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ABSTRACT

This study, presented at the 1979 meeting of the American Educational Research Association (AERA) in San Francisco, examines the relationship between a student's mathematical problem-solving ability and the nature of the student's recall of information from previously-solved problems. Seventy-seven seventh-grade students completed tasks measuring their initial perceptions of problem relatedness, their ability to solve verbal problems, and their recall of information from previously-solved problems. Results suggested that good and poor problem solvers differed in the nature of their problem recall. Good problem solvers tended to recall information about a problem's structure, whereas poor problem solvers rarely did. Nevertheless, poor problem solvers were sometimes able to recall the details of a problem's statement better than were poor problem solvers. A significant transfer effect was found from the solution and discussion of one problem to the solution of a structurally related problem. (Author/MM)

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Problem - Solving Performance and Memory for Mathematical Problems: Solving Related Problems

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Running Head: Solving Related Problems

Abstract

The relationship between problem-solving ability and problem recall was examined. Sixty-seven seventh-grade students completed tasks measuring initial perceptions of problem relatedness, ability to solve verbal problems, and recall of problem information. Results suggested that good and poor problem solvers differed in the nature of their problem recall. Good problem solvers tended to recall information about a problem's structure, whereas poor problem solvers rarely did. Nevertheless, poor problem solvers were sometimes able to recall the details of a problem's statement better than were poor problem solvers. A significant transfer effect was found from the solution and discussion of one problem to the solution of a structurally related problem.

When solving a new problem, a successful problem solver presumably uses information, procedures, and more general notions that have been obtained from previous experience and training. Gestalt psychologists (Duncker, 1945: Luchins, 1942) have demonstrated that prior experience with related problems may have a negative effect in certain new problem-solving situations. In recent years, attention has been focused on identifying the circumstances under which positive transfer occurs.

Reed, Ernst, and Banerji (1974) examined subjects' performance on the "Missionaries-Cannibals" problem and one of its Homomorphs and reported that subjects exhibited positive transfer between the similar problems only when they were told of the relationship between the problems and only when they solved the more difficult problem of the pair first. Kulm and Days (1979) used an information-theoretic approach to study transfer between problems with related structures. They reported that significant transfer occurred when subjects solved an equivalent puzzle problem ("Missionaries and Cannibals") but not for an equivalent algebraic problem. On the other hand, significant transfer was reported when solving a similar algebraic problem but not for the puzzle problem. They reported that the solution of related problems appeared to help subjects focus on relevant strategies, but that different problem contexts appeared to interfere with transfer. Simon and Hayes (1976) also reported that the "cover story", or problem context, may have a significant effect on a subject's problem-solving performance.

The investigations cited above all involved college students and, with the exception of the single algebraic problem in the Kulm and Days study, all involved the solution of puzzle problems - "Missionaries and Cannibals," Tower of Hanoi, and their isomorphs or homomorphs. The present study sought to extend this work by using mathematical word problems, of the kind usually encountered in school, and school-age subjects. Furthermore, the study looked specifically at the role of memory in transfer between related problems.

Memory became a focus for this investigation because the results cited above suggested that a person's problem-solving performance may be intimately connected with the extraction of improtant structural information from a problem solution episode, the encoding of that information, and the retrieval of the information in a subsequent problem-solving encounter.

Recently published research by Krutetskii (1976) has suggested that good and poor problem solvers differ in their recall of information from previously encountered problems. In particular, good problem solvers apparently tend to recall the structural features of a problem, whereas poor problem solvers tend to recall, if anything, the specific details of a problem statement.

The work of Chartoff (1976) and Silver (1977, in press) has suggested that students may also differ in their perceptions of problem similarity. Silver identified four dimensions along which students viewed problem relatedness: mathematical structure, contextual details, question form, and pseudostructure. The first three are selfexplanat ; the latter refers to problem similarity based on the presence of a common measurable quantity, such as age or weight. Silver's data indicated that the perceived salience of the mathematical structure dimension was significantly related to problem-solving competence. Thus, his research suggests that good and poor problem solvers differ in their encoding of problem information, since they differ in their perceptions of cue salience.

To examine adequately the nature of students' memories for mathematical problems, it would appear necessary to consider the students' encoding behaviors as well as the natrue of their recall. Recent research by Bjorklund, Ornstein, and Haig (1977) has suggested that input (i.e., encoding) organization is a mediating factor in memory performance and development. Furthermore, Mandler and Johnson (1977) have reported that the schemata used by subjects to guide encoding of a story are related to, but not identical to, those used to guide retrieval of story information.

Objectives

The principle direction of this study was an examination of the relationship between a student's mathematical problem-solving ability and the nature of the student's recall of information from previously solved mathematical problems. The study looked specifically at the role of such recall in the solution of various problems related to a previously solved problem. A subsidiary purpose was the examination of the relationship between subjects' encoding of and subsequent recall of problem information.

Procedures

Instrumentation. A 16-item card-sorting task (CST) similar to the one used by Silver (1977) was administered to 67 seventh-grade students. Students were asked to form groups of problems that were "mathematically related" and to explain the basis for categorizing them. The 16 problems consisted of four sets of structurally related problems in a 4-by-4 matrix. The matrix was constructed so that the problems in each row were structurally related and the problems in each column were related in details (context, pseudo-structure, and question form).

The Verbal Problem-Solving Test (VPST) consisted of a random selection of 12 of the 16 CST problems. The VPST was administered in a two-day period: four problems on one day and the remaining eight on the next day.

Approximately one week after completing the CST and VPST tasks, students were asked to solve two problems (Target Problems) with different mathematical structures. They were instructed to remember all that they could aboout the "important mathematical information" in the problem and its solution. After they attempted to solve the problems, and after their work had been collected, students were asked to write down all that they could remember about the problem and its solution. On the following day, they were again asked to write down what they remembered, then the problems and their solutions were discussed. On the day following the discussion, and again approximately four weeks later, students were asked to complete the same free recall task.

Immediately following the third recall occasion, students completed the Related Problems Task (RPT). For each of six problems, each student first answered the question, "Is this problem mathematically related to either of the problems you were asked to remember? Please explain why it is or is not related," then the student solved the problem, and finally each student was asked, "Were you helped in solving this problem because you had already solved the two problems you were asked to remember? If you were helped, explain how you were helped."

The six problems consisted of two sets of three problems related to the original two Target Problems. For each Target Problem, one of the related problems was related in structure but not in details, one was related in details but not in structure, and the third was unrelated in structure and in details. Table 1 contains the Target Problems and the related RPT problems. The order of problems (TP1S, TP2D, TP1U, TP2S, TP1D, TP2U) was fixed for all students and was determined by random assignment of problem to sequence positon.

Insert Table 1 about here

Scoring. The CST data were scored in two ways: an association score and a pure category score were obtained for each student. For each clustering criterion of interest (structure and details), the association score was obtained by counting the number of related pairs of problems that a student put into the same CST group. The pure category was obtained by counting the instances of student-formed groups containing three or more related problems and no unrelated problems. The maximum association score was 24 and the maximum pure category score was four.

The VPST data were simply scored as correct solutions or incorrect solutions. Thus, the maximum score was 12.

The recall data was quantified by examining subjects' recall for each of three components of the problem: its structure, its context, and its question. Stduent responses were categorized as (1) total recall - an essentially complete rendering of the information entirely, or almost entirely, in the original language, (2) "jist" recall - a reasonably accurate rendering of the information, correct in its essential features and language, (3) incomplete recall, or (4) inaccurate recall.

Results

The mean score on the VPST was 8.6 (median = 8.0). On the basis of the VPST scores, the sample was trichotomized into good (VPST $\geq$ 11 N = 16), average (5 $\leq$ VPST $\leq$ 10; N = 37), and poor (VPST $\leq$ 4; N = 14) problem solvers.

The CST data were analyzed with respect to the three problem-solving groups. The data are summarized in Table 2 and indicate a strong relationship between problem-solving performance and CST performance. In general, the results suggest that good problem solvers tended to form groups of related problems on the basis of common problem structure, whereas poor problem solvers tended to form groups on the basis of common problem details.

Insert Table 2 about here

Target Problem 1 was solved correctly by 30 students, and Target Problem 2 was solved correctly by 38 students; 28 students solved both problems correctly. The relationship between RPT pre-solution judgments of relatedness and performance on the Target Problems was examined. Figure 1 summarizes the results for TP1. The data suggest a strong relationship between

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Insert Figure 1 about here

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problem-solving success and judgment of appropriate mathematical relatedness. What is not evident in Figure 1 is the finding that the 13 "good" problem solvers who correctly solved TP1 all made correct structural judgments, and that the three "good" problem solvers who failed to solve TP1 nevertheless made correct structural judgments. Furthermore, only two of the "poor" problem solvers judged TP1S to be related to TP1, and these students judged all the problems to be related since they were "all hard to solve".

The results for Target Problem 2 are summarized in Figure 2. Further examination of the performance of "good" and "poor" problem solvers suggested the same pattern as noted above for TP1.

Insert Figure 2 about here

The general accuracy of the written accounts of students' recall of problem information had been examined in earlier work. In this study, eight students were chosen for interviews immediately following Recall 2. In general, the verbal protocols obtained from the interviews agreed substantially with the written responses. Therefore, only the written data are discussed in this section.

The results of the four recall tasks for Target Problem 1 are summarized in Table 3. The data generally indicate that recall of problem structure was less frequent than recall of other aspects of the problem, except that problem structure was recalled more often in Recall 4 than was problem context.

Insert Table 3 about here

Similar results were obtained for Target Problem 2, except that the structure recall scores were somewhat higher and context recall scores were somewhat lower on all occasions; question recall was about the same for TP2. The higher scores for structure may be due to the "easier" structure of TP2. The structure of TP2 is more explicit in the problem statement; in order to recieve credit for recalling the structure of TP1, a student had to verbalize the implicit structural information contained in the problem. The lower scores for context suggest that the "cover story" of TP1 may be more memorable to seventh graders.

The data were further examined to determine the relationship between recall performance and solution performance for each of the Target Problems. No quantiative scheme for scoring the recall data seemed satisfactory; thus, only descriptive analyses and summaries were undertaken. The data in Table 4 suggest that recall of problem structure for TP1 interacted with solution performance in several ways. In particular, good problem solvers who correctly solved TP1 tended to recall accurately the structure of the problem, even after 4 weeks. Good problem solvers who did not correctly solve TP1 recalled poorly the structure of the problem on occasions 1 and 2 but accurately recalled its structure on occasions 3 and 4. Since unsuccessful problem solvers were not likely to have "seen" the structure, their "recall" might be expected to be inaccurate. The surprising finding is that they were apparently able to extract sufficient structural information from the discussion of the problem's solution in order to produce accurate recall of structure on subsequent occasions.

Insert Table 4 about here

A similar improvement in structural recall was evident for some average problem solvers on the occasion immediately following discussion of problem solutions. But the structural recall by these students four weeks later was generally inaccurate or incomplete. Two of the poor problem solvers also exhibited recall of problem structure in Recall 3 but not in Recall 4.

It should be noted that, although page limitations prevent the data from being included in this paper, the results regarding recall of problem details suggest that poor problem solvers recall other aspects of a problem as well as good problem solvers do. In fact, about one-half of the poor problem solvers were classified as having total recall of the context of TP1 after four weeks, whereas, only one of the good problem solvers was so classified.

A comparison of CST performance with recall performance was undertaken. Since good problem solvers had high structure association CST scores and good recall of problem structure and since poor problem solvers had high details association CST scores and good recall of problem details, the correspondence between the encoding and recall tasks was generally clear for those groups. Nevertheless, it was also clear that some good problems also had good recall of problem details; many recalled the questions and the "jist" of the problems' contexts. Furthermore, the average problem solvers provided instances of variation from the encoding - recall agreement noted for the other groups. In particular, several of the average problem solvers had high details association scores but had good recall of problem structure (one remembered the "jist" of both problems after four weeks). Apparently, the knowledge of problem solutions influenced the match between encoding and recall results.

The influence of the knowledge of the target problem solutions on the solutions of the structurally similar problems was also examined. The performance data for TP1 and TP1S is summarized in Table 5A. A McNemar test for significance of changes, with Yates' correction for continuity (Siegel, 1956), was performed and indicated that students showed a significant ($p < .01$) tendency to perform better on the structurally related problem after seeing a solution to the target problem. The results for TP2 and TP2S, found in Table 5B, also revealed a significant ($p < .05$) tendency to perform better on the structurally related problem.

Further examination of the data revealed that, in the case of TP1 and TP1S, the students who contributed to the significant change were generally the students whose recall had also improved. For example, of the 15 students who solved TP1S after failing to solve TP1, 12 of them (3 good, 8 average, 1 poor) had exhibited improved recall of the structure of TP1 in Recall 3. The remaining three correct solvers were classified as average problem solvers; two had exhibited "jist" recall in Recall 2 but had incomplete responses in Recall 3 and the third had incomplete recall of problem structure on all occasions.

Similar results relating memory for the target problem structure and performance on the structurally related problem were obtained for TP2 and TP2S. Furthermore, the performance and memory data for TP1 and TP1D (and also for TP2 and TP2D) did not suggest any relationship between memory for target problem's details and subsequent performance on a problem that was related in details.

Discussion

The results of this study support the findings of Krutetskii (1977) that good and poor problem solvers differ not only with respect to solution performance but also with respect to the nature of their recall of problem information. In particular, this study supported Krutecskii's finding that highly capable problem solvers tended to recall accurately the structure of a mathematical problem.

Nevertheless, there were some differences between the findings of this study and those reported by Krutetskii. For example, he had reported that good problem solvers tend to forget rapidly all but the structural aspects of a problem after they have solved it; in this study, good problem solvers tended to have accurate recall of problem details in Recall 1, 2, and 3. This result may be due to the fact that Ss were told in this study to remember all that they could about a problem; Krutetskii did not tell his Ss that memory would be tested. Another possible explanation for the difference is that Krutetskii's subjects were more highly capable than those used in this study and that the phenomenon he reported is only observable in "gifted" populations.

Another difference that was found regards his claim that poor problem solvers tend to remember very little about a problem after they have solved it. In this study, it was found that poor problem solvers tended to remember well the question asked in the problem and also the context of the problem statement; some students exhibited highly accurate recall of these aspects even after four weeks had passed. Supported was Krutetskii's claim that poor problem solvers recall poorly the structural aspects of a problem.

Of course, it is not surprising that poor problem solvers perform poorly when recalling structural information about a problem that they failed to solve. Their unsuccessful attempts at a solution probably revealed very little of the problem's structure. The data from the present study extend Krutetskii's general finding by suggesting that the difficulty for poor problem solvers may lie in their lack of ability to notice structure, even when it has been presented in the form of a problem's solution.

The findings of this study suggest that good and poor problem solvers differ with respect to the degree to which they can remember and utilize structural information obtained from a presented problem solution. The pattern of results for the two groups in this study suggest that there exist potentially important individual differences in recall behavior that are intimately related to problem-solving performance. Since some poor problem solvers remembered the details of a problem's statement more accurately than did most good problem solvers, the result clearly suggest the differences in memory for problem structure are not due to general memory differences.

The results relating recall performance and subsequent solution performance on a structurally related problem suggest that significant transfer of information occurred from the target problems to the related problems. Since, at least in the case of TP2 and TP2S, the related problem was somewhat more difficult than the target problem, the data stand in opposition to the findings of Reed, Ernst, and Banerji (1974). The different findings in the two studies may be due to the arithmetic or algebraic nature of the problems used in this study as opposed to the puzzle problem used in the other study. The findings of significant information transfer in this study are in agreement with results obtained by investigators interested in such transfer for isomorphic problems (Luger & Bauer, 1977) and for similar problems and generalizations (Kulm & Days, 1979).

Despite the fact that good and poor problem solvers exhibited the above-mentioned differences, there was one aspect of the testing in which they performed quite similarly. Neither good nor poor problem solvers tended to acknowledge having used information from the target problems when solving the structurally related problems. Since the poor problem solvers tended not to solve either one, this finding is not surprising. But the good problem solvers tended to solve both correctly and might have been expected to affirm an influence of the first solution on the second. One possible explanation for their lack of acknowledgement is that the good problem solvers did not learn <u>how</u> to solve the second problem as a direct result of the solution episode for the target problem; that is, the solution of the related problem was accessible to them independent of the target problem experience.

The group of students for whom the judgments would be most interesting is the set of students who failed to solve the target problem and then successfully solved the related problem. Of those students who failed to solve TP1 but successfully solved TP1S, two of the good problem solvers and four of the average problem solvers acknowledged help from the target problem solution; whereas, one good problem solver, four average problem solvers, and one poor problem solver did not acknowledge help. Further study of this phenomenon should be undertaken, and problems should probably be chosen so that they are somewhat more difficult for the subjects.

Further examination of problem recall as it related to initial perception of problem information ought to be undertaken. The results of one such investigation (Silver, Note 1) suggest that dominant encoding and recall features are not always the same. Similar results were also obtained in this study. Nevertheless, interpretation of the results of these studies is severely limited by the nature of the problems used and the difficulty of the procedures for scoring problem recall. A more promising approach than that used in this study might be interviews and protocol analyses with a smaller number of subjects. For example, in several cases in this study, an assessment of the total information recalled by an interviewed subject might not relate clearly to CST performance, but a positive or negative relationship might be evident if the order of recalled information was considered.

As a first step in this direction, the interviews conducted in this study are being analyzed and the written responses of students, especially those for Recall 4, are being re-analyzed. Of particular interest in the re-analysis will be the responses classified as incomplete or incorrect. If systematic errors can be detected, such findings may contribute to the current debate on the existence of schemata and reconstructive memory processes (Royer, 1977). More generally, the results of the re-analysis should contribute some evidence regarding the existence of problem schemata (Hinsley, Hayes, & Simon, 1977) and regarding the existence of possible differences between encoding schemata and decoding schemata (Mandler & Johnson, 1977).

Reference Note

1. Silver, E. A. Problem-solving performance and memory for mathematical problems: Cue salience and recall. Paper presented at the meeting of the National Council of Teachers of Mathematics, Boston, MA, April 1979.

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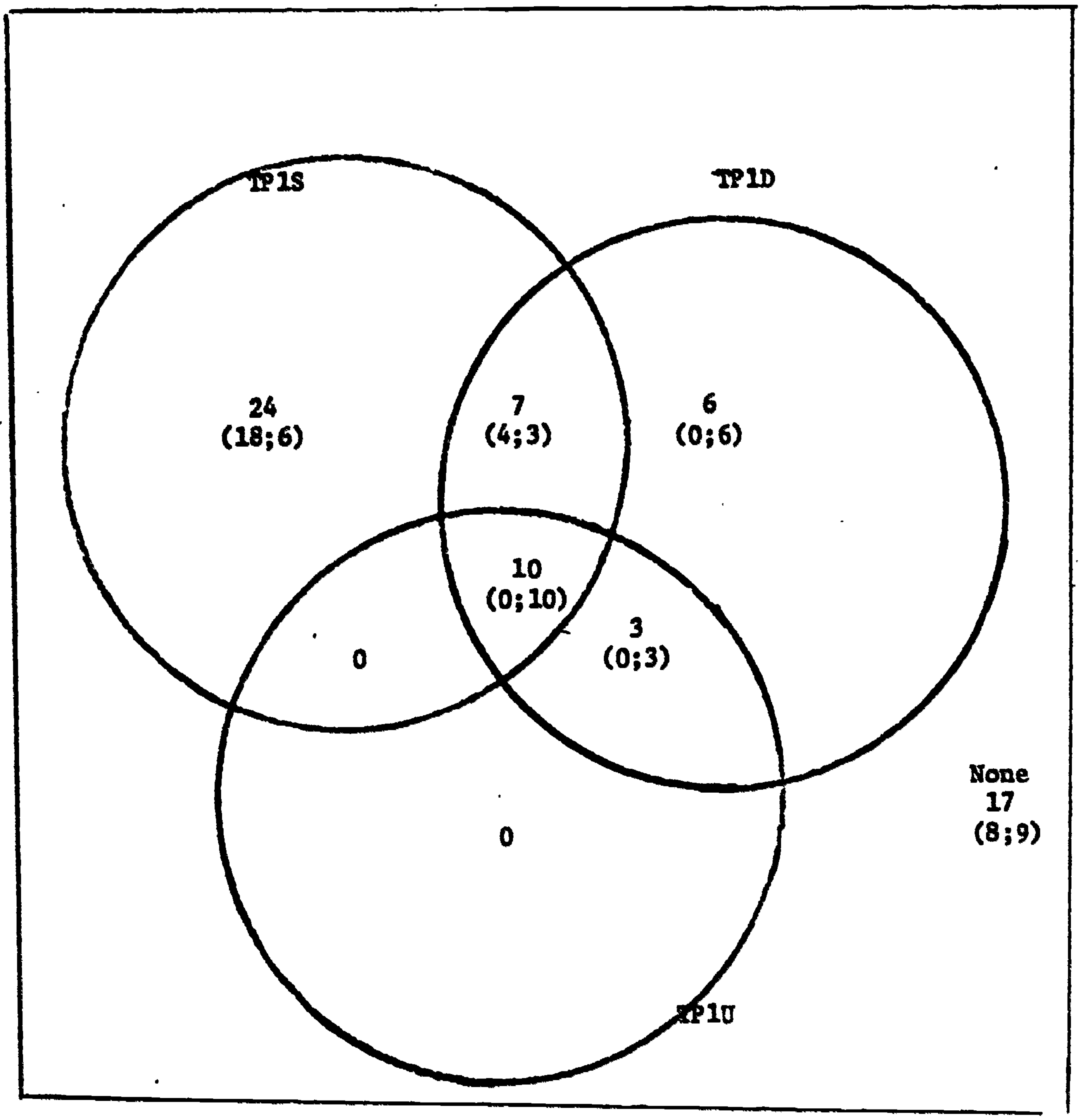

Fig. 1 RPT Judgments for Target Problem 1
[The notation (a;b) is used to denote a successful solvers and b unsuccessful solvers of the target problem judged the indicated problem to be related.]

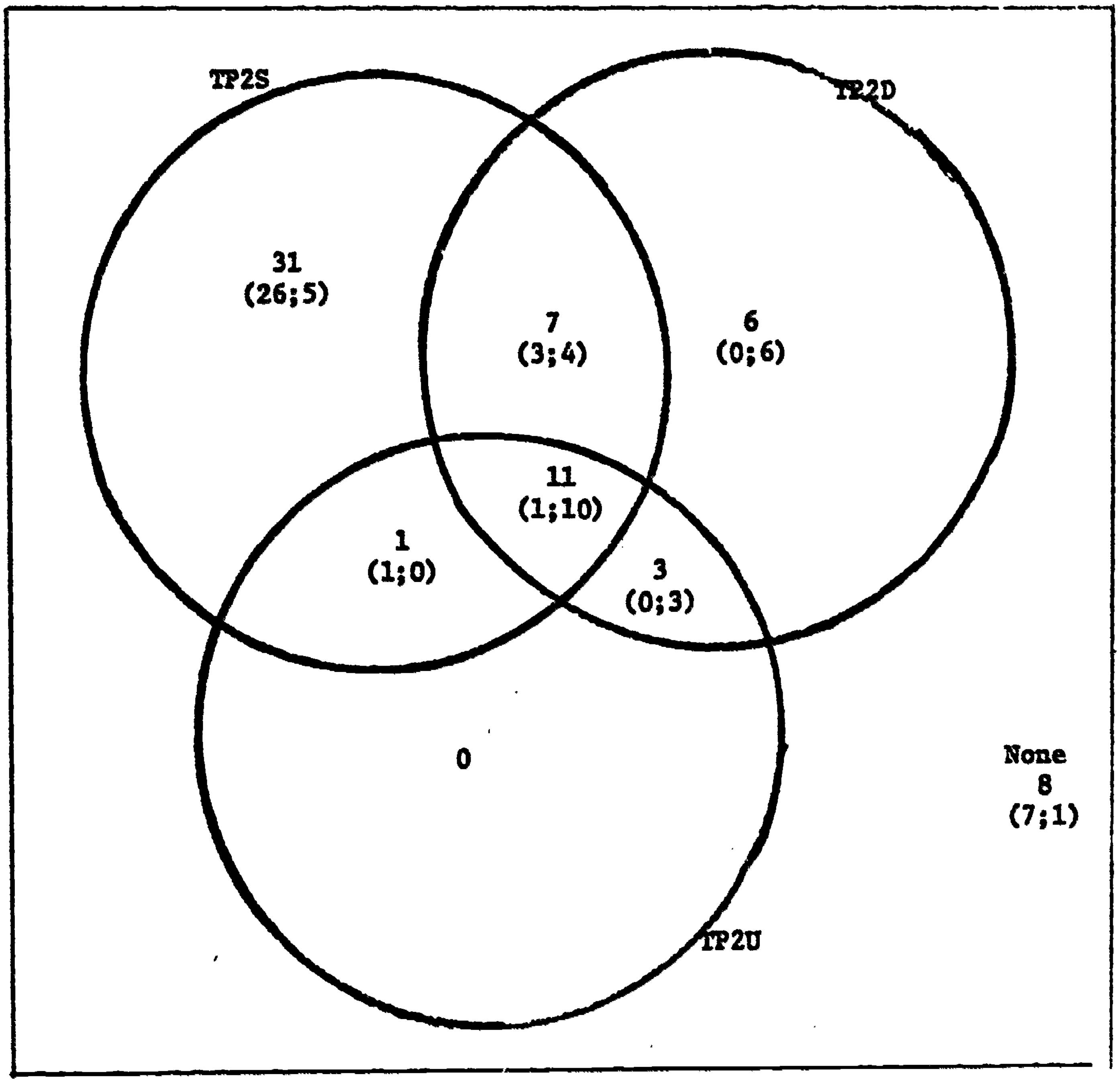

Fig. 2 RPT Judgments for Target Problem 2

Table 1

Target Problems and RPT Related Problems

Target Problem 1 (TP1)	A farmer is counting the hens and rabbits in his barnyard. He counts a total of 50 heads and 140 feet. How many hens and how many rabbits does the farmer have?
Related Structure (TP1S)	Bill has a collection of 20 coins that consists entirely of dimes and quarters. If the collection is worth $4.10, how many of each kind of coin are in the collection?
Related Details (TP1D)	A farmer is counting the hens and rabbits in his barnyard. He counts 6 coops with 4 hens in each, 2 coops with 3 hens in each, 5 cages with 6 rabbits in each, and 3 cages with 4 rabbits in each. How many hens and how many rabbits does the farmer have?
Unrelated (TP1U)	A mother is 31 years old and her daughter is 13 years old. How many years ago was the mother exactly 3 times as old as the daughter was then?
Target Problem 2 (TP2)	Mr. Flank's butcher shop is having a special sale. During the sale, one pound of steak costs twice as much as one pound of bacon, which in turn costs twice as much as one pound of hot dogs. The sale price for one pound of each of these items is a total of $8.75. What is the sale price of one pound of hot dogs?
Related Structure (TP2S)	Three friends compare their record collections. Amy has twice as many records as Betty, who has three times as many as Carol. If the three girls together have a total of 630 records, how many records does Carol have?
Related Details (TP2D)	Mr. Flank's butcher shop is having a special sale. Steak, bacon, and hot dogs are selling for a special price. During the sale, Mr. Flank sells 90 pounds of steak at $3.50 per pound, 50 pounds of bacon at $1.50 per pound, and 60 pounds of hot dogs. He sells a total of $480.00 of these items. What is the sale price of one pound of hot dogs?
Unrelated (TP2U)	There are five differently colored books in a pile. The green one is directly under the blue one and is above the yellow one. The red one is above the brown one but not next to it. The brown book is directly under the green book. Which book is on top?

Table 2

Mean CST Scores by VPST Categories

VPST Category	CST Scores			
	Structure		Details	
	Association	Pure	Association	Pure
	($\bar{X}^a$=12.2)	($\bar{X}^a$=1.8)	($\bar{X}^a$=3.7)	($\bar{X}^a$=0.8)
Good	17.8	3.1	0.6	0.1
Average	12.0	1.8	3.4	0.6
Poor	6.3	0.4	8.9	2.3

[a] $\bar{X}$ denotes grand mean.

Table 3

Percentages of Students Recalling Information for Target Problem 1

Nature of Information		Recall Occasion			
		Recall 1	Recall 2	Recall 3	Recall 4
Structure	Total	22.4	6.0	13.5	0.0
	"Jist"	35.8	37.3	53.7	29.9
	Incomplete or Inaccurate	41.8	56.7	32.8	70.1
Context	Total	35.8	20.9	13.5	6.0
	"Jist"	47.8	55.2	59.7	14.9
	Incomplete or Inaccurate	16.4	26.9	26.8	79.1
Question	Total	32.8	20.9	23.9	10.4
	"Jist"	44.8	46.3	55.2	29.9
	Incomplete or Inaccurate	25.4	32.8	20.9	59.7

Table 4

Structural Recall Performance by Problem-Solving Ability: Target Problem 1

Recall Performance		VPST Category					
		Good		Average		Poor	
		+[a]	-	+	-	+	-
	Total	11	0	4	0	0	0
R1	"Jist"	2	1	9	10	0	2
	Other	0	2	4	10	0	12
	Total	3	0	1	0	0	0
R2	"Jist"	10	0	11	4	0	0
	Other	0	3	5	16	0	14
	Total	10	1	4	2	0	0
R3	"Jist"	3	2	12	8	0	2
	Other	0	0	1	10	0	12
	Total	0	0	0	0	0	0
R4	"Jist"	11	3	5	1	0	0
	Other	2	0	12	19	0	14

[a] + denotes successful solution of TP1; - denotes unsuccessful solution

Table 5A

Performance on Problems TP1 and TP1S

		TP1S Unsuccessful	TP1S Successful
TP1	Successful	1	29
	Unsuccessful	22	15

Table 5B

Performance on Problems TP2 and TP2S

		TP2S Unsuccessful	TP2S Successful
TP2	Successful	2	36
	Unsuccessful	17	12