Report LCHC-08-01
August 1983

PROCEEDINGS OF THE CONFERENCE ON JOINT PROBLEM SOLVING AND MICROCOMPUTERS

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1 August 1983

Conference Report for Period 31 March 1983 - 2 April 1983

Prepared for

PERSONNEL AND TRAINING RESEARCH PROGRAMS
Office of Naval Research (Code 442)
Arlington, Virginia 22217

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Proceedings of the Conference on Joint Problem Solving and Microcomputers		5. TYPE OF REPORT & PERIOD COVERED Conference Report 31 March 1983 - 2 April 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Report prepared by Michael Cole, Naomi Miyake and Denis Newman		8. CONTRACT OR GRANT NUMBER(s) N00014-83-G-0048
9. PERFORMING ORGANIZATION NAME AND ADDRESS Laboratory of Comparative Human Cognition Center for Human Information Processing University of California, San Diego La Jolla, CA 92093		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 667-515
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 442-PT) Arlington, Virginia 22217		12. REPORT DATE August 1983
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Problem Solving
Social Interaction
Human-Machine Interface
Microcomputers
Learning
Intelligent Computer-aided Instruction (ICAI)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

OVER

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S/N 0102-LF-014-6601

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Abstract

A group of American and Japanese psychologists, anthropologists, linguists and computer scientists gathered at UCSD to discuss the role of joint problem solving in the learning process. A central issue for the group was expert-novice interaction both when the expert is a human and when it is embodied in a microcomputer tutoring system. Much of the discussion focused on microcomputers as instruments for organizing instruction. The group addressed questions such as: are new principles of learning likely to arise out of research using microprocessors? What kinds of learning models are likely to be most effective in exploiting the power of this technology? How can principles of human interaction be applied to the design of learning environments?

A major contrast within the group centered on the relationship assumed to hold between the notion of joint problem solving and conceptions of computer-based learning environments. One group emphasized the computer as a "partner" in joint problem solving. This perspective emphasizes the human-like interactions that can be attained by "intelligent tutors" when artificial intelligence is programmed into the machine. The second group emphasized the idea that computers mediate between people. This group concentrates on the environments outside of the immediate person/computer unit which the instructional interactions are designed to influence. From this perspective, systems that include more than one person working on a single machine and activities that make clear that subordination of computer-based activities to the user/learners' higher order goals are of special importance.

A variety of common conclusions were arrived at despite this basic division in underlying conceptions. These included:

1. Computer environments can be constructed which model useful aspects of human interaction.

2. A central aspect of human interaction is the ability of participants to construct problem solving systems that are more powerful than the participants taken individually.

3. Social interaction contains as many pitfalls as opportunities for learning and problem solving. Under many conditions, joint problem solving is less efficient than individual. The conditions under which joint problem solving works and the ways in which these conditions can be embodied in human-machine interactions are crucial issues for continued research.

4. Current impediments to the development of these possibilities is presently as much the result of institutional constraints on invention and implementation as on limitations of people or the technology.

Proceedings of the Conference on

JOINT PROBLEM SOLVING AND MICROCOMPUTERS

University of California, San Diego

March 31 to April 2, 1983

Sponsored by the Office of Naval Research

Report prepared by Michael Cole, Naomi Miyake and Denis Newman

This conference was conducted under Grant N00014-83-G-0048, NR667-515 with the Personnel and Training Research Programs of the Office of Naval Research. Requests for copies of this report should be sent to Michael Cole, Laboratory of Comparative Human Cognition, D-003A, University of California, San Diego, La Jolla, California 92093.

BACKGROUND

For the past several years, researchers from two laboratories at UCSD, the Laboratory of Comparative Human Cognition and the Cognitive Science Laboratory have been interested in computers as environments for learning and instruction. These two groups share two other interests which form the immediate context for this conference. First, both employ interactional models of learning/instruction. Second, both have a history of interaction with Japanese scholars with similar interests and theoretical points of view.

These similarities in orientation form the framework for exploring differences in approach in the specific research programs. These programs are aimed at improving the quality and efficiency of instruction in a wide variety of basic academic skills (reading, writing, mathematics, physics) as well as more practical, widely applicable information processing capacities (such as the use of sophisticated editing systems).

A group of scholars from Japan and several American research centers gathered at UCSD from March 31 - April 2, 1983 to exchange ideas on models of joint problem solving and their special relevance to the design and implementation of computer-based systems of instruction. In the report to follow, we will summarize each of the presentations and the discussions that they generated. At the end of the report, we will list basic principles that arose during the meetings and summarize basic lines of exploration that appear reasonable next steps in our efforts to develop human resources through joint problem solving and the use of computers.

SUMMARY OF INDIVIDUAL PAPERS

Joint problem solving in functional writing environments

James Levin and Margaret Riel
Laboratory of Comparative Human Cognition
University of California, San Diego

Levin and Riel described a research program in which children use a specially designed software system called the Interactive Text Interpreter that allows users to create, save, and edit a variety of kinds of text. Varying amounts and kinds of support are provided by a mix of human and machine sources. Both sources act to structure the users' activities and to record their activity to make possible dynamic support as the user moves through the activity.

Three important concepts were emphasized in the Levin/Riel presentation:

1. Dynamic support. Students should be provided with an entry point to the activity which is in a middle region between entirely structured (as in traditional CAI programs) and entirely unstructured (as in LOGO; see also the paper by Hawkins and Sheingold, as well as Newman and Petitto). Following entry, they should be provided ways to get support for further exploration that is keyed as closely as possible to their current needs.

2. Functional activity. The writing activities should be seen as fulfilling student goals of a reasonably general and enduring sort. These functions are not systems-internal (although the student is likely to develop goals for systems mastery if a proper overall function for the activity is constructed). An important aspect of the Levin/Riel conception of "functional" is that the users have control over as much of the activity as possible, which includes the critical notion of access to the technology.

3. Distribution of mental labor. The underlying cognitive model of learning/teaching is a distributed information processing system of the sort pioneered by Levin, and extended in this and other LCHC work to include the following kinds of distribution:

a) Distribution of mental work between different cognitive elements in the individuals overall problem solving system.
b) Distribution of mental work between the individual and elements of the environment (including other people and computers).
c) Distribution of mental work over distances (in this case, between San Diego and locations in Alaska).
d) Distribution of work over time (thanks to the ability of the computer to hold information over time) so that individuals can control the timing of their responses to previous steps in the process.

Riel demonstrated the application of these principles in a system of activities in which children in San Diego collaborated via a "news wire" system with children in different Alaskan villages. This activity involves joint problem solving in two senses. First, there was joint problem solving between two students over time as they worked to write articles for a student wire service with the help of computers and at times human "coaches." Second, there was joint problem solving among a group of children who must decide which stories to include in their student newspapers.

The importance of functional activity was illustrated by the children's behavior at different phases of the activity. When first asked to write something for the newspaper, the children complied in a very reduced way. Their production was impoverished and was produced in a "reactive" way, according to instructions. At this point, only the adults understood the goal. It was still schoolwork for the children. But when the children began to evaluate and edit the work of children from other locations and especially when they confronted the poor quality of their own initial efforts in contrast with the work of those with whom they were interacting, they began to discover new goals. They began to realize that other children would read to make sense of their writing, and that well written stories would end up in a newspaper. This notion of an audience for their writing made them more conscious of the need for the text to carry their ideas.

When these (previously adult) goals arose as a consequence of the children´s interactions, they began "spontaneously" to engage in the very academic skills that the adults wanted them to practice, but now this practice was subordinated to the children´s own goals. The product was not only far superior writing, but increased motivation that was productive of further growth.

Discussion centered on these points and the possibility of developing diagnostic indicators of children´s skills on line through key strokes, and building further dynamic support within the computer. In this way, one can test specific hypotheses about the effects on the writing process of different degrees of functionality of the writing activity.

Modeling cognitive strategies with a talking microcomputer

W. Patrick Dickson
School of Education
University of Wisconsin

Dickson comes to the study of microprocessors and joint problem solving from many years of research on the socialization of cognitive/communicative skills. In both Japan and the United States Dickson found significant correlations between modes of mother-child interaction and performance in referential communication tasks. He has also found marked social class differences relating socialization to referential communicative skills. In this paper, Dickson described microcomputer-based training tasks aimed at instilling a high level of skill in referential communication; assuming this ability to be important in many and varied instructional settings, Dickson's longer term goal is to create a technology that will insure that all children reach a high level of competence.

In the research described here, Dickson equipped a microprocessor with a random access voice simulator that could give verbal instructions to children on a flexible basis. Dickson was particularly interested in exploiting the computer's ability to simulate another person, so that he could instantiate a referential communication task in which the computer acted as one of the communicants. The computer "instructions" were presented as if the computer were either mumbling to itself, or directly offering advice.

In an experiment designed to test the effectiveness of the system, Dickson found that the children did, in fact, treat the computer as a communicant. He has also begun to exploit the power of the system to conduct experiments on the relationship between the content of the material to be communicated about and the nature of the strategies modeled by the computer. He hopes to model the properties of a variety of sociocultural contexts in order to help the learner acquire generalized referential communication skills.

Discussion focused on the extent to which general metacognitive strategies can be taught explicitly. Discovery learning is less efficient but may have more general effects. Dickson noted that most software leaves the child on their own with respect to any general strategies.

Goal formation between users and computers

Mary Riley
Cognitive Science Laboratory
University of California, San Diego

During the course of interacting with a computer, the user sets goals that correspond to tasks to be accomplished and must plan how to achieve those goals with the available commands and display facilities. A major goal of the Human-Machine Interface (HMI) project is to provide facilities for enabling the computer to interact intelligently with the user to organize, remember, and achieve goals. The following describes the work of one HMI group concerned with providing users with intelligent instruction and help in using an editor.

New users of the VI editor only learn/remember a small subset of the available commands. These commands are likely to be the primitive commands sufficient for accomplishing most editing tasks. However, VI does provide compound commands which enable more direct or efficient plans for accomplishing the same goal--i.e., it is likely that users would eventually benefit from acquiring these additional commands. An interesting question concerns how to introduce new users to these additional commands.

To answer this question, the HMI project is analyzing the problem of parsing command sequences executed by the user during an editing session into a representation of the user's goal structure. To the extent this work is successful, such a parser could provide a basis for instruction and help functions that are directly sensitive to user goals and skill level. For example,

1. The parser could enable the system to recognize recurring plans (e.g., the user always concatenates single space commands to move to the end of the line to change a word) and introduce the user to a more efficient plan (e.g., using the "w" or "$" command to space over to the end of the line).
2. When the result of executing a sequence of commands does not correspond to the user's goal, then the system could provide user with a description of the goal structure underlying the executed commands and allow the user to modify the goal structure to correspond to the desired plan.

Some of the issues that were raised included:

1. When to interrupt the user? That is, should the parser continuously monitor user performance and automatically provide help/instruction or should instruction/help be initiated by a request from the user.
2. In what sequence should new commands and alternative plans be introduced to the user?
3. How do users' mental models of the computer influence their planning ability and how do these models change with continued experience?

Finally, these analyses are being guided by recent theory and methodology in cognitive psychology, thereby maximizing the extent to which this research can benefit from, and contribute to, the development of our theoretical understanding of joint problem solving in learning and performance.

Discussion brought out the issue of standardizing an interface on the basis of general psychological principles. Such standardization could lead back to individualization if users could easily set their own interface values on any machine they have to interact with.

Quasi-understanding induced by verbal instruction

Naomi Miyake
Tokyo, Japan

In her exploration of foundations for constructive interaction, Naomi Miyake observed pairs of subjects as they cooperatively figured out how a sewing machine makes its stitches. This observation lead her to conclude that such a process is fundamentally interactive: one proceeds not only from non-understanding to understanding, but as well from understanding to deeper non-understanding, implying that there are levels of understanding. Two people working together are not always on the same level. Even though two people work side by side, talking back and forth, they are not necessarily working on the same problem. In most of Miyake's cases, the two people pursued different goals, according to each individual's understanding of the problem. According to her analyses the variable understandings of the participants have the effect of promoting, rather than hindering, their understanding, by providing them with different viewpoints to work with.

Thus, even though the problems get solved by individuals, their interaction has characteristics which help promote understanding. Miyake proposed two characteristics which are central to the productivity of joint problem solving. One is a certain pattern of dividing up the labor which makes such interaction productive. According to the sewing machine protocols, the participants divided their roles into a task-doer and a monitor. Miyake has recently found that this is also the case when pairs of adolescents work together on home computers. She suggested this productive pattern with other patterns (for example, the sheer division of the amount of work, "I take this; you take that").

The second key factor derives more from the central nature of verbal descriptions, not necessarily during interactions but in general. The very act of describing a part of the phenomenon under consideration (or an action of it) using and freezing aspects of the phenomenon (the action), thus preventing one from decomposing that aspect (action), which is a necessary step for going into deeper understanding. This importance of words for crystalizing thought has been regarded as one of the advantageous characteristics of verbal descriptions, but in Miyake's analysis, the same effect worked to hinder her subjects. Herein lies the potential advantage of having two people working together. While it is a relatively hard process for one person to give two different descriptions to a single phenomenon, it is seldom the case that two people watching the same phenomenon come up with the same description of it. Useful variability is thus a constitutive feature of discourse, and can also serve as a useful source of variability for cognition.

Developing an automated tutor for radar navigation

Edwin Hutchins
Navy Personnel Research and Development Center, San Diego

For the past two years, a group at the Naval Personnel Research and Development Center (NPRDC) has been exploring the use of interactive computer graphics as a medium through which to provide training in radar navigation. Failure rates in the radar navigation curriculum in many navy schools exceeds 20%. This problem, is at least in part, attributable to the fact that nearly all members of our culture are adept at interpreting motion that is depicted in a geographic frame, but there is no culturally provided interpretation for depictions of motion relative to an observation platform which is itself in motion.

An obvious possibility given the plasticity of the computer graphics is to provide a simultaneous relative and geographic depiction of ship interaction scenarios, so that students can use the geographic depiction (which they understand) to figure out what is happening on the relative depiction, which they typically do not understand.

Such a system was developed and placed in a navy training school. The instructors and students liked it as long as there was a researcher present to run the system for them, but they did not use it on their own because the interface to the system was simply too complex for a student to run easily. In response to this situation, collaborative work with the Cognitive Science Lab at UCSD was undertaken to redesign the interface to the system.

In the redesign process, more than the interface was changed. The new system was centered around the automatic generation and posing of problems. The system randomly generates a problem of a chosen type, and poses it to the student. The student works the solution on an actual plotting sheet, as he would on the job, and gets feedback from the system on the correct answers. Further, if the student desires, he can get either or both of two types of explication from the system. First, the student can see the dynamic simultaneous and relative depictions of the scenario described in the problem.

Second, he can see how the problem should have been solved on the plotting sheet. The system presents the solution process step by step, and the student can compare his own work with that of the system. This system is currently being used successfully in navy training schools.

This problem generation system is the beginnings of an automated tutor, but it has a number of serious shortcomings.

1. If a student fails to arrive at a correct solution, the system has no way of knowing where or why the failure occurred. All it sees are the final answers. If the student does not get the correct answer, the burden is on him to discover where his solution when awry. Having the system show the complete solution step by step helps this process, but does not relieve the student of the task of finding his own errors.
2. The program cannot explain any part of any procedure. The procedures are represented in the program in a way that enables the program to execute the procedures, but not in a way that the program can know how the steps of the procedure are connected together or why they are formed the way they are.
3. The program cannot guide the student to useful exercises. Since it only sees the final answers, it is difficult to determine what a student's problem is or what sort of knowledge would help him improve his performance.

These shortcomings indicate a need for the following requirements on a more advanced system.

1. Higher band width interface that will allow the system to "see" in more detail the process used by the student to solve problems.
2. A dynamic model of the student based on his performance that will support hypotheses about the nature of his conceptual "bugs."
3. A representation for the procedures such that the system can explain procedures and backtrack to find sources of error.

At present they are experimenting with a number of formalisms to represent the procedures in a way that will support modeling the student and providing automated explanations of the procedures. An automated expert capable of solving any closest point of approach problem has been implemented using a Truth Maintenance System formalism (McAlester, 1980). It can solve problems, or monitor the solution of problems done by students interacting with the graphics interface.

An Intermediate Summary

General discussion of the day's presentations raised a number of issues that remained central for the rest of the conference. First, it became clear that human-machine interaction can itself be considered a form of joint problem-solving. Second, the relation of the person's goals to the goals presupposed by a machine or human tutor must be taken into consideration. How a user comes to understand the goals that a microcomputer "tool" is good for is a central problem in designing a tutorial system since a novice user may have a very different analysis of the situation. Third, the notion of expertise itself warrants careful analysis. The ability to coordinate multiple representations is a factor in expertise as several of the presentations made clear.

How to teach somebody something they don´t already know

Denis Newman
Laboratory of Comparative Human Cognition
University of California, San Diego

Andrea Petitto
School of Education
University of Rochester

Newman opened the presentation with a discussion of learning in interaction. He argued that conceptualization in this domain is hampered by a false dichotomy between explicit instruction and individual invention. The process of learning from other people often falls somewhere between the two extremes. The goal of this presentation was to provide examples which illustrate the intermediate process.

The dichotomy between instruction and invention comes partially from the Piagetian heritage in which there is a strong concern that children not be coerced into learning but rather be given the freedom to invent their own solutions to problems presented by the environment. The dichotomy can be seen most clearly in two approaches to computers in education: traditional CAI and LOGO. Complaints about CAI center on the "rote" nature of the learning it supports. It is often claimed that while such systems can promote information accretion of the kind usually called learning, they do not promote the kinds of qualitative change in understanding that are often referred to as development. LOGO, on the other hand, is often criticized for its inability to support learning, while pinning its hope on development through discovery.

Newman went on to argue that implicit in this contrast is the assumption that any kind of teacher-child interaction can be assimilated to explicit instruction. While this assumption may be suitable for standard models of teaching and assessment it does not work so well with the approach that Levin and Riel called dynamic support. The standard assessment or teaching strategy presents small segments of the task ordered to begin with the simple and end with the complex. Assessment keys on the points at which failure occurs. The dynamic support assessment system always holds the entire task in the interaction, but assesses what part of the task has to be maintained by the teacher (or computer coach etc.). Over time in the standard approach, the learner confronts harder and harder tasks. Over time in the dynamic support approach, the learner takes over more and more of the task that the teacher and learner are doing together.

The dynamic support sequence is not just a case of the teacher telling and the child doing, i.e., explicit instruction. First of all, the task is transformed in the process of transmission to the learner: the learner acquires new goals that were not understood at the beginning of the process (thus, the title of this presentation). Second, the process of teacher-learner interaction transmits information that is not encoded in explicit statements by the teacher. These features are illustrated in the examples from Petitto's analysis of a fourth grade lesson on long division.

Teaching of the long division procedure is interesting because the critical "gazinta" ("goes into") step is taught explicitly in one way and learned by the children in quite another way. In the explicit lesson the teacher provided a precision procedure in which the children go through all the multiples of the gazinta number until they reach a number that is just a bit larger than the number being divided then they go back one multiple to the answer. Although this procedure works, it is not the one actually used by the children who have learned to do long division. Instead, what was learned was a successive approximation procedure in which an approximate multiple is tried out and then adjusted up or down. In her interactions with children who have difficulty, where the difficulty is interpretable as a wrong guess, the teacher gets the learner to try out other approximations that converge on the answer. Thus, successive approximation arises in the interaction without being explicitly taught. The teacher's adaptive expertise with long division allows her to work with the child's wrong answers as though they were a step in the approximation process. An interesting result of this analysis is the observation that when there is more than one child and the children can overtly bid against each other in search of the answer, the crucial estimation activity needed for "gazinta" is increased.

Petitto provided additional examples that showed that the emergence of new goals in expert-novice interaction is a very common aspect of learning in interaction. In many cases the goal of the activity as well as the procedures must be learned. But teaching the goal, like teaching successive approximation often goes on implicitly on the basis of the teacher's "corrections" of the learner's initial attempts.

Programming in the classroom: Ideals and reality

Jan Hawkins and Karen Sheingold
Bank Street College of Education

LOGO is currently being promoted in schools as a computer language designed for kids which encourages "discovery learning" and provides a means for acquiring a variety of general problem solving skills. Jan Hawkins reported on collaborative work with Roy Pea, Midian Kurland, and Karen Sheingold investigating this claim and the impact of this computer-based curriculum on classroom learning.

Her report covered three points, (1) LOGO in reality compared to the LOGO ideal, (2) students' learning over the course of the first year of the study, and (3) the evolution of the learning environment.

Interest in LOGO stems from claims that in addition to teaching the logic necessary for programming it provides a domain for learning general problem solving strategies by encouraging precise rigorous analysis of problems, decomposition of problems into small, well organized steps, and evaluation and revision (debugging). Based on a self discovery model of learning, the teacher, it is claimed, need only acquire minimal expertise to support this form of learning.

The actual use of LOGO in classrooms with teachers with ten months of LOGO programming experience does not appear to support some of the ideal claims of this educational vehicle. The system is not transparent enough for students to discover their own goals and ways to implement them. The teachers felt that they lack the expertise necessary for guiding their students and have difficulty integrating LOGO into the classroom learning context.

At the middle of the second year of the study there is little support for the development of general problem solving strategies. The results of four studies were discussed which indicate that students have learned specific pieces of information but only a very few students have developed a rich understanding of the LOGO language. Specific attempts to locate differences between the LOGO and control group in the development of general problem solving strategies have been unsuccessful.

The final topic dealt with some of the changes in the teaching environment that resulted from the teachers' disappointment with the learning environment. While it may still be too early to evaluate results, the complexity of the language and difficulties of developing an effective instructional context for LOGO remain important issues.

The discussion centered on ways to better integrate LOGO instruction with the goals of the students and ways the computer might be used to provide more support to the learners.

A computer game environment for the study of stress and performance

Yoshiro Miyata
Cognitive Science Laboratory
University of California, San Diego

Yoshiro Miyata reported on his attempt to study the effect of stress on behavior in emergencies like fire or accidents using computer games as experimental environments. Why do we make errors in critically important situations, errors which we never make in normal situations?

The stressors that have been used in most of previous experiments on stress are noise, air pressure or dangerous experiences like parachute jumping or sky diving. However, these situations are different from these emergency situations in one important respect. In these experiments the task required of the subjects is usually unrelated to the stressor, that is, the stressor continues to exist regardless of whether the performance in the task is successful or not. However, in emergencies, the task is to escape from or to cope with the stressor.

Computer games have the potential to solve this difficulty. In a microworld of a computer game, the player has a well-motivated and well-defined goal and attempts to achieve that goal. When something in a game interrupts the player's attempt to achieve his/her goal, it is likely to cause some stress in his/her mind. If this is possible, the computer will become a very powerful tool for studying stress because the whole environment for the player is packed into a microworld which can be easily brought into an experimental laboratory.

Miyata developed a computer game as an experimental environment in which the task is to cope with the stressor. The task is to type the words flying across the screen. The words typed correctly will disappear and make a pile at the center of the screen. The goal is to make the pile reach at the top of the screen. However, the pile will be destroyed whenever a flying word hits the pile.

The results show that the overall error rate is very high compared to that observed in normal transcription typing. The error rates in different situations were different within the game. For example, subjects made more errors when the word they were trying to type was close and approaching rapidly to the pile. The limited amount of time available for performing the necessary action appears to be an important factor to characterize an emergency.

Controlling the relation between rule statements and Piagetian problem environments

Laura Martin
Laboratory of Comparative Human Cognition
University of California, San Diego

Martin described prior research on the acquisition of basic scientific concepts by children in terms of the difficulties of analysis that arise because the learner's prior history and the natural world may not be ideally matched to produced learning. These difficulties render ambiguous the conditions of cognitive change since the contribution of a specific instructional event cannot be easily separated from the contribution of similar events in everyday circumstances. Furthermore, it was found that children are often correct in their guesses about the world but do not get appropriate feedback; the statement of rules is not a reliable indicator of learning or knowledge, and in group situations coherence of problem-solving doesn't depend on participant's knowledge.

Children do seem to learn more when paired with a child at a higher level of mastery. Because the cultural analysis of the correct sequence of understandings of the balance scale problem covaries with general cultural competence it is not clear on what basis higher level learners organize interactions. The issue cannot be clarified in the ordinary situation, but given properly constructed microworlds, alternative conceptual rules to naturally-occurring ones can be "realistically" embodied, allowing the analyst to tease apart problem solving ability due to greater conceptual competence from effects due to more effective communicative ability.

Martin proposed the construction of such microworlds. As one example she offered a thought experiment in which an alternate world is organized so that the "lower level" understanding of the normal physical world may be veridical, thereby separating a problem from prior knowledge of its rules. The feedback from the microcomputer, furthermore, can be controlled so that "rules" can be shaped or instructed; the relation between the mode of learning rules and their control of problem-solving can be studied.

Discussion raised the problem of negative transfer that might result if a counterfactual world were used as the medium of problem solving. The very fact that people had this concern underlined our current uncertainty about the real world--microworld relationships that typically characterize computer-based research. It also helped to sharpen the distinction between those who view the computer primarily as a training environment and those who see in it a research device which is powerful precisely because it can break habitual relationships and provide analytic power to psychologists, leaving open the real world applications of that analytic knowledge.

Buggy and beyond

Kurt VanLehn

Xerox Palo Alto Research Center

Computer science has given psychology tools for developing detailed and precise models of cognition. Unfortunately, there exist no correspondingly detailed and precise arguments to support these models and therefore the models fail to meet the traditional criteria of scientific theories. In his talk, VanLehn discussed the kinds of tools he and others are developing to help cognitive scientists build computational theories of cognition that will meet some widely accepted scientific standards. These new tools fall under the general title of "competitive argumentation." Competitive argumentation functions to show the lack of support for some theoretical principles assumed by a model while favoring other principles, thereby allowing the model/theory to be revised incrementally.

The specific example VanLehn used to illustrate his point concerned Repair Theory (Brown & VanLehn, 1980) applied to the study of children's errors in solving multi-column subtraction problems. The major theoretical assumption underlying Repair Theory is that while following an incorrect procedure students will overcome difficulties through local problem solving strategies involving a small set of repairs. That is, children make a minimal change to the procedure's execution in order to circumvent the difficulty and get back on track. Repairs are simple strategies, such as skipping an operation that can't be performed or backing up in the procedure in order to take a different path. Repairs do not in general result in a correct solution to the problem but instead result in systematic errors called "bugs." Competitive argumentation is then applied, using a comparison of predicted bugs against students' bugs. Not only must the model correctly predict errors actually made by students, it should also predict the absence of "star bugs"--bugs that no students would ever make.

Van Lehn sketched an extension to repair theory. It is a new theory that aims to explain how student´s procedures, both correct and buggy are acquired from lesson sequences. Five of the principles on which the learning model is based are felicity conditions or tacit conventions followed by teachers and students. These provide the basis for communication in lessons setting up the expectation, for example, that the student will learn one simple subprocedure per lesson. The felicity conditions provide a solution to problems with inductive learning such as the need to infer the existence of invisible objects.

Discussion focused on the interactive nature of felicity conditions--they describe mutual knowledge shared by teachers and students as part of the basis for interaction. The assumed relation to Grice´s conversational maxims was criticized, however, since the felicity conditions were very specific to the domain of arithmetic instruction.

Prescribing effective problem solving procedures

Joan I. Heller
Graduate Group in Science and Mathematics Education
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Heller described research designed to evaluate a "prescriptive" model of physics problem-solving performance. Her work investigated the solution of well-structured, routine textbook problems of the type used in undergraduate courses for homework and exam items. While these problems are clearly constrained, they are also quite complex and are notoriously difficult for students.

Unlike less-structured problems, these problems are amenable to analysis of specific processes and knowledge structures that can be relied upon to reach problem solutions. Heller's work (in which she has collaborated with Fred Reif), proposes a theory of the specific procedures and conceptual knowledge novices can use to solve mechanics problems involving Newton's law, $F = ma$. Her claim is that students, whether working individually or in joint efforts, need to acquire and use appropriately these kinds of procedures (or functionally equivalent ones) if they are to solve problems effectively.

Before attempting to design instruction to teach such knowledge, the model must be evaluated. If students, working in accordance with the model, do perform well, then efforts to teach these procedures would be a reasonable next step. However, if the model did not reliably lead to good performance, instructional studies would be premature; the model would need revision before instruction should be attempted.

Heller distinguished her "prescriptive" approach from the "descriptive" models others have developed to account for differences between experts' and novices' observed performance on physics problems. Rather than describing naturally-occurring problem-solving performance, Heller and Reif prescribe steps which are postulated to lead to good performance, even if they are not those exhibited by experts. In fact, Heller asserted that it is not necessarily desirable or possible for novices to learn to solve problems using experts' strategies. This is because novices cannot rely on the kinds of automatic processes and repertoires of familiar patterns which experts have available as a result of years of experience.

Heller described a method for testing prescriptive models of human performance. The method is to induce human problem solvers to work in accordance with a model by creating procedural scripts (analogous to artificial intelligence programs which constitute prescriptive models of computer performance) for the students to follow. These scripts consist of a series of directions which are read to subjects, one step at a time. The performance of three groups was compared in Heller's study: One group solved problems following directions corresponding to the complete procedure specified in Heller and Reif's theory; a second group solved problems following a modified set of directions from which selected components of the full model had been deleted; a third, control, group solved problems on their own, without external guidance. Results showed that the model was sufficient to lead to good performance, and the components deleted from the modified model were in fact necessary--the second group made errors that could be traced to the absence of the deleted components of the model, and both the full and modified model groups performed significantly better than the control group.

Discussion centered on alternative conceptions of what is meant by "problem solving." Some stressed that controlled use of well-specified solution procedures is only applicable to a narrow range of problem-solving situations. Another issue arose with Heller's mention of three areas of research which have contributed to understanding human problem-solving performance: Studies of novices and experts, information-processing analyses of performance, and artificial intelligence models. This claim was challenged by some members of the group, revealing differences of opinion related to the scientific traditions that Heller was characterizing. Some did seem able to identify the labels and to agree on the utility of making clear task analyses. But there was disagreement on the relevance of AI work for the study of human performance, and the utility of studies of individual performance for understanding joint problem-solving activities.

Joint solving of physics problems by college students

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Yutaka Sayeki contrasted two cases, in one two college students tried to solve a physics problem without any success, in the other Sayeki himself discovered the law of gravity with minimum amount of inter-person interaction. These two examples illustrate that joint problem solving is not always successful but that even when individual problem solving does work it is in essence social.

The study of problem-solving by pairs of Japanese undergraduates illustrates several ways that attempts to maintain good social relations may lead students to avoid confrontation and to reinforce false convictions. Rather than using conflicts of opinion to help reach a deeper synthesis, students often moved toward a superficial agreement.

A second example came from his own puzzlement over a physics problem, but through intra-person problem solving activities. He characterized this latter intra-person process as yet another type of interaction, where he himself posed questions, answered them, and tested their validity. Moreover, Sayeki emphasized that this problem was originally brought to his attention through inter-person interaction. Thus, according to him, an intra-person problem solving process is always a joint activity. Such a process develops not as a result of modeling some social behavior, or any other type of modeling for that matter, but as a formation of an internalized conflict resolution schema which he called the "society" in mind. He also emphasized that for the development of such a society, the existence of the third viewpoint becomes critical. Resolution of any conflict involves a system of allocating importance among the conflicting elements, and this allocation can only be done by the viewpoint that does not belong to either of such conflicting elements.

Sayeki´s presentation sparked a broad range of responses. Some questioned whether the difficulties found with joint problem solving were specific to that particular role relation: would similar difficulties arise in an apprentice-master relation. In general, how do role relations like leader-follower affect the problem-solving process? Interest also focused on cultural differences in interactional styles that may affect joint problem solving. For example, can errors in individual problem solving be traced to internalization of cultural styles of interaction.

GENERAL DISCUSSION

General discussion for the day was lead by Donald Norman who noted that the topics of learning and instruction are extremely broad and it is always necessary to slice off a small piece to study. The main theme throughout the day was the social aspects of problem-solving. But the day´s discussion went well beyond simply saying that cooperation was good. In fact many of the presentations showed difficulties in interaction--for example, the mismatch between the teacher and child that Petitto discussed. With respect to microcomputers little new on the technological side was reported. But the discussion of the difficulties in teaching LOGO that Hawkins reported showed that technology produces as many new problems as it solves--now educators have the problem of teaching LOGO. In general the sessions indicated a move toward studying education in very interesting ways. Further discussion centered on the issue of whether microcomputers create qualitatively new forms of interaction. From the purely technological perspective, microcomputers are not doing much that large computers could not do before. But their low cost and availability is having a profound impact on forms of education.

Appropriating an expert's understanding

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Griffin called for a type of representation which is not an individual mental object nor immutable nor atemporal. She relied on studies of learning, using specific theoretical constructs. Appropriation is a reciprocal process: The learner appropriates cultural systems from the experts; the expert appropriates the learners' behaviors into the cultural activity. Education is an interpsychological process (between people) that may change intrapsychological processes. The expert and the novice enter the interaction with analyses that should be representable for study, as should the joint analysis that they negotiate on-line, and their exiting analyses. The past history of the participants in the interaction and the future, novel creative contributions to the domain, need to be represented.

A presupposition of this view is that a task is not uniquely analyzable. The objects, talk and tasks are analytically vague. The representation should show that the expert and the novice can interact in the task situation "as if" there is a shared analysis. Preference is given to the teacher's analysis as a socio-cultural norm, not as "truth" about the domain, nor on the basis of formal properties attributed to the expert's mental model. According to Griffin, we should not assume that the elements in a single mental model are divided up among the participants; instead, multiple analyses of the task situation are assumed to be present, unified by the division of labor that emerges in the interaction. Mental model representations define boundaries on the basis of the task studied or on the grounds of abstract hypotheses about the domain. Socio-cultural domain representations cannot rely on these procedures, since abstractions about the domain are time and culture bound: the "last word" is merely the "latest one" in some culture.

One approach (based on Vygotsky, his colleagues and students) applies to educational activities, which provide for the genesis of the culture´s abstractions about the domain, not just the normatively correct answer to a problem or to a set of them. Domain boundaries are related to genetically primary examples (the material in a task that requires that all of the abstractions relevant to the domain be used for its analysis). In a putative domain of addition, a problem like "1 + 1" makes it difficult to deal with permutation, while "3 + 2" doesn´t. Educational activity should use examples which provide for the genesis of the whole task of addition, using joint problem solving with an expert as the way to insure success for the novice.

The machinery for representation is a quadrant, using specific vs. general as the vertical dimension, orthogonal to concrete vs. abstract. The concrete specific acts (some, genetically primary examples) occupy the top left cell. The set of socio-cultural abstractions are in the bottom right. Above that appear the abstractions brought to bear on a specific problem; the bottom left cell contains the culturally normative answer--the "expert" solution. Teachers and students share the content of the concrete-specific cell; other cells attributed to each of the participants may differ. The scientist studies the interactional quadrant as dynamic and the abstractions as vague, joined (across participants and to the concrete observable actions) on the basis of "as if" not on the basis of "identity."

Griffin discussed two multiplication problems: ".2 x .3" and "12 x 6." Undergraduates could work with the decimals as arabic numerals, but not by manipulating numberlines. The whole numbers were no problem. Their discussion focused on successive addition, but they couldn´t apply it to the decimal case. Considering the many different words (times, of, by) used to refer to the "x," and the prohibition against adding apples and oranges but the encouragement to multiply (successively add) unlike units, Griffin pointed out the difficulties of relating the verbal, numeral and number line representations of these issues. Griffin discussed a seventh grader, Estela, who had mastered multiplication as successive addition for the whole number case, but had no other procedure or approach available. Accurate but very slow, her grades kept her from advanced lessons where more genetic problems might make available more aspects of the culturally elaborated system of multiplication.

Griffin speculated that, with microcomputers using numberline estimation games (like those developed by Levin), one could introduce a problem like ".3 x .2" on a number line as a genetically primary example for multiplication, making possible quite different educational interactions. Locating .3 on a line, then locating .2 of that line matches the ordinary verbalization, "two-tenths of three-tenths." The special case of whole abstract numeral multiplication as successive addition could be derived as an interesting discovery rather than as the only and possibly terminal representation available to a child.

Mathematically sophisticated participants argued that concepts of dimensionality could be introduced to make it plausible for repeated addition to be the fundamental concept in a multiplication curriculum. Griffin asked how this notion of the domain would consider the whole number and decimal cases or if there were different candidates for a genetically primary example. The participants appeared skeptical about the idea that domains were cultural objects and that the representations should be, in principle, mutable and, perhaps, fallible.

The nature of the 'joint' in joint problem solving

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In most psychological research on joint problem solving, it is taken for granted that the activities of the individuals are directed at a common goal, and all that varies is the effectiveness of the individuals in implementing that goal. When the outcome of an interaction does not conform with the stated goals, the trouble is located in failure of the student to learn or the teacher to teach, or some aspect of the situation which prevents otherwise competent participants from achieving "their" goal.

McDermott questions this taken-for-granted assumption and asks instead, what if instructional scenes, especially instructional scenes in school, are "about" creating and maintaining social hierarchies as much or more than they are "about" learning/teaching? Drawing on his analyses of many instructional scenes, McDermott points out that in fact, American schools put evaluation and social sorting in the forefront of the interactions that are referred to in other frameworks as joint problem solving. Given that learning does not necessarily occur in those contexts which society creates with the explicit purpose of creating learning, how do we specify the systems characteristics that allow new information to enter?

These questions were made more pointed by reference to videotaped scenes in which adults organized children's learning in such a way that (theoretically) very little learning could occur even though at many moments in the interaction, the relevant academic procedures were visible in the interaction. The key seems to be the way in which understanding of the procedures is organized by the participants, especially the more expert or more powerful participant (in one case a mother helping with homework, in another a teacher helping with a reading lesson). In each case, the way that interaction around procedures was organized reflected the mixed understandings of the participants and the mixture resulted in the acquisition of behavioral sequences that ultimately limit learning as defined by the psychological ideal.

McDermott, who has taught and conducted research in Japan, discussed the way that the Japanese organize this same set of activities. While Japanese elementary schools put display and hierarchy way into the background, creating excellent learning environments, hierarchy is achieved in other learning environments. He urged those present to consider Japanese educational practices in the context of the overall Japanese scene, and not to focus on narrow comparisons based only on the elementary school classroom. The critical relations, he said, are those relating behavior in one context to behavior in others; failure to keep this in mind leads to interventions which fail eventually because they ignore the mixture of constraints which shape, in the end, the success or failure of any one "joint" problem solving episode.

Microcomputer networks and presuppositions about modes of communication

Ron Scollon
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Scollon reported his experience in attempting to construct microcomputer networks linking individuals located in small Alaskan villages. Because this networking crosses the State Department of Education and the University of Alaska, it is especially problematic. This case takes on special interest, because the conditions of transportation and communication in Alaska make face to face interaction for people expensive in many cases. The existence of satellite receivers in most villages makes computer-based networking an economical enterprise.

In three separate cases, the need for a distributed network was seen to be in direct opposition to the perceived need for centralized decision making. To explain his experience, Scollon introduced the notion of "complimentary schizogenesis," taken from the work of Gregory Bateson. Complimentary schizmogenesis refers to situations in which a person or institution identifies a problem and takes steps to solve it, but the solution creates another problem, which demands another solution, etc. The net result of this sequence is that the social arrangements that were obtained before solution was sought are maintained. In Scollon´s case, the "problem" was to provide greater coordination between the department of education and its teachers and students in remote villages. The "solution" was to set up a computer-based message system. However, the "solution" that was implemented did not solve the problem. It created new problems.

Scollon´s analysis of the problem-solution-problem sequence in the case of the Alaskan educational system suggests that the lack of communication between villages and the Department of Education was not solely, or even principally, the result of constraints on time and distance. Rather, the problem was itself the consequence of the importance of the institutional relationships to the people in the Department of Education. When they implemented a solution, they did so in a way that restricted access to the very people who were supposed to gain access. A message system was set up that completely bypassed the networking power of the microprocessor (as evidenced by experiences at UCSD and between UCSD and Alaska). Instead, the system that was created allowed teachers to contact only their supervisors one step up the authority system. Teachers and students in villages could not communicate with teachers or students elsewhere.

Hence, in thinking about joint problem solving and microprocessors, it is crucial to look at the systems into which they are placed and to insure that the potential of the new medium to increase access and joint problem solving is not subject to the "prior restraint" of the larger social system into which it is placed.

Collective scientific discovery by day care children

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Chiba University

Giyoo Hatano and Kayoko Inagaki proposed a conceptual model of the processes by which children acquire knowledge about the natural world through their interaction with peers and through feedback from the external world in daily life situations. Hatano explained this model through a demonstration case involving the acquisition of "folklore" knowledge regarding the making of ice.

The proposed model is different from the Vygotskian vertical interaction model in that it implies the following points that were neglected in the Vygotskian model. First, a child could do more than she could do alone with equally capable peers (or even less capable peers). Even if each child does not have enough ability to acquire the target knowledge, each can contribute to the group. Second, this model assumes that the member who is most capable in a group can change from moment to moment during the processes of knowledge acquisition. Furthermore, the model differs from the Piagetian horizontal interaction model in that it takes into account the role of feedback from the external world and the adult's roles in setting up the situation and in temporarily acting as a more capable peer.

According to the model, the processes of knowledge acquisition through peer interaction consist of cycles of four stages: 1) the initiation of information seeking, 2) the production of a number of hypotheses, often implicit, 3) the informal experimentation, and 4) the collection of data and induction.

The following are pointed out as the advantages of having a group of peers in acquisition of knowledge by children.

1) Curiosity is amplified (and stabilized) by social interaction.
2) An alternative hypothesis may be proposed by another child.
3) "Control" conditions are provided by children against the hypothesis.
4) Comparison is facilitated socially (between mine and her/his) in induction.

SUMMARY OF MAIN ISSUES

The conference brought out fresh approaches to the old questions of learning and teaching. The focus on joint problem solving provided an interesting interpretation of human-computer interaction as a form of joint activity. There was general agreement that the conference had broken new ground and that in spite of the diversity of disciplines, problem domains and cultures, several important unifying themes had emerged.

Learning as a complex problem solving process involving interaction with other people, with mediating tools and with reality was outlined clearly by Hatano during the final period of general discussion. His formulation sparked a lively debate about the way technology mediates our relations with other people. Are there fundamental differences between adaptive human experts and other forms of human technology? In what ways might the social interaction between two learners reshape the cultural technology or medium for representing the world?

Throughout the conference and into the final discussions, the participants were generally cautious in interpreting the value of joint problem solving. To cite several examples: Miyake noted that language often traps joint problem-solvers into holding onto inadequate solutions. Hawkins showed that LOGO, far from being a solution to the problem of how to teach general problem-solving skills, was itself a difficult domain to teach. Sayeki listed several ways in which people in interaction hinder their joint problem solving efforts by attempting to avoid disagreement. Griffin talked about how an expert can get worse or less efficient at solving particular problems as a result of being in interaction with a novice.

The healthy skepticism shown over the course of the conference strengthened the general feeling that there are several important basic research issues to be tackled. Joint problem solving is not a solution to the theoretical and practical difficulties facing us in the realm of education. Rather, it is a tool that can be used to find out more about learning and about how people learn from interacting with computers and with each other.

Among the specific issues that warrant further investigation are:

What features of expert-novice interaction can or should be imitated by microcomputer tutoring systems?

Under what conditions will peer interaction facilitate learning or discovery of general problem solving strategies?

Under what conditions will expert-novice interaction break down or be unable to proceed?

How can instructional sequences be organized to take advantage of the division of labor implicit in expert-novice interaction?

How can microcomputer environments be used to control the task being presented to a subject or group of subjects working together?

Can the concept of dynamic support be used in describing progress through a complex conceptual domain such as physics or mathematics or is it applicable only to learning more concrete practical tasks?

There was general agreement that we have only begun to probe these issues. Perhaps more important is the fact that we have only begun to take advantage of the profound differences in outlook found among American and Japanese cognitive scientists. The cultural differences between the US and Japan became an explicit topic in only two of the presentations (Sayeki and McDermott) but they arose implicitly in the direction of discussion and the distinctions that were raised. It was generally agreed that the differences were far more of a mutual resource than a hindrance to communication. Future gatherings could profitably focus more attention on cultural styles and differences in their respective technologies of representation while maintaining the overall concern with the social context of learning.

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