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ABSTRACT

This study examined ways in which two independent variables, peer collaboration and the use of a specific tool (the TAPS interface), work together and individually to shape students' problem-solving processes. More specifically, the researchers were interested in determining how collaboration and TAPS use cause metacognitive processes to differ from those that occur when students engage in individual problem solving using standard tools. The TAPS systems help students develop metacognitive skills and awareness. Forty-eight undergraduate students were selected and randomly assigned to one of four research groups: pairs and TAPS; individuals and TAPS; pairs and standard tools; and individuals while thinking aloud. Protocols of these problem-solving sessions were videotaped for analysis. For coding and analysis, each protocol was broken down into 15-second segments. Results showed that TAPS users differed from users of conventional tools in both time taken in problem solving and reading time; TAPS use appeared to serve as a catalyst for more strategic planning behavior; collaboration also produced more planning behavior; and more behavior associated with metacognitive monitoring occurred in the pair groups. (Contains 16 references.) (JLB)

The Effects of Collaborative Interaction and Computer Tool Use on the Problem-Solving Processes of Lower-Ability Students[1]

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Objectives of Study

The main purpose of this study was to examine ways in which two independent variables, namely (1) peer collaboration and (2) use of a specific computer tool (the TAPS interface), work together and individually to shape students' problem-solving processes. Because the TAPS interface was designed to enhance metacognition, we were especially interested in determining how collaboration and TAPS tool use cause metacognitive processes to differ from those that occur when students engage in individual problem solving and use standard (pencil, paper and a calculator) tools. This question is motivated by the work of Vygotsky (1978), Lave and Wenger (1991), and others, who have postulated that thinking is both physically and socially situated, meaning that problem tasks can be significantly shaped and changed by the tools made available and the social interactions that take place during problem solving. Like other researchers (e.g., Newman, Griffin, & Cole, 1989), we seek to understand whether and how the "same" problem-solving task is transformed by tool use and different social organizations. This question is of general interest to the extent that peer collaboration on word problems is common instructional practice and that the TAPS interface resembles a number of non modeling, reflection-type instructional computer tools that have been developed in recent years (e.g., Collins & Brown, 1988; Lajoie & Derry, 1993).

In addition to this basic research question, this study also addresses a practical issue: a need to obtain baseline data on how cognitive processing is shaped by an instructional system's interface alone; that is, the basic interface design unenhanced by tutoring or other instructional treatment. This baseline data will help us more precisely gauge the 'value added' by various intelligent tutoring strategies that will overlay the interface in future studies.

In previous research (e.g., Derry, Hawkes, & Kegelmann, 1991) we have informally observed that students who engage in collaborative problem solving using TAPS interface tools appear to exhibit what most cognitive psychologists would regard as more mature metacognitive behavior than do students who think aloud while solving problems alone using pencil and paper. That is, student pairs working together on TAPS appear to reflect upon their problem-solving processes more often, conduct more strategic planning, and overtly monitor and check their work more frequently. Overall, these observations suggest that even without tutoring or other instruction, social problem solving using TAPS interface tools may help shape and develop students' thinking processes in potentially productive ways. This expectation formed the basis for the research hypotheses of this study.

The primary questions addressed by our study can be summarized as follows: Compared to students who solve problems using the TAPS interface, will students who solve problems without using TAPS tools exhibit different types and frequency of metacognitive activity? Also, when students are asked to think out loud while working individually, do they exhibit metacognitive performance that is different from what is exhibited in collaborative problem solving? Finally, do the effects of computer tool use differ for pair versus individualized instructional conditions? One of our hypotheses was based on the assumption that by making covert, abstract reasoning processes visible, public and manipulable, TAPS would serve as a necessary catalyst for reflective metacognitive activity that would not take place in its absence (Vygotsky, 1978; Collins & Brown, 1988). Another hypothesis involved eliminating the possibility that the relevant key to enhancing metacognitive activity during problem solving is merely thinking aloud, for thinking aloud itself can produce more reflection and self-monitoring and has been associated with improvements in problem solving performance (e.g., Gagne' & Smith, 1962).

Background : Description of System

TAPS is a computer-based instructional tool, programmed for the NeXT machine (soon to be available for 486 machines running Microsoft Windows) and designed to help students develop metacognitive skills and awareness, where *metacognition* refers to one's knowledge of the thinking process itself and how to control it. Examples of metacognitive processes targeted by TAPS instructional activity include planning, self-monitoring, and self-awareness of the nature of complex problem solving and one's thoughts and behaviors during problem solving. A metacognitive approach is justified by numerous detailed analyses of typical problem-solving difficulties experienced by older children and adults (Derry, 1989; Schoenfeld, 1983), which have shown that many problem-solving errors are due to metacognitive failure rather than, or sometimes in addition to, lack of basic mathematics knowledge.

In designing TAPS we embraced Vygotsky's (1978) notion of cognitive tools -- objects provided by the learning environment that permit students to incorporate new auxiliary methods or symbols, which otherwise would be unavailable, into their problem-solving activity. The major cognitive tool provided by TAPS is a graphics interface that facilitates construction of problem trees, network structures showing interrelationships among all relevant sets in a problem situation, specifying the subgoal structure of the problem, and illustrating a solution path. Such trees provide graphic reifications of abstract structures that otherwise would be invisible to students, making them public and available for discussion, manipulation, and comparison. This type of instructional environment is widely believed to encourage and afford greater metacognitive awareness (e.g., Reusser, in press; Collins & Brown, 1988).

Insert Figure 1 About Here

As shown in Figure 1, a student or group working on TAPS is presented with a complex word problem to solve. (Henceforth in this discussion, the term "student" should be understood to mean either an individual student or a group of students working together on the system.) Complexity and story content of each problem can be varied to match the abil ·s and backgrounds of the student. To make possible the construction of a tree, the ir ıace provides a menu of blank three-node subtree diagrams ("schemas"), shown to the right of the screen in Figure 1. Students proceed by selecting subtree diagrams from this m nu and moving them into the workspace one at a time.

In the workspace each subtree is filled in with labels, values and an operator so that it represents a particular set relationship from the problem. When filled in, each subtree represents a simple equation such that the two nodes at the top of the subtree represent two sets that can be related by an arithmetic operation to produce the set value represented by the bottom node. It is important to note, however, that in the naming of sets, students make explicit their *semantic* understanding of the concepts underlying arithmetic operations. By requiring this set labeling and providing possibilities, the system unobtrusively scaffolds students in the process of thinking conceptually about arithmetic structures.

Each blank schema in the subtree menu is shaded differently to indicate where it can be attached to another subtree. System users select the appropriate subtree diagram and then "click" with the mouse at the point on the problem tree (in the workspace) where the new schema will be attached. In this manner, students can chain subtree schemas together to form complex tree structures, as shown in Figure 1.

Method and Data Source

Volunteer subjects, who received course credit for participation, were solicited from a large undergraduate educational psychology course. All volunteers completed a survey instrument designed to help determine their attitudes and abilities toward mathematics. Since TAPS is designed primarily for lower math achievers, students were eliminated if they reported evidence of above-average achievement in college mathematics. Examples of the type of evidence considered included the following: Above-average performance on SAT or ACT mathematics achievement tests; advanced college courses in mathematics with a grade of B or better; A grade of "A" in a recent college-algebra course; Self-ratings on attitude scales such as, "I am very good at word problems" or "I really hate math word problems."

Forty-eight students were selected and randomly assigned to one of four treatment conditions. In Treatment 1, eight pairs of students work collaboratively in pairs on the TAPS system. Each session consisted of presenting the students with one training and one practice problem on the system, followed by two experimental problems, the "pizza problem" and the "politics problem," shown in Table 1. The experimental problems were presented in counterbalanced order within treatment, so that four pairs received the pizza problem first, and four received the politics problem first.

Insert Table 1 About Here

Treatment 2 was identical to Treatment 1, except that eight students worked their problems on TAPS individually rather than collaboratively, and were instructed to think aloud during problem solving. In Treatment 3, student pairs worked collaboratively on identical problems, but without the TAPS system. Rather, subjects in Treatment 3 used pencil and paper for developing their joint solutions. In treatment 4, eight students worked independently using pencil and paper while thinking out loud.

Protocols of these problem-solving sessions were videotaped for analysis. A practice effect was possible with TAPS subjects, who appeared to use the system with greater ease for their second experimental problem. Thus, to minimize the effects of unfamiliarity with the TAPS system, we analyzed only the second experimental problem from each protocol.

For coding and analysis, each protocol was broken down into fifteen-second segments. Coding involved studying each fifteen-second interval on each tape and assigning codes to indicate the type of behavior observed during each interval. Coding followed the scheme shown in Table 2. This coding system was derived over a period of several months through the research and discussions of videotapes carried out in the first author's graduate research group. It represents a synthesis of ideas from the literature on metacognition and social problem solving (e.g., Schoenfeld, 1987; Clements & Nastasi, 1988).

Insert Table 2 About Here

During development of the coding system we examined the reliability of an intermediate version by having two researchers independently code the same three videotapes. A reliability coefficient was derived by computing the average percentage of matching fifteen-second coding intervals for each general coding category. These initial reliability computations ranged from a high of .93 for the category of reading to a low of .70 for the category of monitoring. At this point the two coders met to discuss their discrepancies and to clarify and elaborate the coding system for the purpose of obtaining better reliability. After two rounds of reliability checks and discussions, all tapes were coded by a single rater. The reliability of this final coding was estimated by having a second researcher code a random sample of four protocols and then calculating the percentage of agreement between the two raters. All reliability computations in this final analysis were greater than .90.

Results

To help determine how different social and tool conditions differentially affected cognitive processing, the four treatments were compared on the basis of total time spent in problem-solving activity (expressed as average number of fifteen-second intervals used to complete the experimental tasks in each condition), and also on the basis of what types of cognitive activity were observed during problem solving in each treatment (expressed as percentage of intervals spent in each of the coding categories of Table 2). Results of this comparative analysis for each major coding category are displayed in Tables 3 and 4 and are graphically depicted in Figures 2 through 7.[2] Since our analyses revealed no statistically significant differences between the pizza and Macintosh problems, all data and analyses reported combine the two problems.

Insert Tables 3 and 4 and Figures 2 - 7 About Here

Table 3 shows the mean "duration" of each treatment as well as the percentage of total problem solving time for each treatment spent in activities related to reading, planning, monitoring, attending to the computer interface. or actually carrying out a solution. The coding category *exploration* is not shown in Table 3 because no exploratory behavior was observed during processing of the experimental problem, although some exploratory behavior did appear during practice sessions. We note that the sum of total percentages for each treatment exceeds 100% because the coding categories are not mutually exclusive. For example, it is very possible to be engaged in planning a strategy and at virtually the same time be monitoring how well that strategy is working.

Statistical tests for main effects (pen/paper versus TAPS and pairs versus individuals) for the categories of reading, planning, monitoring, and carrying out a solution strategy are shown in Table 4. These tests were computed using adjusted Mann-Whitney U tests, a procedure that does not require homogeneity of variance. It was also possible to test for significance of interactions by comparing the significance of the difference between two U statistics, provided there is homogeneity of variance on at least one of the two main effects involved (R. Serlin, personal communication, April, 1993). Homogeneity tests were computed using Levene's test, resulting in the rejection of the homogeneity hypothesis for only one main effect, the individual versus pair comparison in the coding category of planning. Hence, it was possible to test for all possible interactions.

As indicated in Table 3 and Figure 2, students working with the TAPS tool spent nearly four times longer working on their experimental problem compared to subjects in the non-TAPS conditions, a clearly significant difference. It is possible to adjust these means by removing time spent attending to the computer interface, on the assumption that the additional time added by the interface is possibly irrelevant since it presumably would disappear with further practice. This adjustment is reflected in Figure 3, where bars labeled "TAPs problem time" reflect time spent in problem-solving activity with interface time removed. Using either adjusted or unadjusted means, however, the time difference is marked and obvious: Without guidance, TAPS interface users require much more problem solving time than do subjects solving the same problems with the standard pencil and paper tools.

Given this difference, it is natural to ask whether TAPS subjects performed noticeably better or worse than subjects using pen and paper. Our current sample size was too small to answer this question for certain, but the probability of obtaining a correct solution was .50 (4 out of 8 protocols) for Pen/Paper-Individual, .50 (4 out of 8 protocols) for Pen/Paper-Pair, .875 (7 out of 8 protocols) for TAPS-Pair, and .750 (6 out of 8 protocols) for the TAPS -Individual group. This difference is not statistically reliable, although it is suggestive of a positive trend.

Several a priori hypotheses were advanced with respect to the metacognitive categories of planning and monitoring. It was hypothesized that both social interaction and use of the TAPS interface would increase attention to planning. As shown in Figure 4, pairs using the TAPS system spent a much greater percentage of their time in planning activity than did any other group. Pairs did significantly more planning than did individuals ($z=2.47$, $p<.05$), and TAPS subjects did significantly more planning than did subjects using pen and paper ($z=1.97$, $p<.05$). The test for the interaction was not statistically significant ($z = -0.544$), although TAPS tool use combined with collaboration produced substantially greater planning activity than did any other condition. Further inspection of data indicated that this was predominately forward, short-range planning of strategy.

In addition, it was expected that pairs working together would display relatively more monitoring behavior as a natural consequence of cooperative engagement in problem solving. It was also anticipated that TAPS would increase monitoring behavior, which would result from making abstract aspects of problem solutions more concrete and visible, thus prompting more discussion and questioning. As shown in Table 4, pairs did significantly more monitoring than did individuals ($z = 4.35$, $p< .05$), but the difference between TAPS and non-TAPS subjects was not statistically reliable ($z = 0.31$).

Post hoc tests for the categories of reading and carry-out also were conducted, revealing one statistically significant main effect: Those using the TAPS system spent only 30.34% of their problem-solving time in the activity of reading, whereas subjects using standard tools (pen and pape., spent 69.62 percent of their time reading. Closer inspection of coded data revealed that not only did percentage of reading time differ, but that TAPS use greatly changed the *nature* of the reading activity. Students using pen and paper were able to take notes as they read and to underline or mark their text to facilitate focusing. But more evidently, students using traditional tools seemed to interweave reading with other problem solving processes so tightly that it was not easy, for the traditional tools conditions, to isolate reading from other problem solving processes such as carrying out a solution. For TAPS subjects, reading was a distinctive form of processing that was more easily separated from activities such as carrying out and planning.

Discussion

Current findings add validity to the situated cognition viewpoint (e.g., Newman, Griffin, & Cole, 1989) that the same problem-solving task under different social organization and tool conditions is not the same task at all. This study has added to our understanding of how word problem tasks are changed by two common situational modifications: use of a computer interface and the social condition of pair problem solving. Several differences related to tool use were evident: Although they solved identical word problems, TAPS interface users differed from users of conventional tools in both time taken for problem solving and relative reading time. There also were clearly observable qualitative differences in reading style between TAPS and non-TAPS subjects. With conventional tools, but not with TAPS, reading and other problem solving activities are tightly intertwined such that reading is not easily identified as a distinctive processing stage. Moreover, there is a wider variety of reading activity, including note taking and underlining, with the conventional tools. Another difference was that TAPS use appeared to serve as a catalyst for more strategic planning behavior.

With respect to the influences of social (versus individual) problem solving, collaboration also produced significantly more planning behavior, such that the combined use of TAPS and collaboration produced a marked increase in planning. This planning was mostly short-term planning of problem-solving strategy, such as how to approach the next step. Also, significantly more behavior associated with metacognitive monitoring occurred in the protocols for pairs. This finding relates to our research question regarding the relative effects of social negotiation versus thinking aloud. With respect to monitoring, at least, merely thinking aloud about problem solving does not produce as much metacognitive activity as does discussion between two cooperating problem solvers. We plan to investigate the effects of collaboration in greater depth through further analyses of the social interaction on our tapes.

The search for instructional activities that enhance reflection and focus students' attention on the quality of their thinking processes, rather than procedural efficiency, is compatible with goals of the current reform movement in mathematics education (e.g. NCTM Standards, 1989). To the extent that more planning and monitoring are desirable byproducts of instructional activity, then pair problem solving with the TAPS tool does appear to encourage certain desirable behaviors, especially evident when the conditions of social problem solving and tool use are combined. Compared with conventional pencil/paper problem solving, TAPS problem solving is more like the separate stages of problem solving as described in models of "ideal" problem solving, such as the one proposed by Polya (1957). One can thus easily envision the use of TAPS with problem solving instruction or tutoring that builds on students' natural tendencies to plan, monitor, and work in discrete stages. The fact that the TAPS interface can be expected to slow problem solving so greatly might seem undesirable to some. However, we emphasize that this study has examined baseline processing changes associated with an interface design unaccompanied by tutoring, instruction, or other on-line help. It should be possible to increase the efficiency of TAPS use by adding improvements in interface design, as well as various forms of tutoring or other on-line assistance.

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[1] An earlier version of this paper based on half the current data was presented as a poster at the 1993 annual AERA meeting.

[2] Because of the rotated perspectives in Figures 2 through 7, readers are cautioned to read mean values directly from Tables 3 and 4.

Table 1. Experimental Word Problems

The gang is sending Sam out for pizza. Dominoes sells its large pizza with three toppings for 12 bucks. Extra cheese is 2 bucks, and extra sauce is another 2 bucks. Additional toppings are $1.00 each. Sam is supposed to get two large pizzas. They want one with four and one with five toppings. Both pizzas will have extra cheese. Sam has a coupon that gets him 2 dollars off per pizza for an order of two or more. So far he has collected 20 dollars from the group. How much more must he collect?

In the State of Forgottonia, Representative Black is pushing a new college loan program. fifty minority and 80 majority party representatives present today are in favor of the bill. One hundred representatives present today are unalterably opposed to the bill. Following Governor White's impassioned attack on the bill, enough uncommitted votes switched to opposed so that the same number of representatives are pledged against the bill as are pledged in favor of the bill. No other vote switches tool place. If there are still 120 uncommitted representatives on this bill, how many were uncommitted before Governor White's speech?

Table 2. DESCRIPTION OF PROTOCOL CODING SCHEME

R: READING

A fifteen-segment interval was coded "R" if any reading behavior occurred during that interval. Reading is defined as any attention paid to the actual words of the problem. Something other than reading is taking place if any math work is performed, if there is any discussion of how the problem is to be solved, or even speculation as to whether or not the problem is understood correctly. In addition to the main category, reading was coded by the subcategories described below

Sub-categories of Reading:

R.r: Reading (First Time)

First Time Reading is narrowly defined as the first time each word in the problem is read. Most subjects read the whole problem through once at the beginning, but occasionally a subject will work on part(s) of the problem before going back to read the rest. Note taking, underlining, focusing and inferencing can take place in parallel (if done as the words are read for the first time) but these are different activities.

R.a: Reading(Again)

Reading Again is the partner of first time reading. It includes any reading of the problem after the first reading. Note taking, underlining, focusing and inferencing can take place in parallel but these are different activities. If the subject goes back to underline (infer or focus) without reading the words aloud first, it is coded as only underlining (inferencing or focusing) and not as reading(again).

R.u: Reading(Underline/Mark)

Underlining or marking consists of simply identifying words in the problem statement in any way to make them visibly distinguishable from other words. If attention is drawn to particular words, with no actual underlining or marking, it should be coded as reading(focusing) instead.

R.f: Reading(Focusing)

Reading(focusing) consists of drawing attention to words in the problem statement. If the words are marked or underlined, it was coded as reading(underline/mark) instead. Focusing is often preceded by remarks like, 'it says here', 'look at this', or 'oh, I see' which are used to bring attention to part of the problem statement. Focusing is actually a broader category than underlining/marking, distinguished in that the focus leaves no permanent record while underlining/marking does.

R.n: Reading(Note Taking)

Note taking consists of any copying of information from the problem statement to any other medium, such as scratch paper. TAPS does not currently have a facility for note taking on the computer. Writing is considered note taking only when it is information directly from the problem that is being written. Computations and writing of inferences were viewed as not note taking but as means of adding information. Jotting the problem information in a different form, order or representation than the original counts as note taking so long as no information is added.

R.i: Reading(Inferencing)

Inferencing consists of looking at the problem statement and directly inferring information that is not explicitly there. Calculating numbers not given but deducible is not inferencing. For example, if an allowance is $1 a week, it would be an inference to say there are 52 weeks in a year but a calculation to say the total allowance in a year is $52. Inferencing is often accompanied by remarks like, 'Oh, that means...', 'that is saying that...', or by simply stating as fact a statement not in evidence. Questioning or clarifying which results eventually in an assumption or shared assumption (e.g. Should we assume that . . . ?) was not be classified as an inference. An inference was viewed as a product of reading the problem statement and not a negotiated agreement.

PL: PLANNING

A fifteen-second interval was coded "PL" if it included decision-making about what to do. The four subcategories are range(how far away is the focus of the plan), direction (is the plan forward or backward), goal(has a goal been stated), and what(is it an operation, goal or strategy that is being planned). Normally a planning activity will be classified according to all four subcategories. It is possible, however, to discuss strategy, for example, without discussing other aspects of planning. It is also possible to plan interface use as opposed to planning the problem solution. Planning activity can be identified by phrases such as 'what we need to do'. Simply stating what is being done as it is being done is not planning (see carry out).

Sub-categories of Planning

PL.r: Planning(Range: Immediate or Distant)

Planning is considered immediate range if the focus is on the next thing to do and distant if the focus is beyond the next thing. Immediate planning is often identified as deciding 'what to do next' while distant planning is often identified as 'what needs to be done'. Immediate planning is usually followed by the planned action, but it is still immediate planning if the subject changes his or her mind, forgets, or is distracted.

PL.d: Planning(Direction: Forward or Backward)

Planning is considered forward if it starts with the givens of the problem and works towards the answer. Planning is considered backward if it starts with the answer needed and then considers how to get that answer. Forward planning is often identified with phrases such as, 'let's do [ ] next' or 'where do we go now'. Backward planning is often identified with such phrases as 'how can we get that' or 'we need to have [ ]'.

PL.g: Planning(Goal: Directed or Undirected)

Planning is considered goal directed if the plan is in pursuit of a goal that has been stated explicitly (e.g. by 'we need to do [ ]' or 'we are going to find [ ]'). Planning is considered undirected if no goal has been stated explicitly (i.e. by planning what to do or how to do it without saying what the desired result is). It is not goal directed planning unless the goal has been stated in advance.

PL.w: Planning(What: Operation, Goal, or Strategy)

Planning is directed towards deciding on either an operation, a goal to be pursued, or a strategy to be used. An operation is narrowly defined as a mathematical operation, such as +,-,*,/. A goal is defined as WHAT is desired to be found and a strategy is defined as HOW to find what is desired (or by what method).

EX: Exploration(General)

Exploration is defined as search by constructing trial full or partial solutions. (This can be done for fun, in an effort to better understand the problem, or simply as an attempt to find a solution when an obvious path is not known.) Exploration can be identified by statements such as 'let's try this' or by (re)constructing a full or partial solution without indication that this is believed to be a better way. Simply correcting a mistake is not necessarily trial and error. In a trial, there is no expression direct or indirect that this is 'the right way' and there may be a statement indicating uncertainty. When a mistake is made, as opposed to a trial, there should be direct or indirect evidence that it was believed to be correct at the time. If multiple partial solutions are tried at the same point, it would normally be categorized as exploration unless there are clear verbalizations that a series of mistakes are being corrected.

Sub-categories of Exploration

EX.t: Exploration(Trial and Error)

Trial and error exploration is unstated or stated but with no evident system of organization. To distinguish this from correcting mistakes, look for whether or not each partial solution tried is believed to be correct as tried(mistake) is believed to be tentative (trial) or, in the case of multiple partial solutions at the same point, is different but with no stated or obvious reason it should be better than the previous partial solution.

EX.s: Exploration(Systematic)

Systematic exploration attempts to be in accord with a stated system of organization, or follows an obvious system of organization (e.g. try all possibilities in some kind of order).

M: MONITORING

An interval was coded "M" if it included metacognitive activity. Metacognitive activity is thinking about thinking. In each subcategory the subject is aware of some aspect of their thinking about the problem, the process of problem solving, or the problem solution. Comprehension monitoring is looking at the comprehension of the problem, and implies awareness of the subject's own comprehension. Error checking is looking at the correctness of the solution of the problem, and implies awareness of the correctness of the subject's understanding of the problem and the subject's developing solution.

Clarifying/questioning is any seeking of further information, and implies awareness of missing or ambiguous information. When monitoring is of the interface instead of the problem itself, this should be coded by checking the interface category as well.

Sub-categories of Monitoring:
M.e: Monitoring(Error Checking:Calc, Concept, Macro, Micro)

Error checking is looking at a full or partial solution in an attempt to determine if it is correct. This can be done as a precaution or because a possible problem has been noticed. Error checking is often marked by a statement like 'let's see if this is right' or a rhetorical question such as 'is that right?'. Error checking, especially with paired subjects, can often have a questioning/clarifying component in parallel as a means to seek the possible error. Most error checking is either checking math calculations(calc) or checking conceptual understanding(concept). Checking a single step of the problem is classified as micro checking as opposed to checking a larger part of the problem which is called macro checking. Checking for errors in how the interface is used is also possible, and this should be coded as general error checking combined with interface interaction.

M.cm:Monitoring(Comprehension Monitoring)

Comprehension monitoring is defined as any behavior indicating subject's awareness of whether subject has or has not correctly comprehended the problem. If the subject summarizes part of or the whole problem this is an example of comprehension monitoring. Reading activities are excluded as part of the initial attempt to comprehend rather than as an attempt to monitor correctness of current comprehension. (Underlining was previously included in comprehension monitoring). Comments such as 'let's see if I understand this' or 'no, I understood it wrong' indicate attempts at comprehension monitoring. A comment like 'did I do this right' would not be comprehension monitoring, because it is not aimed at comprehension.

M.q: Monitoring(Questioning/Clarifying)

Questioning/clarifying is defined as any attempt to seek information by inquiry or discussion. This is possible for individual as well as paired subjects. If the information sought is a better comprehension of the problem, it is also a comprehension monitoring interchange. It is also possible todiscuss the interface, discuss the effectiveness of possible strategies, etc. In pairs this is often indicated when one partner asks the other a question. Individuals can ask themselves questions in a verbal protocol. Care should be taken to be sure the question indicates the seeking of information and to note what type of information is being sought.

IN: INTERFACE

Interface interaction is defined as any attention paid to the interface, as opposed to merely using it. This often occurs when the subject does not know how to do what they want with the interface, or when the interface gives an error message. Interface interaction often occurs in parallel with other activity. For example, if the experimenter is asked a question about the interface this is coded as questioning/clarifying and interface interaction. This coder makes a note whenever the experimenter is involved in any way. Normal use of interface without difficulty to solve the problem is NOT in this category.

C: CARRYING OUT

"Carryout" is defined as doing the steps to solve the problem, often in the absence of metacognitive activity. (Note taking had previously been in this category.) Carryout can occur in concert with other activities. It is often characterized by a lack of statements, other than to state what is being done at the moment. Often subjects carrying out a solution forget to verbalize entirely, unless reminded.

TABLE 3. TREATMENT DURATION (EXPRESSED AS TOTAL NUMBER OF CODING INTERVALS) AND MEAN PERCENTAGES OF THOSE INTERVALS ASSOCIATED WITH TYPES OF COGNITIVE ACTIVITY: FOUR TREATMENT GROUPS COMPARED

	IP: Individual with Pen/Paper	PP: Pair with Pen/Paper	IT: Individual with Taps	PT: Pair with Taps
READING	71.46	67.78	28.68	32.00
s.d.	12.40	15.94	18.03	12.31
PLANNING	0.00	4.43	1.86	22.71
s.d.	0.00	5.96	3.08	12.99
MONITORING	9.58	48.31	14.70	46.99
s.d.	16.93	17.74	9.91	15.76
INTERFACE	NA	NA	10.71	9.23
s.d.	0.00	0.00	10.07	10.05
CARRYOUT	45.70	30.06	52.30	38.40
s.d.	30.91	19.91	16.65	16.82
*DURATION	11.00	17.88	40.50	43.88
s.d.	7.78	11.42	20.02	26.05

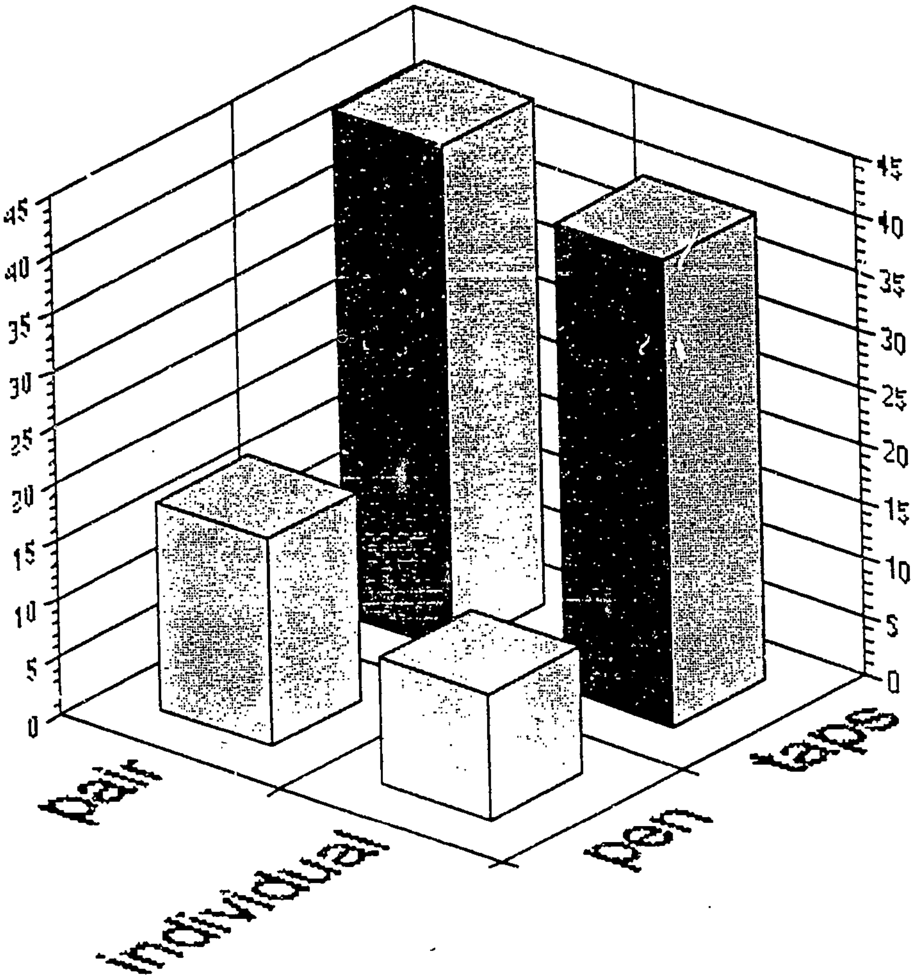
*Duration is number of 15 second intervals in the problem solution.

TABLE 4. TREATMENT MEANS AND RESULTS OF ADJUSTED MANN-WHITNEY TESTS OF HYPOTHESIZED TREATMENT EFFECTS

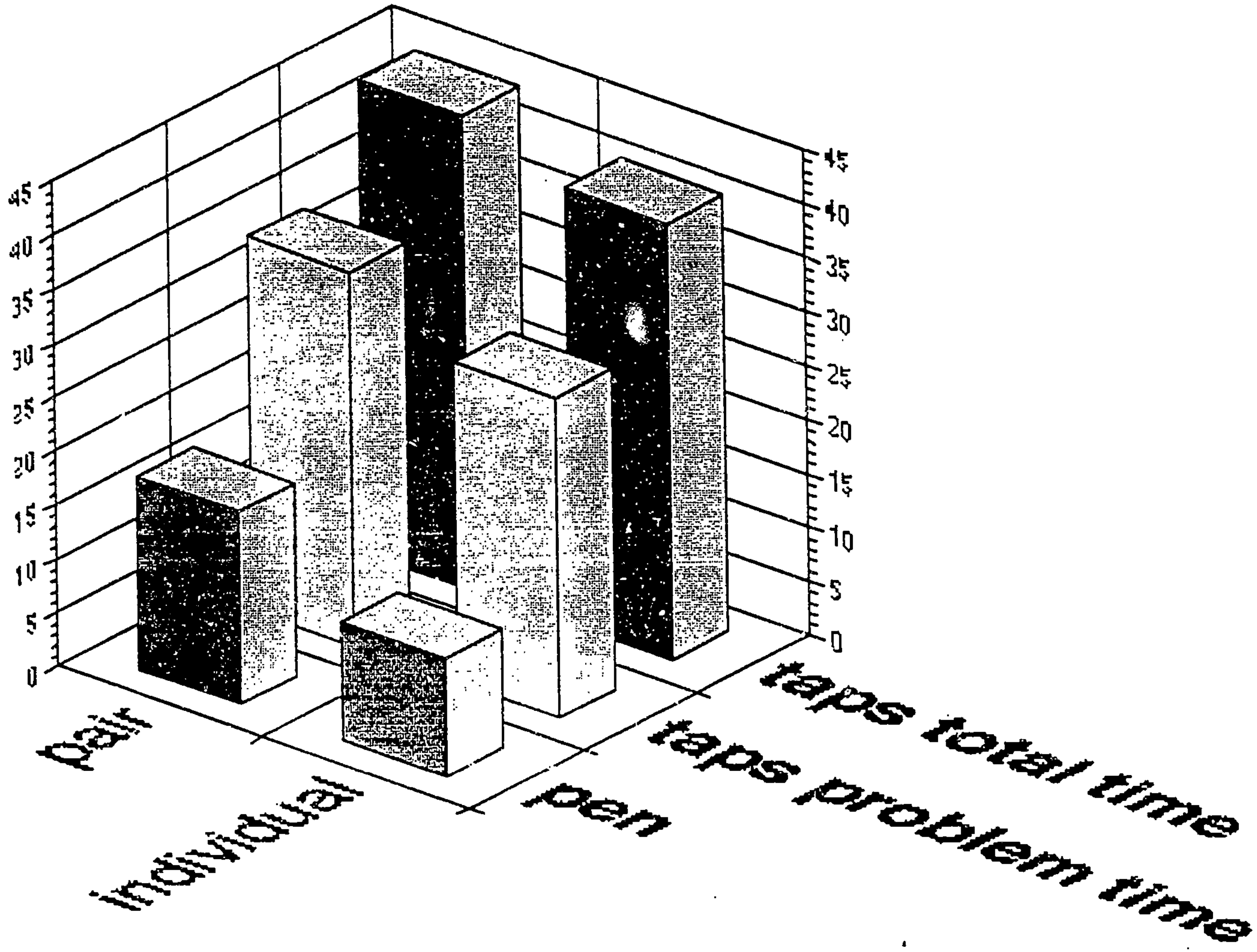
	individual vs. pair			pen/paper vs. taps		
	X	X	z	X	X	z
READING	50.07	49.89	0.01	69.62	30.34	4.88*
PLANNING	0.93	13.57	2.47*	2.21	12.29	1.97*
MONITOR	12.14	47.65	4.35*	28.94	30.84	0.31
CARRYOUT	49.00	34.23	1.10	37.88	45.35	0.66
DURATION	25.75	30.88	0.34	14.44	42.19	3.92*

*P<.05

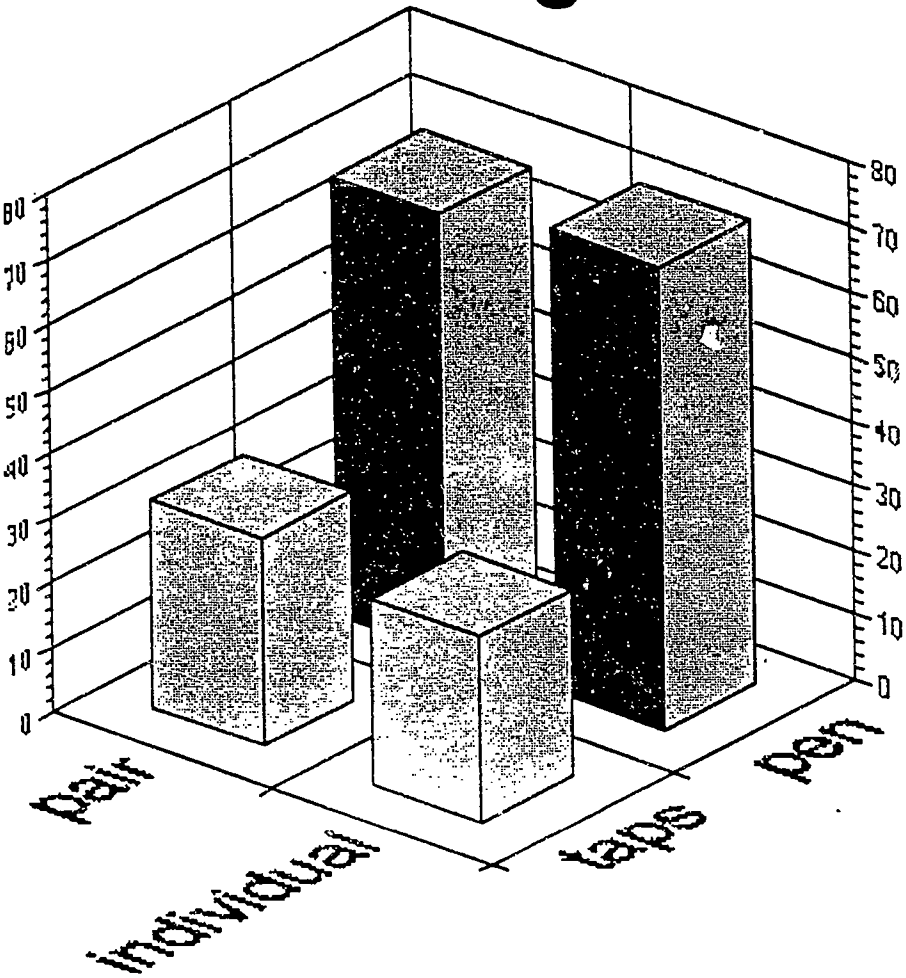
Duration



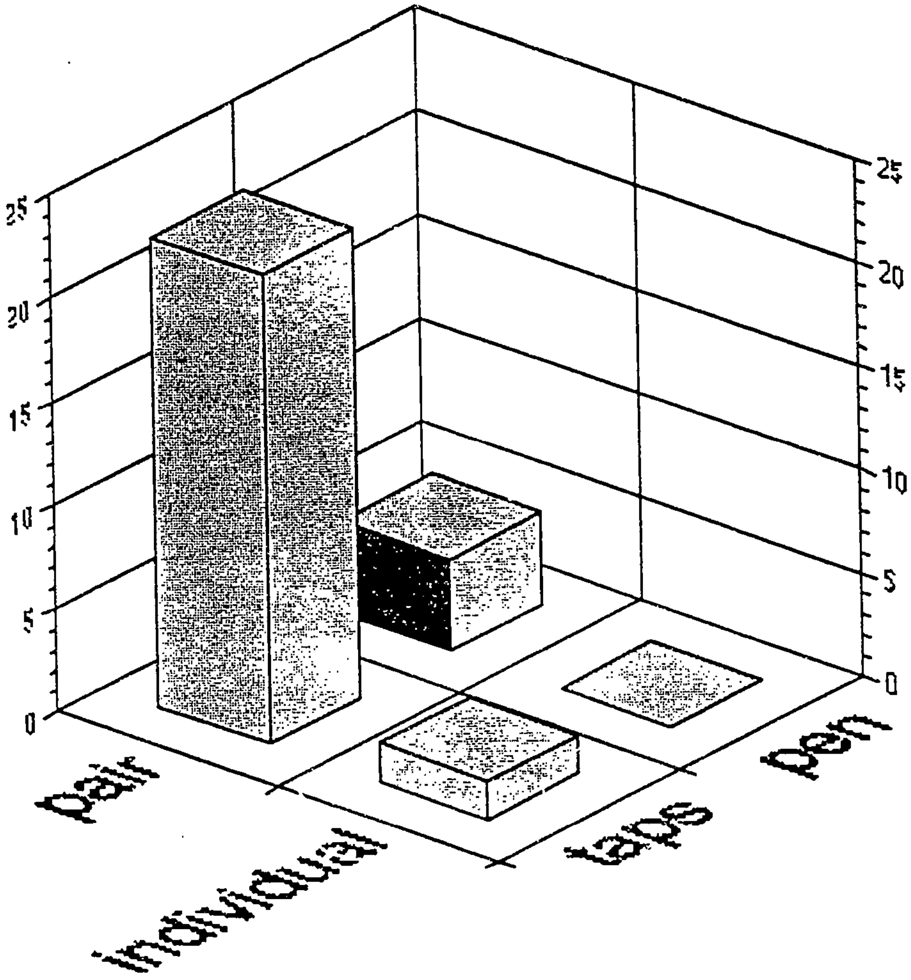
Problem Time



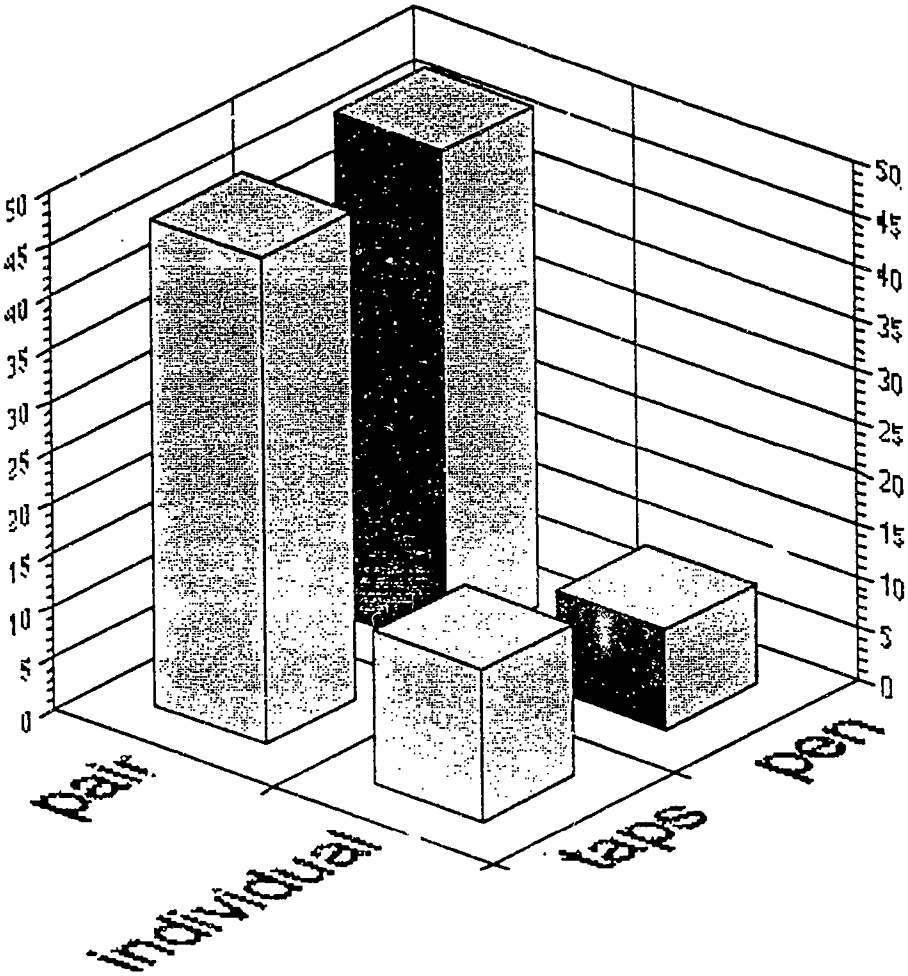
Reading



PLANNING



MONITORING



50
45
40
35
30
25
20
15
10
5
0
pair
individual
taps
pen
50
45
40
35
30
25
20
15
10
5
0

Carryout