NATURALISTIC PROBLEM SOLVING AND MICROCOMPUTERS

Report of a Conference

Edited by

Michael Cole, Edwin Hutchins, James Levin and Naomi Miyake

CENTER FOR HUMAN INFORMATION PROCESSING

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INTRODUCTION:

The overall theme of this conference was to explore ways in which the generality of standard laboratory procedures for the study of problem solving could be expanded through explicit examination of problem solving in "naturally occuring" settings. The major specific theme was an exploration of the potential role of microcomputers as an aspect of problem solving environments which can be studied in both laboratory and field settings.

The structure of the conference reflected the ordering of these general and specific themes. On the first day participants whose major work has involved the study of problem solving in experimental task environments and natural settings presented an overview of their work, emphasizing what they considered to be the underlying logic of the enterprise. On the second day, researchers who have a specific interest in microcomputers presented their work, emphasizing the logic of their attempts to make the microcomputer a generally accessible problem solving environment which could be used flexibly by a wide range of users. The final half-day session was devoted to formulating the generalizable principles which were embodied in all of the individual research enterprises.

The structure of this report will mirror the structure of the conference. We begin with summaries of the individual participants' presentations. This is followed by a discussion of the methodological suggestions and general theoretical issues which reoccurred often enough in the discussion to suggest that they are general issues in the study of problem solving in natural settings. Finally, we will suggest some general conclusions concerning future research in this area with respect to microcomputers, education, and cognitive science theory.

Michael Cole

Cole presented videotaped data on problem solving by two 10 year old children who were baking a cake together. An analysis of the demands of baking a cake from an information processing perspective indicated that the task called for the coordinated application of a variety of identifiable cognitive skills: attention to relevant steps in the baking process, search for needed ingredients and utensils, reading of instructions, measurement, and memory for already-completed aspects of the task were some of the subskills identified.

The two children were seen to divide up the task in a way that accorded with independent diagnoses of their intellectual strengths. One of the children was a proficient reader, but had difficulty attending to the task or coordinating his efforts with those of his partner. The partner was a poor reader who seemed to "supply" the first child with needed attentional and planning skills. Working individually, these children would have great difficulty with the task, but they carried it out with reasonable proficiency by subtly blending their resources.

This work demonstrated that even in a very noisy environment (7 children and an adult all working together and in small groups) it is possible to carry out cognitive analysis. Moreover this analysis reveals important ways in which children modify their task environments using other people to get through the task at hand. It illustrates the importance of considering the context in which a subskill (attending, reading) is embedded if one wants to understand the way in which cognitive skills will be assembled and used.

Other principles important to the study of thinking in non-laboratory style task environments were also discussed. These included the fact that "thinking" was not the goal of the childrens' activity, but a means to goals. The term "goals" marks the fact that in the scenes under discussion, the children were clearly time sharing on several problems at once. The disutility of separating social from cognitive problems was another salient point of the analysis and discussion.

Jim Levin and Edwin Hutchins

Levin and Hutchins described some preliminary work they are doing studying problem solving in a "quasi-naturalistic" setting. They set up a "computer club" where they video taped children working jointly to get a microcomputer to draw pictures. They described two classes of phenomena that occur within this setting, the use of other people as problem solving resources, and the use by problem solvers of alternate organizations of their knowledge about the problem. Examples of the use of other people as social resources for problem solving were shown, ranging from low level repair work to higher level assistance with determining tactics and strategy for tackling problems. They also showed video tape segments illustrating the use by children of alternate representations and organizations of the elements of the problem in the course of moving toward a solution. As an example of this, they traced the work by two children in developing a computer program to draw an "S" on the computer screen, from their initial sketches of an "S" on paper, through several intermediate stages (including the stage of an "S" shaped "S" program) to the final form of the functioning program.

Levin and Hutchins described the critical importance of the problem solver's simultaneous pursuit of multiple peer level goals, and described briefly a processing framework they are developing that allows them to construct an explicit model of problem solving which has many cognitive processes operating simultaneously and interactively.

Their overall research effort was described as a two pronged attack, with a bridging mechanism. One prong is the gathering of rich data in quasi-naturalistic problem environments; the second is an effort to develop a process model of the problem solving activity; the bridging attempt is an effort to develop coding techniques so that human coders can be trained to extract from the rich data selected phenomena important for evaluating the process model.

Hugh B. Mehan

Mehan presented a preliminary report of research on naturally occurring decision making in schools. School children are assigned to curriculum 'tracks' ostensibly in order to meet their individual educational needs. Mehan and his co-workers are collecting data on the decisions which move children from one "track" to another. Such a decision process typically begins with the teacher filing a report on the child indicating that the child's presence in the classroom is in some way inappropriate. Theoretically this could happen if the child were much brighter than his or her classmates, but more usually, it is because the child is seen by the teacher as being disruptive of the classroom activities. This data includes not only the "official" data of test scores and teacher and school psychologist reprots in the child's file, but also video tapes of the children in their original classrooms, the same children being interviewed and tested, video tapes of the decision making meetings, and finally video tapes of the children in classrooms after placement.

Mehan reported that one focus of his research is the progressive construction of a representation of a given child as the decision about the placement of that child proceeds through levels of the decision making system. This data provides a way to trace in detail the process by which a child is labeled as "gifted" or "learning disabled".

Another focus of the research is the complex set of processes the decision makers use in reaching a decision about the placement of a child given diverse kinds of information about that child, especially when the decision maker is performing within a group setting.

Arthur Elstein

Elstein and his colleagues found that naturalistic observations in the clinic were not useful mainly for two reasons. The first is that the data in such an unconstrained environment are simply so rich that it is hard to know where to begin or what to look at. The second reason is that what ever that rich data is, it often seems not to contain the reasoning of the physician because it is part of the physicians technique not to reveal his speculations and early hypotheses to the patient. This is of course responsible medical practice, and asking physicians to do otherwise in real situations would be of questionable ethics.

The high fidelity simulation is a research setting in which the physician is faced with an actor who is trained to behave as a patient suffering from a particular disease. The physician conducts a work-up of the patient's case as he would with a real patient, EXCEPT that he is periodically interupted in the course of the work-up and asked to verbalize his reasoning about the problem he faces in the diagnosis of the case. The situation is also life-like in that the physician can ask for particular lab tests, the simulated results of which will be made available to him, and he can ask for a consultation or second opinion if he wishes.

The data collected included the Transcript of the work-up report, the transcript of the think-aloud protocols, and the transcript of a commentary session where the physician reviewed the video taqpe of the examination with one of the researchers and provided extra commentary on his behavior. As is the case with all studies of natural or near natural situations, there is the temptation to look at everything. In order to keep the study manageable, they chose to foucs on what they called a COGNITIVE ACCOUNT OF CLINICAL INFORMATION PROCESSING. The doctors would have liked a study of the doctor patient interaction - something that they could immediately apply - but this study was not that. It focused instead on how the doctors made sense of what gets into their heads in the course of the work-up. The focus was on information gathering and processing rather than on the communication between doctor and patient.

A central concept in the study was the notion of hypothesis formation and evaluation. When were hypotheses formed? On the basis of what information? What sort of information was sought in the evaluation of hypotheses. Was there an attempt at disconfirmation? Confirmation?

This research uncovered an interesting paradox. Medical school teaches the postponement of hypothesis formation. It is known that medical (and other professional training) remove variation - their goal is the production of a uniformly competent community of practitioners . Yet in the obnservations of the study, both good and poor diagnosticians employ a heuristic of early hypothesis formation with information gathering aimed at confirmation. The resolution of the paradox comes from the realization that the constraints of the real world circumstances of the practice of medicine determine the doctors behavior more strongly than medical school education. That is , no matter what they are taught in medical school, if what they are taught does not fit the realities of the world in which they practice, they will disregard what they are taught and do what they must to keep working. In this case, the global constraints of the environment, primarily constraints on time, determine the global cognitive strategy employed. What is carried over from medical training is the uniformity in the information sought and the questions asked. Note that what one asks is not the same thing as what one does with the answers obtained.

It was also observed that the variablity in the performances of the physicians was accounted for better by the variablity of the cases seen than by enduring differences between the doctors. This is again an argument that cogntion cannot be considered without reference to the specifics of the environment in which it is occurring. As Aaron Cicourel pointed out though, this is also an excellent argument for truly naturalistic situations rather than high fidelity simulations, because doctors meet a much greater variety of cases in the real world than they do in the simulation.

Because of all this, it turned out to be surprisingly difficult to evaluate the individual physicians in terms of their performance on this complex task.

Jean Lave

Lave's general strategy is to look at a natural situation in some sense as if it were a laboratory situation. True, the researcher did not structure the activity, but the activity never-the-less has a structure. The first task then is to do the ethnography in the sense of discovering how the environment is structured. In Lave's case the environment is a tailor shop in West Africa.

The research is iterative in nature because it consists of alternating cycles of:

1) description of environment structure
   observation of real-world problem solving
   development of theory
   predictions about problem solving process.

   and then

2) design of laboratory tests of predicted processes
   observation of task behavior
   modification of theory
   further predictions which guide the observations in 1.

Unlike test and school exercise situations, in real life performing a computation (or any other cognitive activity) is rarely a goal in itself.

Thinking in the real world is almost always a means toward the achievement of some goal other than exercizing one's brain. Since computations are not isolated activities in the real world, we have to look closely at how they fit together into bigger units. A corollary of the above is that the requirements of the current computation may be determined by the subsequent computations into which the results of the current computation will enter.

As soon as one attempts a laboratory type task situation in a foreign culture, it becomes apparent that a great deal of cultural knowledge is brought to every cogntive task. No matter how careful the researcher has been to provide all of the information required in the task, the subject is still going to bring his prior conceptions to the interpretation of that information.

In natural settings, knowledge is organized in ways appropriate for its use. This has important implications for the structuring of knowledge which is to be taught. Elstein has indicated the need to consider the cognitive complexity of problems which are presented as a part of a medical curriculum. We can consider the constraints of cognitive complexity to be one sort of constraint on the design of a curriculum. Lave's point forces us to recognize that there are other constraints to be met simultaneously; one being that the knowledge taught should result in a conceptual organization which is appropriate for the contexts in which the training is to be used.

An examination of real world cognition reveals that the job of everyday thinking is not to develop optimal algorithms, but to get a particular job done in a satisfactory way. This observation when pursued raises strong questions about the relevance of normative/rational decision theory as a description of human information processing. It is clear that we need more descriptive studies, and that the studies need to be informed by a theory of information processing in natural settings.

Theory is necessary in such studies to allow us to 1) detect and classify errors which occur, and 2) to make predictions about behavior. Without the second of these we have no way to constrain our speculations about what is going on.

Karl Zinn

[He did not present any of his specific research.]

By observing children who have chances to interact with micro-computers today, we notice some interesting changes in people's view of technology. Children view computers as a natural medium to allow them to interact with machines. This change can be of very long-term nature (i.e., from generation to generation) as well as of relatively short-term nature (i.e., in 5 or 10 years from now). Since the change has just started to begin, we now have some very interesting children to look at.

Mark Miller

[He did not give any specific presentation, either, but he described the "Lamplighter School" and what he would like to observe there.]

One possible example of the place where we can do some short-term observations, like the ones Karl Zinn mentioned, would be the "Lamplighter School Project" (a cooperative project involving Texas Instruments and M.I.T.) The school is for 2nd and 3rd graders and is an innovative and open to technological innovation. Every 2nd graders is being given access to a personal computer which they can take home and use 24 hours a day. A major impact on education from this new trial can be expected and it is important to start some experimental research on these students while they are still "naive."

Some specific questions which can be investigated would be:
How do parents react?
How would the use of a computer be effected by its presence in a home?
Who is going to use it?

The answers to these questions should be connected to more general questions like:
How does the style of research change from lab to more naturalistic situations like a home?
How does the use of computer change educational systems?
How do computers help research on more ill-formed problem solving?

David Robson

He is a member of the "Learning Research Group" of Xerox PARC, one of whose current research objectives is to develop a software system which can be used for versatile purposes by people of all levels of sophistication, by "children of all ages." In last 8 years, they have developed prototypes of programming systems for various kinds of hardware and have been experimenting with both adults and children to see what kind of things they do with computers, what kind of things make it easier for them to do what they want to do, etc.

Computers can be regarded as one type of media for problem solving. There are many different media for problem solvoing (pencil and paper, books, etc.,) but there are two points which distinguish computers from other media.

1. A computer itself is relatively neutral (i.e., flexible) in the sense that it can simulate any kind of existing media. It is, however, not always

effective when used as a mere substitution for another media. Its strongest point is that a computer can be used to create a new, different kind of media.

2. A computer is fundamentally interactive, in the sense that it can erase, animate, etc.

Robson's basic view of what a computer represents is that it is a meta-tool, to be used for creating tools for problem solving in its general sense. There are three fundamental ways in which micro-computers can interact with people who are interested in natural problem solving (like the participants in this conference).

1. A computer provides a tool that other people can use for their problem solving. Studing how others use computer to solve a problem can tell us about the nature of human problem solving.

2. A computer provides a tool for studying problem solving. In this case, the "problem" is of our own, and studing how we solve the problem would also tell us something.

3. We can create a computer which solve a problem by itself---an AI view. An issue of early vs. postponed hypothesis making, raised in the medical diagnosis research, is one of the example problems which could be treated here.

As a brief summary of the Learning Research Group, there are three characteristics of program languages which they think essential for the versatile use.

1. Everything is an object. Everything is represented in a same way. This uniformity of representation should allow people to solve a large range of problems. One of the ways people think about their problems is by objectifing parts of the problems by doing things, by getting feedback from the environment, etc.

2. One of the things the objects can do is to remember. This is important in order to imcorporate past changes into the system.

3. Objects communicate by messages. The medium for the communication between objects are the same. This means everything happens in the system in a same way, i.e, by sending messages. This uniformity is also fundamental because this makes the learning easy---one learned metaphor works everywhere. You should only have to know what result you should expect, not how they were obtained. The ease of learning was observationally evidenced by children who could learn to make up new "objects" by saying to the system what kind of things should be remembered and how it should respond to certain messages.

John Seely Brown

At Xerox, they are concerned about what happens in a real office situation. Brown emphasized three aspects of introducing computers as part of natural scenes where problem solving occurs.

1. What happens if an office, by automating, has the capacity of monitoring everything?

Even when the purpose of the automatization is not to monitor, people tend to think they are monitored. They do not like it, and may change their reaction. The fact that such people get fired can give such wrong impressions. How can we assure them that actually they are <u>not</u> monitored?

2. Theoretical description---How do people communicate their aims?

Traditionally, the problem was how to run a program on a computer. Now that systems have got much smarter, the problem is not how but what to run.

3. How do you come to a common sense understanding of technology?

By 1990, arbitrarily complex systems will be possible. Constraints will come from people's ability to understand the systems they use, not from the limitations of the technology.

When unexpected things happen, some go to manuals or other persons, some get intuitive guesses for soluton. What common sense knowledge/strategies do people use to guess? At Xerox, they are presently trying to build better models of what common sense knowledge people use; how they use common sense knowledge for simple problem solvings; how they use common sense knowledge to guess, etc.

GENERAL ISSUES:

From the individual reports and the discussion which followed, a variety of general issues emerged. These topics seem to have implications for the study of problem solving in naturalistic environments as well as the special role of microcomputers as environments and as tools for problem solving.

Perhaps the most general issue addressed had to do with the concept, naturalistic. This term ordinarily implies a distinction between 1) environments that have been arranged so that the analyst can be certain that a particular type of problem solving activity is in fact being engaged in and 2) environments that have not been specially arranged by the analyst. This distinction breaks down for a number of reasons. First of all, while it is the case that the analyst may not be the individual who arranges all of the problem solving environments that we would like to study, it is also the case that all such environments are arranged. The question of who does the arranging seems to be not so much a matter of analytic principle as a matter the difficulty that the analyst will have subsequently in carrying out his analysis. This point is brought out quite clearly in presentations such as Lave's discussion of mathematics use and measurement in tailor shops, Elstein's discussion of medical diagnosis, Cole's cooking club, and even Mehan's study of tracking of children in the schools. In each of these cases the behavior is highly organized according to rules provided by the culture and embodied in the behavior of the individuals in the scene. The participants also work constantly to maintain the organization of the scene in which they are participating. When the environments have been constructed by someone other than the analyst, the analyst has to go through an extra step in his research. That is, he must first try to specify the nature of the problem solving environment and then go on to carry out his analysis of the behavior in that problem solving environment. More than one conference participant pointed out that even when the analyst is the person who creates the problem solving environment it cannot be assumed that the environment as responded to by the subject is the environment as it is imagined to be by the analyst. On the one hand, this possible discrepancy within experimentally constructed environments leads to arguments about the appropriateness of the experimentalist's claim concerning the problem solving environment. On the other hand, it points to a variety of difficulties in specifying what the problem solving environment actually is. In the last analysis the conference participants believed that there is no really principled distinction between naturalistic and non-naturalistic problem solving environments. In either case, the analyst must specify the constraints operating on the participants [subjects] and the rules relating variations in the environment to variations in behavior.

A second issue concerns the criteria for identifying a "good natural research setting." This issue was raised, for example, in Elstein's presentation on medical diagnosis. When Elstein began he would have preferred to work directly with doctors and their real patients. However, he found out quickly that doctors could not be induced to be the objects of analysis while they were working with actual patients and he was gradually pushed into working with actors who simulated real patients. This retreat carries with it a number of difficulties with respect to the appropriateness of the research setting. There has to be residual doubt that the setting which the analyst [in this case Elstein] has constructed actually represents the properties of a real [medical] setting where real decisions are being made.

A closely related issue concerning research settings is the extent to which the social constraints in the setting can be identified by the analyst. A repeated theme in the conference was that problem solving often involves many individuals and almost always involves solving several problems simultaneously in any one setting. When the setting is sufficiently constrained it is possible to claim that a particular problem, a particular goal, and particular behaviors are relevant. But in a great number of settings (the tailor shop and the cooking clubs discussed by Lave and Cole respectively, for example) there are enough different kinds of problems seemingly present at one time to make analysis extremely difficult. The difficulty is compounded when several problems being worked on simultaneously by several people are considered. Difficulties not withstanding, the possibility of identifying relevant features of the environment must be specified.

Closely related to the issue of what constitutes a good research setting is the question of what types of settings and what types of research procedures will produce generalizable results. The participants discussed the problems of generalization where the concern was to make statements about individuals across settings rather than to simply compare individuals in a single setting. Traditionally in psychology, such generalization entails correlation between performance in a "test" environment with some aspect of behavior in a natural setting. At this point in the list of issues it should be clear to the reader that the issue of generalizability of results depends directly on the ability to specify problem environments, which in turn is a prerequisite to having a good research setting. Some general conclusions concerning procedures which produce generalizable results were reached in the conference. We will return to these when we have had a chance to lay out the remaining issues.

Another issue which was the object of a great deal of discussion had to do with the notion of rich phenomena and rich data. Reference here is to the fact that in the tailor shop or in a diagnosis of a patient or in a committee in a school, there is so much going on, there are so many phenomena of potential interest to analyze, that the analyst is hard put to know how to deal with the richness of the data that are obtained. This is a special problem when the analyst does not have a strong theory to predefine the relevant data. The problem is seen in very clear form when researchers interested in non-experimental environments videotape the behavior of their subjects. A variety of coding schemes have been produced which select out particular parts of the data for analysis but at present there are no strong criteria for establishing the relevance of any existing coding scheme having to do with cognitive behaviors. A number of such coding schemes were discussed and their inadequacies agreed upon. What was not agreed upon was any set procedure for arriving at a way to deal with the rich data. It should be noted here that there is a strong disciplinary split with psychologists being far more ready to arrive at coding schemes for complex scenes than anthropologists or sociologists.

SUBSTANTIVE ISSUES:

From the variety of presentations made during the conference we have been able to abstract some assertions about what one can expect to see in problem solving generally and naturalistic problem solving in particular that could guide researchers in the future.

1. Multiple Goals: Consistent with the observation made earlier that in all

problem solving environments (and in very obvious ways in problem solving environments that have not been specially constructed by the analyst) there are multiple problems being dealt with by subjects at all times. In any experiment, the subject is trying to please the experimenter, trying to demonstrate his intelligence and trying to solve the nominal problem at the same time. It is even more obvious in the scenes that one encounters outside of the laboratory, that is scenes which have been constructed as a result of the cultural organization of behavior. For example, in Cole and his colleagues's study of children in a cooking club it was quickly seen that the children were literally working on several problems at once. These included not only the nominal problem of cooking according to a recipe and its sub-problems (reading, measuring). One could also see the same children negotiating with each other for who was going to work with whom, demonstrating their prowess to each other, jockeying with each other for the friendship of a particular individual, and so on. A common sense description of such scenes says that cognitive and social goals are combined. The participants in this conference agreed that a division between cognitive and social problem solving is probably not particularly useful except insofar as it identifies particular organizations of problem solving environments. However, the existence of multiple goals was recognized by everybody as a severe strain on current analytic procedures. The inadequacy of current models is exacerbated by the realization that the observed stream of behavior is being molded by simultaneous attempts to solve multiple problems.

2. Social interactions: Closely related to the issue of multiple goals is the fact that in a great variety of problem solving environments the individual is not working in isolation. Group problem solving research does not help in the analysis of cognition in natural problem solving environments because the research tradition in group problem solving focuses more on outcomes or upon classification of different kinds of people (leaders and followers) than it does on an information processing analysis of people's problem solving behaviors. In a variety of the examples discussed by the participants, it was clear that individuals mediate their problem solving activities through other individuals in addition to using their past experience. In fact, it was possible to find examples of an intuitive division of mental labor between children, with identifiable parts of the problem solving process being shared among them in a subtle and well-articulated fashion.

3. Functional analysis of problem solving activity: A clear outcome in many of the presentations was the fact that when one looks at problem solving activity as it arises in culturally organized settings, one finds that thinking is not the objective of the activity. Rather, people have some other goal in mind. For example, they might want to get a cake baked, they might want to make sure that a patient won't die of cancer, they might want to get a pair of pants made. They use not only social, but other kinds of resources to which we will turn in a moment. In doing so, it is clear that the object of the activity is not thinking itself; rather, what we ordinarily refer to as thinking is clearly a means to an end. This implies a very different structure of activity in such environments from, for example, environments where one has mentally to get missionaries and cannibals across a river or move rings from one

Tower of Hanoi to another. In such settings, thinking is very clearly an object of activity and many of the participants believe that this distinction between thinking-as-means versus thinking-as-goal is an extremely important one to make.

4. Limited effort and precision: It was pointed out that Herbert Simon's notion that in most problem solving individuals work at a level of precision and a level of effort in processing information that is the minimum required is in fact characteristic of problem solving in a great many environments. Lave, in particular, pointed out that the degree of precision needed in reaching solutions is very often only an order of approximation rather than an exact right answer and that this is an important feature of problem solving environments that has to be considered.

5. The use of media/tools: A very general issue that was raised repeatedly in the conference and which provides the direct link between the general study of naturalistic problem solving and problem solving that involves microcomputers has to do with the notion of mediation and tool use in problem solving. In a previous section we talked about the mediation of problem solving through other people. A general conception of problem solving as a process in which the problem-as-presented is transformed by the subject into a working representation seems to encompass almost all of the research under discussion. The difficulty, of course, is to specify the exact nature of the mediated activity that is engaged in. In Cole's cooking club, mediation was very often through another individual. The same kind of phenomena was observed by Lave, who found that each tailor, when he encountered a difficulty, knew the strength and weaknesses of other people in the tailor shop so that he could select the individual whom he wanted to advice from. The tailors, of course, also used a variety of intellectual tools, including their mathematics system, to accomplish their tasks. This same idea came up in other presentations. For example, Zinn talked about computers as performance aids. In the presentation by Hutchins and Levin, one saw examples of mediation both through the computer, through language, and through other individuals in the course of solving the problem facing the children. Once it is recognized that individuals carry out their problem solving activities using a variety of tools (where "tools" now is understood as a wide range of mediational devices) the potential role of computers both as an analytic device and as an environment for problem solving becomes clear. The computer is a tool with which individuals interact to carry out a variety of goals. The individual may be working in interaction with some other cultural device, including another individual. The issue of effectiveness of microcomputers then becomes a question of what type of mediating device it represents. This point was brought out quite clearly in the presentation by John Brown, who talked of the difficulties of creating office machines which would amplify the productivity of workers in the office. Brown clearly articulated the difficulty of taking into account both the nominal problem solving power of the computer and the way in which that power would be integrated into the social organization of the office so that it would have the desired effect.

Here the analogy of a computer or any tool which can mediate problem solving as a prosthetic device was found to be extremely useful. In order for a prosthetic device to be useful, one has to have a finegrained analysis of the physical system into which the device is being placed and the larger functional system that the human being has to operate within when using the device. An analysis of the musculature and the laws of motor activity is necessary to provide a really effective prosthetic device to replace a leg. Cruder prosthetic devices such as a stick or a crutch will accomplish some ends if the individual's motor behavior is reorganized and can be reorganized into an effective system. When this analogy moves from the motor sphere into the intellectual sphere it is clear that the effectiveness of microcomputers will depend upon the effectiveness with which they can be integrated into existing activities to make people more powerful. The difficulty arises because we do not have a strong theory of mental activity which can approximate our theory of locomotion. The response to our general theoretical ignorance is to try to produce locally effective prosthetic devices and that is what Xerox is doing when they worry about office automation. This is still a general enough problem to be very difficult but it at least specifies certain functions, certain activities, and certain environments which then can become the object of analysis.

GENERAL CONCLUSIONS:

On the last day of the conference, once the anthropologists and psychologists involved in problem solving in laboratory and non-laboratory environments had had a chance to speak and once people engaged in the applications of computer sciences to microcomputer technology had had a chance to talk about their concerns, we returned to examine the general points of agreement that had emerged from the group discussion.

Perhaps the most general point that emerged was that it is probably not particularly useful to spend a great deal of time talking about problem solving in naturalistic environments assuming that one could talk about problem solving in general or naturalistic environments in general. We have already discussed the fact that the concept of a naturalistic environment is an inappropriate notion. There is an important sense in which laboratory tasks are as natural as any other kind of task that people might be asked to deal with. The laboratory task is distinguished by the fact that it was constructed by an analyst for a specific purpose and is generally distinguished by the fact that individuals are very restricted in the mediational tools that they are allowed to use to solve the problem. It is usually the case that only individual subjects are present, that people are not allowed to use pencil and paper to solve the problem and so on. The reason for these restrictions are well known: they facilitate analysis. The difficulty caused by these restrictions are obvious as well: they make the environments that are studied systematically unrepresentative of a lot of other environments that one would like to be able to talk about.

But what other problem solving environments can one talk about? Here it was agreed that to do an analysis of any problem solving setting, one needs as careful a description of that setting as possible. This injunction applies equally to settings contrived by an analyst or by a culture. Moreover, when one wants to use the laboratory as a setting to start one's analysis and then generalize to some other setting, it is essential that one have an analysis of both the initial setting and the setting to be generalized to. If these settings do not have a similar task structure then it is unreasonable to think that generalization about individuals behaviors from one setting to another will be possible. This point should be obvious but a great deal of research which looks at non-laboratory settings and tries to make statements about people's problem solving behaviors simply does not take it into account. Rather, categories derived from the laboratory are simply laid upon non-laboratory scenes as if they are applicable when in many cases they are not.

As obvious as this point may seem, its implications seem not to have been followed up in any systematic way. There are a great many culturally organized scenes that we care about but have not been submitted to systematic analysis. The operation of an office, which is currently occupying Xerox, is but one example of such a scene. The utility of the analysis of that scene will depend upon how full a description the analyst can make of what is going on in the office, the multiple problems that are being engaged in there, an analysis of the nature of a microprocessor that one might put into the office in order to augment certain parts of the work, and finally an analysis of the change in the structure of problem solving activity that results from the introduction of that machine. Another important setting that has been inadequately analyzed is the home environment.

Within this context, the computer was seen to be a crucible for testing theoretical assertions as well as an extremely important device in and of itself. The fact that a computer company must make money with its product provides a very strong incentive for the company to consider the full range of factors that will influence the kind of activity that is engaged in with the computer. That is, it is simply a very large gamble to take one's folk intuitions about how a microprocessor will be used and to base a large production effort on that intuitive knowledge. That is why Xerox is studying social interactions in an office in order to figure out where their microprocessor might fit into an office and why Texas Instruments is doing research on the effect of microprocessors in a classroom. However, Texas Instruments's program at the moment does not really provide for an analysis of the individual-computer interactions that will go on in the classroom or in the home when the children take the computers home. In effect, they have no plans to implement the research strategy implied by the discussions at this conference. Rather, they are planning to put computers into a classroom and then compare that performance with a performance in a control classroom to see what the effect is. While this type of outcome research may give them evidence that the computers are useful, it will give them almost no evidence about how the computers restructure activity. And if it turns out that the computers are not particularly useful, they will have no clue whatsoever as to how to make them more useful.

The implications of this kind of statement are that in order for such research to be useful, one has to make observations in the context where the device is being used. Put another way, one has to make direct observations of the non-laboratory as well as the laboratory setting in order to discover what new kinds of mediated activity are produced by the existence of the microprocessor. In carrying out this research program, all of the difficulties of dealing with rich data and of getting people to permit you to make the observations arise. This suggests that academic researchers who are interested in problem solving in a variety of environments may do well to join forces with computer companies who have a strong vested interest in trying to get information about the way in which computers change problem solving activities.

At the end of the conference, a general model of inquiry into human thinking in all of its environments was proposed. A test case for such an approach would be one that placed current activities in cognitive psychology more or less at the center of an enterprise which interacted on one side with larger social environments which produced the types of constrained settings that cognitive psychologists ordinarily study and on the other side with attempts at providing microenvironments in microcomputers that embodied strong models of very particular problem solving processes. In this enterprise, cognitive science models would have to account for 1) the information processing that went on within the very limited environments produced by interaction with the microprocessor, 2) information processing modifications in the use of the microprocessor that arise because the individual is engaged in a variety of problems, and 3) the use of the microprocessor while interacting with other individuals.

The research strategy implied by this overall program clearly requires the collaborative work of a variety of people interested in cognition. It is not sufficient to have artificial intelligence people who have outstanding skills at modeling on computers. It is not sufficient to have cognitive psychologists who are good at constructing analyzable environments for thinking. It is not sufficient to have anthropologists who have worked out procedures for describing social scenes. It is not sufficient to be able to put together the hardware for a microprocessor. Rather, all these activities need to be considered in an integrated effort where the individuals have an appreciation of the issues at all levels of the enterprise.