	14
Mother uses a computer	09
Friend uses a computer	14
Contact with another computer using adult	09
Have used a computer for games	70
Have used a computer for programming	29
Have used educational software	19
Have used a computer for drawing	05
Have used a computer for word procesing	01

Based upon an examination of the interviews, we abstracted an initial set of categories or "ideal types." Subjects were then classified according to the type that they most clearly resembled. Agreement among raters was high (79%); most ratings differed by only one level. Based upon their relationship to grade and experience, and upon increased approximation to a "correct" answer, the categories were ordered into the following developmental sequence.

Level I: No Concepts about Computers

Children at this level do not understand how computers work and deny them any intelligence. When asked how they worked, for example, a third grader said, "I really don't know, I wish I did." and another said, "Magic, not really, I don't know, but it seems like magic."

Level II: The Computer as Just a Machine

At this level the children have some idea of how computers work, but still deny them any intelligence. Computers are thought to work analogously to some other familiar machine, most frequently a video-game, VCR or TV. When faced with questions about the relative intelligence of humans and computers, children at this level refuse to answer the question, e.g., "That's silly. They're only machines, and they can't think." "No, computers can't think - they're just like a VCR. It's different because they make them so you can move the pictures around on it." "They're like a video-game, but the cartridges are for work not play."

Level III: The Computer as a Thinking Machine

At this level children view the computer as an intelligent but mysterious machine. They cannot explain how the computer works, but know it has some intelligence, e.g., it can solve some problems. Their explanations contain many references to computer components, e.g., chips, but they cannot explain what they do beyond a very global statement like "think."

A key issue at this level is the idea that the "programming" was done at a factory, and then put into the computer, on a disk or a tape. The user can not alter this "programming." The computer is seen as similar to a video game, or a video-tape recorder. Many children at this level used the word "programming" to refer to putting a cassette or disk into a computer.

For example:

Child: It works like a video game, only you do work on it. It uses a different kind of chip.
Interviewer: What do chips do?
C: Think.
I: How do they do that?
C: I don't know.
I: Where are chips made?
C: In a factory.
I: Can you get the computer to do different things?
C: You can. (You just) put different cartridges in it.
I: Is that the only way?
C: Yeah.
I: Can anyone make a cartridge?
C: No! You need special things to make it.
I: How do cartridges work?
C: I don't know, like a video tape. It has film in it.

Another child at this level said computers worked because they had "calculators inside" that thought for the computer, but she could not be more explicit.

At Level III most children (82%) see people as smarter than computers, because people make computers, e.g., "People are smarter because they make computers, and computers don't make people." No mention of any specific differences in processes or cognitive abilities were given at this level.

A few children believe that people are smarter than most computers, but that there are some super-computers who are smarter than anyone. In most cases they cannot give a reason beyond hear-say for why super-computers are smarter. However, some of the older students said intelligence could accumulate in a computer, e.g., "If you got a bunch of geniuses together, they could make a computer as smart as all of them."

In other words, Level III children attribute some global intelligence to computers, but cannot be specific about what it is, how it functions, or how it gets into computers. It is as if computer intelligence is accepted as an act of faith.

Level IV: The Computer as a Dictionary

Children at this level see the computer as a data storage device. They focus on memory as the main cognitive function of the computer. Children now know that a computer can be programmed by most users, but they see programming as putting facts in the computer for latter retrieval. Many children at this level, for example, believe that if a computer can answer the question of 1,873,821 X 6731, then someone had to put in that specific answer. The computer does not calculate it! Many children at this level make a spontaneous analogy between rote learning, e.g., the multiplication tables or a spelling list, and the programming and functioning of the computer, e.g., "It learns like me. I say the numbers to myself and I remember them. You put the numbers into the computer and it remembers too." Children with some experience with programming sometimes hold this belief and say, "You need to do all that, so the computer can understand you, because it uses another language -- binary."

Most children at Level IV (78%) believe that computers and people think alike, but that computers are smarter, e.g., "Computers and people are like comparing a motorcycle with a bicycle." They usually explain their similar thinking process on the grounds that both people and computers give the same answer. Some children also explain their response on the basis that people program computers, "so they must think like people." The idea of the greater intelligence of a computer is based upon some perceived greater capacity of computers, e.g., speed, memory resistance to forgetting. Other children at Level IV believe there may be a few people (e.g., Einstein or the "guy who invented the computer,") who are more intelligent than computers; but they still believe that computers are more intelligent than most people.

Level V: The Computer as a Programmable Machine

At the highest level children know that computers can be programmed to follow directions, *and* that they can come up with answers that were not specifically put into them. Children at this level (87%) believe that computers and people do not think alike, but that people *are* smarter than computers. The children at Level V justify their responses by saying that people program computers. These children stress the human ability to invent a solution, e.g., "Computers might solve a math problem like people, but some person had to think of how to solve it." Or, "People can teach themselves; someone has to teach a computer." In other words, they see the computer as being able to carry out cognitive operations, but as being unable to create or spontaneously acquire these operations.

As may be seen in Table 2, the proportion of children at each level shifts considerably with age (chi-square = 39.74, $p < .0001$).

During the period from the third to the seventh grade, a decreasing number of children see the computer as a vaguely-defined machine, and an increasing number have an accurate picture of it. Nevertheless, there is considerable variation within each age group. Only in the seventh grade are more than 50% of the subjects in a single category, and even then 46% fall in other categories. Children at the highest level could be found even in the fourth grade, and many adolescents in the seventh grade (21%) were still at Level III. Furthermore, about 25% of the children in each grade see the computer as a programmable data storage device (Level IV). Thus, while age and grade are highly related to the child's conceptual level, they cannot fully account for it.

Table 2

Levels of Understanding Computers by Grade (%)

	Grade					
Level	3rd	4th	5th	6th	7th	Total
I. None	11	0	4	0	0	3
II. Denial	18	11	7	0	0	7
III. Machine	50	43	29	36	21	36
IV. Dictionary	21	32	25	29	25	26
V. Programmed	0	14	36	36	54	28

Independent of grade, the progression through the levels appears to be most strongly related to having: Friends who use computers (tau = .19, $p < .01$), and a mother who uses a computer (tau = .16, $p < .05$). Use of a computer by the father or siblings of a child had no impact on the child's level. The difference between father and mother influence may result from the greater frequency of communication between mothers and children (Youniss & Smollar, 1985). Surprisingly, contact with computers outside of class was not related to level of understanding. Perhaps dialogue is more important for an advanced understanding of computers than extra experience would be.

Discussion

Our observations suggest that children progress through levels of understanding computer thought, with the explanations at each level becoming increasingly articulated and more psychological in content. These findings are consistent with those of Sherry Turkle (1984). In Level I children have no model of computers. At Level II, children's models of computers are purely mechanical and do not include any cognitive components. In Level III, the children attribute intelligence to computers, but are very vague about how intelligence is actually placed into a computer, and how computer thought differs from human thought. Level IV children have an explicit model of computer thought based upon rote learning and memory storage and retrieval. At Level V, children's model of computers includes computational activity as well as memory, but human and computer thought is differentiated on the basis of creativity, autonomy, and emotions. It seems plausible that the level of computer understanding is not necessarily dependent on knowledge about computers, but rather on knowledge about human thought, which is projected onto the computer. Children's models of human thought may serve as a prototype even when they do not believe that computers and people think alike; just as children's models of human beings may serve as a prototype for their thinking about animals, even though they do not think of people as animals at all (Carey, 1985).

References

Becker, H. J. (1985). How schools use microcomputers: Results from a national survey. In M. Chen, & W. Paisey, (Eds.), *Children and Microcomputers*. Beverly Hills, CA: Sage Publications.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge: MIT Press.

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

Youniss, J., & Smollar, J. (1985). *Adolescent relations with mothers, fathers, and friends*. Chicago: University of Chicago Press.

∞ ∞ ∞ ∞ ∞ ∞ ∞ ∞

It is impossible to so forecast any future conditions that depend upon the evolution of society as to be able to govern our conduct by such a forecast; it is always the unexpected that happens, for we have to recognize not only the immediate change that is to take place, but also the reaction back upon this of the whole world within which the change takes place, and no human foresight is equal to this... What we have is a method and a control in application, not an ideal to work toward.

George Mead, 1964

Reconstructing Work as an Object of Research

Yrjö Engeström
University of Helsinki, Finland

Introduction

Work is not the most fashionable research object in social and human sciences today. If we look at the themes discussed in cognitive and developmental psychology, for example, we find a lot of research directly connected with schooling and play--but very little that has any obvious link to the activity of work. My intention is not to make work more acceptable or appealing to researchers. Work doesn't need that kind of marketing. To the contrary, if researchers won't realize the importance of work, it is going to be a problem for the researchers themselves.

In the following, I shall substantiate this claim by pointing out three essential developments currently shaping the world of work. After that, I will discuss three dominant dichotomies that undermine today's work research. I will suggest ways to overcome these dichotomies and illustrate these ways with glimpses into new types of work research.

What is Happening in Work: (1) Impossible Tasks

Traditional psychological and sociological work research has concentrated on skills, competencies and qualifications as demanded by the normal, continuous running of the industry or business under scrutiny. Certain daily events in workplaces are rendering this approach obsolete.

Two classes of such events are becoming increasingly obvious: *disturbances* or *breakdowns* of the work process and *rapid overall changes* in technologies and organizational patterns. These two are interconnected: the introduction of novel technologies and organizational patterns often increases the likelihood of disturbances and breakdowns--and serious disturbances often force the management to seek new technological and organizational solutions (Hirschhorn, 1984). Moreover, both are connected with the changing national and international market demands and opportunities (see e.g., Noyelle, 1987; Stanback, 1987).

Both factors create situations where workers (on all levels of the hierarchy) face tasks that they find impossible to solve. There is something curious about this impossibility. Each individual worker (including engineers and managers) may testify that the situation was clearly beyond his or her control. Yet, most of those situations are somehow resolved.[1] Moreover, it may well happen so that none of the persons involved can quite reconstruct or fully understand what actually happened and how the resolution was found.[2]

Charles Perrow's book *Normal Accidents* (1984) is probably the most thorough sociological study so far on work breakdowns. Normal accidents or system accidents refer to multiple and unexpected interactions of failures in technological systems. Such accidents are caused by two basic properties of modern work: high interactive complexity and tight coupling of the system. In tightly coupled systems such as nuclear power plants or chemical refineries, system accidents may produce spectacular catastrophies.

However, this does not imply that less tightly coupled complex systems, such as those of professional work in hospitals or research centers, are free of the fundamental problem. In our own studies of janitorial cleaners on the one hand (Engeström & Engeström, 1986) and of health center physicians on the other hand (Engeström, 1987a), we encountered the phenomenon of impossible tasks time and time again. It is just that in these contexts the consequences of such situations are less dramatic and explosive. Thus, instead of system accidents or breakdowns, such situations are usually characterized as disturbances, difficulties, or just noise in the flow of work. Importantly, nobody seriously claims that they are discrete, clearly definable problems which are successfully solved (at least analytically, after the fact). To the contrary, the problem is that people cannot define the problems (see Schön, 1983). The prevalence of such impossible tasks eventually creates a nagging atmosphere of insufficient mastery over what is actually happening.

What is Happening in Work: (2) The Threat of Silence

Two incidents described by Perrow are particularly illuminating. The first is a part of the Three Mile Island accident.

> (...) someone on the floor - there were perhaps twenty people there - knew that there had been a hydrogen explosion. Fearing another pocket of gas might appear and be ignited by a spark, he asked another operator not to restart a failed pump. The operator replied, "I already have." (Pumps have motors; they are big and make sparks.) That means, the first fellow said, that we don't have more hydrogen. That is, he knew there had already been one hydrogen "burn." If this story is true a lot of people went through the rest of the day ignorant of a vital piece of information. (Perrow, 1984, p. 30)

The second example is from the collision of two ships in the Chesapeake Bay in 1978.

> On one of them (...) the captain (...) saw the other ship up ahead as a small object on the radar, and visually he saw two lights, indicating that it was proceeding in the same direction as his own ship. He thought it possibly was a fishing vessel. The first mate saw the lights, but saw three, and estimated (correctly) that it was a ship proceeding toward them. He had no responsibility to inform the captain, nor did he think he needed to. Since the two ships drew together so rapidly, the captain decided that it must be a very slow fishing boat that he was about to overtake. This reinforced his incorrect interpretation. The lookout knew the captain was aware of the ship, so he did not comment further as it got quite close and seemed to be nearly on a collision course. (Perrow, 1984, p. 215)

Interesting in such cases is the assumption that communication is not needed. It is somehow assumed that each *other* individual has all the necessary information and incentive for rational action--even though each individual *him/herself* may feel that the situation is beyond his/her control. Typically, in our studies of physicians in primary health care, the doctor often assumes that a patient with problematic complaints will act rationally and return for further examinations or follow-ups without explicit discussion and agreement to that effect--regardless of ample evidence of contrary behavior from the very same patient. Furthermore, the doctor often fails to inform colleagues in the same health center who have previously treated the patient about the patient's visit and complaints--not to mention the neglect of checking the patient's eventual next contact with the center (Engeström, 1987a).

Usually communication barriers are envisioned as structures that prevent us from understanding what the other person is trying to say. In the cases discussed above, the problem is that *people remain silent*. They never say what they should and could say in the first place.[3]

Work researchers have traditionally been concerned with obstacles and barriers of communication within organizations. The psychological counterpart of "fractured organizations" (Salaman, 1986) or compartmentalization of work is deep-seated individualistic rationalism. However, this classic problem is qualitatively altered as it gets intertwined with impossible tasks. The inability to communicate contributes to the impossibility of the task. And the reverse: the impossibility of the task aggravates the disconnectedness between people (it's hard to disclose that you are failing). Silence becomes a direct threat instead of just a latent pathology.

What is Happening in Work: (3) Elusive Quality

Quality has become a magic word in business and industry. Japan's competitive edge over the United States is attributed to superior quality consciousness. The solution to quality problems is seen in participatory management and quality circles, enabling workers to bring about improvements in the quality of their procedures, tools and products.

The curious thing about this movement is that the meaning of "quality" of the products is itself regularly taken as something self-evident and given. Quality is seen as a *technical* term, indicating *perfection of whatever is produced.*

This makes the quality propaganda very vulnerable in the face of high production pressures, demands for cost-effectiveness, speed and quantity of output. For example, our health center physicians face two demands which they feel are mutually exclusive: the demand for humane, individually tailored quality in their services, and the much more effectively sanctioned demand for a high number of patient visits per time unit. The discussion of quality is bound to remain technical when such constraints are accepted and internalized. Typically, when interviewed about alternatives to the detested quantitative measure of their productivity, the doctors only emphasized quality in the most general terms but were unable to identify any substantive indicators of quality.

Similarly, our colleagues in the Finnish Institute of Occupational Health questioned paper mill operators about the objects and products of their work. Among the highly skilled workers, a somewhat astonishing lack of cognitive insight into what actually is produced and for what purposes was found (Auvinen & Leppänen, 1987).

So workers are caught between technical quality propaganda and equally technical pressure toward high quantitative output. This becomes easily a real Catch 22 situation--or a double bind, to paraphrase Gregory Bateson (1972). Both demanded courses of action seem equally unacceptable or impossible. Moreover, it is not difficult to see the connection between this bewildering double pressure and impossible tasks. In the case of our doctors, a problematic patient is likely to become an impossible task because such a patient fits neither the demand for quality nor the demand for quantity. Unclear, complex complaints are a poor opportunity both for "high-quality service" and for speedy output.

From Dilemmas in Workplaces to Dichotomies of Research

The phenomenon of impossible tasks may be named the cognitive dilemma. The phenomenon of threatening silence may be named the communicative dilemma. And the phenomenon of elusive quality may be named the motivational dilemma. These three dilemmas currently developing in workplaces are a compelling research agenda. Traditional work research, whether conservative or radical, does not address the issues in this agenda.

The traditional research interest has been twofold. Conservative research has tried to find out *the optimal fit* between available human resources and the given technology and/or organization of work. Radical research has searched for and revealed the *negative effects* of the capitalist form of the labor process and automation of the skills and personalities of the workers: deskilling and alienation (Braverman, 1974; for a re-examination, see Wood, 1982).

In recent years, the realities in workplaces have given birth to budding research efforts that cannot be easily classified into either one of the traditional camps. A good example is Sylvia Scribner's cognitive research on work (see Scribner, 1984).

In the following, I will point out three basic dichotomous thought forms that are common to both types of traditional work research. These thought forms effectively prevent work research from facing the dilemmas described above. In a preliminary way, I will also sketch some ways of overcoming those dichotomies.

Work vs. Worker

The most fundamental and persistent dichotomy is that between *work* as a structural framework given from above and *worker* as an individual who enters the framework. The effects of the given framework on the individual as well as the required remedies are pictured differently depending on the ideological stance of the research. But the basic relationship is seen in terms of one-dimensional determination. Surely the radical tradition nowadays acknowledges the "resistance" and "negotiation" going on in workplaces (e.g., Willis, 1977; Edwards, 1979). But these are seen mainly as defensive functions which actually defeat themselves by keeping up the status quo.

This dichotomous thought form is a real fetish rather than pure fiction. It has its roots in our daily experience. Organizations and their technologies do look untouchable and directed by the all-powerful management somewhere above. And the individual worker certainly is replaceable and malleable.

However, this thought form overlooks one crucial and indisputable fact: the work would not be done without the workers. It would not continue, it would not exist without workers. To regard workers as external additions to a self-sufficient "work" is mystification.

The alternative is to depict workers as constitutive parts of an interactive, dynamic system. We may call such a new unit of analysis an *activity system*. The reciprocal and self-organizing nature of such a system implies that the workers actually construct their work--including what used to be considered as the organizational and technological "framework." Here management has to be seen as a specific part of the workforce. Its relation to the "lower echelons" of workers may be superordinate and antagonistic, but it surely is not able to construct the work independently of the rest of the workforce.

The construction of the technological "framework" from below is graphically demonstrated in the study of paper mill operators mentioned above. The huge, seemingly absolute self-sufficient and "given" paper machine is in reality under continuous repair, modification and alteration done by the workers. This construction does not follow prescriptions and algorithms given from above; the engineers are often lagging behind what is actually going on in the running of the machine. The alterations done are often of experimental nature. They include major changes not envisaged by the original makers of the machine. Without such a construction, the machine just would not run (Auvinen & Leppänen, 1987).

Larry Hirschhorn calls this kind of construction "second-order work" or "developmental work."

> The sheer complexity of the mechanical-electrical processes and the continual modification of the technical equipment places developmental responsibilities on workers. We do not have to posit a series of extreme breakdowns or accidents to forecast the development of second-order work at the center of worker responsibility. (Hirschhorn, 1984, p. 101)

Convincing analyses of such construction in work require and should aim at strong theoretical models. Otherwise, such analyses are bound to remain interesting case studies with limited effects on the practical elaboration and mastery of the dilemmas described above. So far, this seems to be the case in the constructivist sociology of science (Latour, 1987a & 1987b). In our own research, we have developed and applied a model of mediated activity systems, built on the tradition of the Soviet cultural-historical school of psychology (see Engeström, 1987b).

High vs. Low Level of Skill

The second persistent thought form in traditional work research manifests itself most abundantly in the discussions concerning the fate of skills in automation. One school says it is essentially a process of deskilling, or lowering the level of skills required. Another school says the predominant process is an upgrading of the skills. Finally, a third school combines the other two arguments and says there is polarization, i.e., upgrading for a few and deskilling for the majority (for a more thorough analysis, see Toikka, Engeström & Norros, 1985).

This discussion presupposes that there is an undebatable unit for measuring skills on a unitary linear scale. A closer examination reveals that it is usually taken for granted that the ideal high level of skill is manifested in the work of the classic craftsman.[4] The ideal craftsman supposedly has a high degree of autonomy and a highly versatile repertoire of skills. This may be true--given the type of objects he produced, the kind of instruments he used, the type of division of labor and community he was embedded in, and the kind of rules he had to follow. All these are specific to the socio-economic formation where he worked (classically, medieval feudalism in the early stages of the accumulation of commercial capital). No serious researcher would claim that today's jet planes are "better" transportation vehicles than medieval horses, or that medieval peasants were "happier" than today's farmers. But when we talk about skills, sweeping linear comparisons suddenly become commonplace.

It should not be too difficult to give up measuring "more" or "less" skill and to concentrate instead on the cultural-historical quality and "location" of the various procedures, mental models, artifacts, modes of interaction and organizational patterns we encounter in workplaces. So far, such culturally oriented assessment of "skills" seems to appear only in anthropological studies of traditional crafts outside our western industrial societies--and even then mostly without a historical perspective (see Wallman, 1979).

The curious feature in our modern workplaces is that a careful examination reveals a multitude of different, often conflicting cultural-historical "layers" of procedures, mental models, etc. in one and the same workplace, even within one and the same individual. In the formally highly rationalized and streamlined cleaning work we studied, we found a strong core of tacit assumptions and procedures that the cleaners had brought from the archaic model of home cleaning. These assumptions and procedures collided with the rationalized expectations partly thrust upon the cleaners by their superiors, partly internalized by the cleaners themselves, thus creating acute tensions and contributing significantly to the appearance of impossible tasks. Many seemingly stupid and irrational actions and conceptions become understandable and rational through such an analysis (Engeström & Engeström, 1986).

To acknowledge the relative cultural-historical functionality of each form of thought and action in workplaces does not imply an indifference toward their relative merits. However, their comparison cannot be based on a predetermined universal measure. What is advanced and what is not has to be assessed against the need to master the historically formed inner dilemmas or contradictions of the specific work activity under scrutiny. In other words, the basis for evaluations should be worked out through a historical analysis of the given activity system.

Research vs. Intervention

Some of the most influential research on work has been based on interventions: notably Taylor's elaboration of scientific management, Elton Mayo's Hawthorne studies, and Eric Trist's work on sociotechnical systems. These were essentially experiments in the change potential of workplaces. Powerful general concepts were derived from those studies.

Today the situation is different. Interventions have all but become the monopoly of private consultants whose reports seldom have much scientific value while academic researchers have all but settled for the safe roles of the observer and detached analyst.

There are two essentially moral arguments used to justify this stance. The conservative moral argument says that the active involvement of the researcher spoils objectivity by mixing the researcher's values into the processes to be recorded and interpreted neutrally. The radical moral argument says that interventions in workplaces unavoidably benefit the capital and the management, making the researcher actually an instrument of exploitation. Both these are arguments for purity.

A supposedly scientific variant of the same stance insists on the generalizability of the findings as the criterion which makes interventions questionable--pre-scientific in the best case. It is said that intervention by definition creates an exception, a unique case which cannot be used as a basis of generalizations.

There is, however, an alternative view of generalizations. The common statistical view regards as general only such features as exist in sufficiently great quantities in a given representative pool of data. Features not exceeding the given limits are considered accidental and non-significant. In effect, this procedure attributes significance only to features that have *already become* prevalent.

The alternative is demonstrated by Marx. He claimed that the working class will play a decisive role in the political and economic development of nations. When he was writing the first volume of *Capital*, the working class of the most industrialized nation, England, made up only about 8% of the population. From a statistical point of view, Marx's claim would be nonsense. History proved otherwise.

In the alternative perspective used in our own research, generalization is seen as a *material process of becoming general* of an emerging new basic relation (a germ cell). The researcher's task is to find and unfold those budding new relations or germ cells. For that, two basic steps are required. *First,* the inner contradictions and developmental tensions of the system under scrutiny are traced and tentatively identified through historical and actual-empirical analysis. Such analyses have to be sensitive to the exceptional and new that arises "from below," often only momentarily, in conflicts and in impossible tasks. This enables the researcher to formulate a hypothetical model of the next developmental step or "zone of proximal development" of the system (Engeström, 1986).

Secondly, the hypothesis is tested by means of a developmental intervention. Such an intervention typically involves a reconceptualization of the object and product of the work activity, a reorganization of the division of labor and social relations, and an intensive elaboration of new tools and theoretical instruments. All this takes place within a limited setting, as if still in a natural test tube, where the process and its discoordinations can be carefully followed, recorded and its growth nurtured.[5]

If the hypothesis is on the right track and the intervention is carried out well, there will eventually be a snowball effect. The emerging new model of work is adopted and further elaborated in a number of other settings. It becomes materially generalized--which of course enables the researcher to engage in further conceptual generalization.

Notes

[1]Here Jean Lave's discussion of the difference between solution and resolution is most helpful (see Lave, forthcoming).

[2]Even a catastrophe like the accident in the Three Mile Island nuclear power plant was eventually resolved. Perrow (1984, p. 29) shows how the crew did not very well understand their own resolution: "Two hours and twenty minutes after the start of the accident, a new shift came on. The record is unclear, but either the new shift supervisor decided to check the PORV, or an expert talking with a supervisor over the telephone questioned its status, and the operators discovered the stuck valve, and closed a block valve to shut off the flow to the PORV. The operator testified at the Kemeny Commission hearings that it was more of an act of desperation to shut the block valve than an act of understanding."

[3]As a contrast, Middleton and Mackinlay (1987) illustrate how informal gossip and "tidbits" can function as decisive mediators in the activity of a child development center.

[4]In a similar vein, apprenticeship and "direct learning from experience" are often idealized as universal models for human learning and instruction (e.g., Dreyfus & Dreyfus, 1986). The basic double role of experience in cognition--as source of competence and source of "mental inertia"--very clearly observed by Dewey (1910), is easily forgotten in the nostalgic praise of apprenticeship.

[5]The concept of discoordinations is elaborated and used in a powerful manner in an unpublished manuscript on the remediation of reading difficulties by Peg Griffin, Michael Cole, and associates. An earlier version of the same methodological approach of "model systems" is presented in a paper by the Laboratory of Comparative Human Cognition (1982).

References

Auvinen, E., & Leppänen, A. (1987, June). *Developing the work activity of paper mill operators.* Paper presented at the International Workshop on Activity, Work, and Learning, Karjaa, Finland.

Bateson, G. (1972). *Steps to an ecology of mind.* New York: Ballantine Books.

Braverman, H. (1974). *Labor and monopoly capital: The degradation of work in the twentieth century.* New York: Monthly Review Press.

Dewey, J. (1910). *How we think.* Boston: Heath.

Dreyfus, H., & Dreyfus, S. (1986). *Mind over machine: The power of human intuition and expertise in the era of the computer.* Oxford: Basil Blackwell.

Edwards, R. (1979). *Contested terrain.* London: Heinemann.

Engeström, Y. (1986). The zone of proximal development as the central category of educational psychology. *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 8*(1), 23-42.

Engeström, Y. (1987a, August). *Developmental studies of work as a testbench of activity theory.* Paper presented at the conference on Context, Cognition and Activity, Stenungsund, Sweden.

Engeström, Y. (1987b). *Learning by expanding: An activity-theoretical approach to developmental research.* Helsinki: Orienta-Konsultit.

Engeström, Y., & Engeström, R. (1986). Developmental work research: The approach and an application in cleaning work. *Nordisk Pedagogik, 6*(1), 2-15.

Hirschhorn, L. (1984). *Beyond mechanization: Work and technology in a postindustrial age.* Cambridge, MA: The MIT Press.

Laboratory of Comparative Human Cognition. (1982, July). A model system for the study of learning difficulties. *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 4*(3), 39-66.

Latour, B. (1987a). *The Pasteurization of French society.* Cambridge, MA: Harvard University Press.

Latour, B. (1987b). *Science in action.* Milton Keynes: Open University Press.

Lave, J. (in press). *Cognition in practice.* New York: Cambridge University Press.

Middleton, D., & Mackinlay, D. (1987, June). *"Gossip" and "tidbits" in teamwork: Conversation as an instrument of multi-disciplinary practice in child-development centres.* Paper presented at the International Workshop on Activity, Work, and Learning, Karjaa, Finland.

Noyelle, T. (1987). *Beyond industrial dualism: Market and job segmentation in the new economy.* Boulder: Westview Press.

Perrow, C. (1984). *Normal accidents: Living with high-risk technologies.* New York: Basic Books.

Salaman, G. (1986). *Working.* Chichester: Ellis Horwood.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action.* London: Temple Smith.

Scribner, S. (1984). Cognitive aspects of work. *Quareterly Newsletter of the Laboratory of Comparative Human Cognition, 1&2,* 1-50.

Stanback, T. M., Jr. (1987). *Computerization and the transformation of employment: Government, hospitals, and universities.* Boulder: Westview Press.

Toikka, K., Engeström, Y., & Norros, L. (1985). Entwickelnde Arbeitsforschung. Theoretische und methodologische Elemente. *Forum Kritische Psychologie, 15,* 5-41.

Wallman, S. (Ed.). (1979). *Social anthropology of work.* London: Academic Press.

Wood, S. (Ed.). (1982). *The degradation of work? Skill, deskilling and labour process.* London: Hutchinson.

Review Article

Michael Cole
University of California, San Diego

D. Holland and N. Quinn (Eds.). *Cultural Models in Language and Thought.* Cambridge: Cambridge University Press, 1987.

This volume represents collaborative efforts of anthropologists, linguists, and psychologists combining insights provided by their respective disciplines to explain people's everyday reasoning. The editors' introduction concisely summarizes the evolution of cognitive anthropology, setting an excellent context for the chapters to follow. Holland and Quinn recount how early attempts to describe cultural knowledge focussed on linguistic behavior. Using multivariate analyses of semantic similarity judgments, the early proponents of "ethnographic semantics" hoped to reconstruct native understanding by examining the way the natives labelled their world. This approach is faulted, in part, for its inability to account for tasks encountered in daily life; readers of this Newsletter for whom the artificiality of laboratory tasks has long been a sore point, can appreciate the need for "ecologically valid" models of cultural understanding.

The cultural models focussed of this volume are defined by the editors as "presuppposed, taken-for-granted models of the world that are widely shared...and that play an enormous role their understanding of that world and their behavior in it" (p. 4). The kinds of situations, behaviors, and models studied by contributors to this volume are quite varied: lying, talk about gender types, thinking about problem solving and how minds work in general, anger, home heat control devices, interpreting emotions or an encounter with the spirits of the dead, illness, and marriage. There is a more or less general consensus that cultural knowledge is organized into schemas that are then used by people to guide their behavior in corresponding task situations. Two sources of ideas about schemas are highlighted in the editors' introduction and in many of the later chapters: Schank and Abelson's notion of a script as a stereotyped sequence of events; Lakoff and Johnson's treatment of metaphors as models of thought. In contrast with the earlier "ethnographic semanticists," current analysts are likely to generate their data from the analysis of protocols in which people are asked to explain some phenomenon. In some cases the "speaker's intuitions" which serve as the hypothesis for the model are then tested against further intuitions by the same informant. In other cases, especially those in which the analyst is analyzing his or her own cultural phenomena, the analyst's intuitions are used to generate hypotheses, which are then verified by interviews with other people.

These procedures are clearly consistent with dominant trends in linguistics, and in so far as they are used to generate hypotheses about knowledge understood as cultural content that is "out there in the world" the way that shovels, wedding rings, and thermostats are "out there in the world" they are likely to raise few eyebrows among psychologists. However, as I read them, the ambitions of the contributors to this volume are not restricted to "out in the world" phenomena. To varying extents, they are making claims about how people think, not just the cultural artifacts with which they think. Sorting out the methodological implications of these stimulating essays for cultural theories of learning and development is an important task for the future.

In my opinion, the contributors are correct in attempting to tear down the barriers between anthropological, linguistic, and psychological theories of cognition because the objects of study (knowledge generating, interpretive processes) are simultaneously shared and unique, internal and external to individuals. The time has passed for the decades-old division of labor according to which anthropologists study the content of thought while psychologists study thought processes. Many psychologists will find here a wealth of stimulating ideas about both the content and process of thinking; they may want to verify the claims made using alternative techniques, and it may be that various conclusions will be found to be wanting. But the general trend toward conceiving the human mind as constituted by cultural artifacts evident in this set of essays strikes me as correct, and well worth broad examination.

SUBMISSION OF MANUSCRIPTS: Please send three copies of manuscripts, double-spaced, figures and illustrations in **original, camera-ready form** to Peggy Bengel (*LCHC Newsletter* Managing Editor).

NOTICE OF SUBSCRIPTION RATE CHANGE: To help cut our losses we have increased our rates, effective January 1, 1988 to $20.00 per year; single and back issues are available for $5.00 each.

Subscription Form

Name ______________________________

Address ______________________________

______________________________ Zip __________

Please enter my subscription to *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition.*

I am enclosing $ for years at $20.00 per year
For mailing outside US and Canada, please add $7.00.

Please make your checks payable to UC Regents and mail them to:
Peggy Bengel
Managing Editor
Laboratory of Comparative Human Cognition, X-003
University of California, San Diego
La Jolla, CA 92093

MOVING?
Please give us as much advance notice as possible and avoid missing an issue of the Newsletter.