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ABSTRACT

Current research continues to attempt to determine factors, or combinations of factors, which influence efficacy in problem solving behaviors. This presentation combines several viewpoints regarding the most important component, or combination of components, needed for the most successful problem solving behaviors to occur. Quantitative literature is reviewed in the area of problem solving with emphasis in both: (1) the interacting influence of strategies and knowledge, and (2) the influence of strategies independent of knowledge. Findings suggest that knowledge permits an individual to engage in higher levels of reflective thinking or metacognitive strategies. With knowledge, the problems can be represented more completely. A more complete representation allows for more efficient and effective reflective monitoring of the problem solving process. It appears that the reflective thinking processes, which encourage elaboration on a problem, are instrumental in producing the most efficient problem solving behaviors. Findings suggest that these metacognitive strategies need to be specifically taught to students. Also of interest, is the finding which suggests that use of examples of problem solutions facilitates transfer to analogical problems. (Contains 17 references.) (Author)

The Role of Strategies and Knowledge in Problem Solving: A Review of the Literature

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Running head: PROBLEM SOLVING

Abstract

Current research continues to attempt to determine factors, or combinations of factors, which influence efficacy in problem solving behaviors. This presentation examines several viewpoints regarding the most important component, or combination of components, needed for the most successful problem solving behaviors to occur. Quantitative literature is reviewed in the area of problem solving with emphasis in both (1) the interacting influences of strategies and knowledge, and (2) the influence of strategies independent of knowledge.

Findings suggest that knowledge permits an individual to engage in higher levels of reflective thinking or metacognitive strategies. With knowledge, the problem can be represented more completely. A more complete representation allows for more efficient and effective reflective monitoring of the problem solving process. It appears that the reflective thinking processes, which encourage elaboration on a problem, are instrumental in producing the most efficient problem solving behaviors. Findings suggest that these metacognitive strategies need to be specifically taught to students. Also of interest, is the finding which suggests that use of examples of problem solutions facilitates transfer to analogical problems.

The Role of Strategies and Knowledge in Problem Solving: A Review of the Literature

Recent research evaluating the role of strategies and knowledge in problem solving indicates that success in problem solving requires the ability to competently use and combine the most efficient strategies while eliminating the less useful ones. Additionally, one must be able to reflect on possible problem solution strategies and determine which of these solutions would be most useful in arriving at a particular problem solution. Thus, effective problem solving behaviors includes "both a strategic and metastrategic component." (Peverly, 1991, p. 77; Swanson, 1990; Brown & Kane 1988). In addition, the knowledge and skills of the problem solver influence and interact with strategic and metastrategic components of problem solving (Lehrer & Littlefield, 1993).

Some researchers are interested in the nature of the progress toward effective problem solving by observing a subject's selection choice of a more or less efficient strategy. (England, 1992; Swanson, 1990). Researchers have also investigated the nature of the progress toward effective problem solving by comparing problem solving abilities between the expert and the novice in a particular field of knowledge (VanSickle & Hoge, 1991; Novick 1988).

Other studies focusing primarily on the evaluation of the efficacy of general executive strategies during problem solving tasks are interested in the effects of these strategies on the process of problem solving. These executive strategies include defining a problem, considering alternative strategies, considering the probable outcomes of those strategies, and monitoring progress through the process. Researchers continue to examine either the effects of these domain general strategies and/or domain specific strategies as an entire process on problem solving, or the effects of a particular strategy on the process of problem solving.

Still other researchers support the view that knowledge and not the use of strategies, both domain general and domain specific, plays a primary role in the nature of problem solving abilities (knowledge-based position). A comparison between a earlier study and a more current study (Delclos & Harrington, 1991) suggested that improved performance in problem solving due solely to use of examples, practice, and feedback on performance of practice examples when learning a new domain/area, can be expected without special training in problem solving. Schauble (1990) supported this finding in her study. Even though the children in her study haphazardly explored through the problem space given them, Schauble noted improved progress toward problem solving in children receiving feedback as they were allowed explore the effects of their problem solving decisions.

Finally, findings by others (Peverly, 1991; Swanson, 1990; VanSickle & Hoge, 1991; Brown & Kane, 1988; Lehrer & Littlefield, 1993), report data to support the interaction of domain-specific knowledge and strategies, and domain-general knowledge and strategies as contributors to problem-solving competency. Lehrer and Littlefield (1993) examined the relationship between cognitive components such as working memory, knowledge, and metacognition that influence problem solving and the transfer of problem solving skills. Rebok (1987) reports research which reveal that greater knowledge facilitates more efficient metacognitive abilities and more efficient problem solving behaviors. However, even with prior information, VanSickle & Hoge (1991) report studies which demonstrate the importance of explicit teaching in organizing knowledge and relating metacognitive knowledge and skills to knowledge. In describing the relationship between knowledge and strategies used to monitor the problem solving process, Peverly (1991) states that studies indicate that "the ability to learn and profit from self-control training is modulated by the knowledge and skills the learner brings to the situation" (p.82). It is the purpose of this paper to review and critique current literature concerning the role of strategies and knowledge in problem solving and the interaction between the role of knowledge and strategies in problem solving.

Summary of Research Results

Interacting Influences of Strategies and Knowledge

Peverly (1991) notes that "the data argue for the theoretical integration of knowledge, related strategies, weak-general strategies (e.g., rehearsal), informedness [how the strategies can be used most efficiently], and executive control processes." (p. 82)

English (1992) studied the nature of the progress toward effective problem solving in young children. He evaluated the interaction between domain-specific knowledge and general strategies in young children. Further, he examined the nature of that interaction. In this study, children of varying ages from 4 years 6 months to 9 years 10 months (developing children from preoperational to concrete operational children according to Piaget) were given combinatorial problems of increasing difficulty requiring them to dress toy bears in various combinations of outfits. English evaluated children's problem solving activities on three dimensions: (1) knowledge in combinatorial domain (knowledge strategies) reflected in item selections and success in arriving at "different outfit" combinations, (2) general strategies (executive control processes) reflected in the children's scanning actions which monitored their progress toward goal attainment and (3) goal attainment reflected in the degree of success in achieving the goal. English determined that the toy bear task was an appropriate task which would test the interaction of domain-specific knowledge (combinatorial mathematics) and general strategies (monitoring strategies of progress toward task completion).

The results of the study demonstrated that older children used more sophisticated combinatorial strategies, and more sophisticated general monitoring strategies as they progressed toward more difficult problems than the younger child. The study indicated that there was a significant association between the children's choice of combinatorial strategies and their use of general monitoring strategies for each problem and for each age group. In the older child, the use of certain levels of combinatorial strategies required the use of certain general monitoring strategies for successful goal attainment. These combinations were chosen by the older child for successful goal attainment. The most effective problem solvers were those who had sufficient domain specific knowledge to solve the problem, but also engaged in the sophisticated monitoring strategies required for goal attainment. Others (Swanson, 1990) have found the same results.

Brown and Kane (1988) investigated the interaction of reflective strategies and new information in developing a positive learning set or a "mind set to look for analogies" (p. 498) in problem solving. Novick (1988) explains that when we encounter a new problem (a target problem), a good strategy to use involves reaching into our memories to find a similar problem we solved in the past (a source problem), and try the same solution procedure on the new problem. This is an analogical transfer. Brown and Kane (1988) demonstrated that preschool children as young as three could be taught a "guiding principle" (p. 495) (problem solution) through an example of its use in a source problem; and then, they could transfer the problem solution to an analogous target problem. In the first of a series of studies, 3, 4, and 5 year olds were taught solutions to different types of problems using pairs of short narratives. Each pair was analogical, requiring the same problem solution. Each set of narratives required a different solution from the other two. There were three pairs or sets of analogical narratives. The researchers were attempting to teach the children to develop a mind set to look for analogies between each narrative in the pair. Through the mind set, transfer of the problem solution from the first narrative in the pair to the second narrative in the pair was anticipated. Each age group was divided into three groups: a reflection group, a non-reflection group and a control group. The reflection and non-reflection group were shown the solution to the problem of the first narrative. The reflection group was encouraged to tell the similarities between the two problems or to reflect on the problem similarities. There was no discussion of the solution in the non-reflective group. The control group was not shown a solution. The three year olds benefited from the reflection. The older children were able to make the transfer after experiencing the solution through the first narrative. The three year olds also required more experience using the reflective process before they understood the idea of creating a mind set to look for analogies. There was a significant difference between the control group of all three age groups and the non-reflective groups demonstrating the benefits of the example in transferring the problem solution to the analogical narrative. In subsequent studies, Brown and Kane demonstrated that even with more abstract themes, the children were equally successful in transferring problem solutions. In the final studies, Brown and Kane compared transfer effects of four year olds who were assigned to one of three groups: those given an abstract rule (problem solution) and an example of that rule, those given a rule only, or those given an example only. The results of this study revealed that having examples is better than having the rule. Having a rule and the example was only significantly better when the child was required to state the rule through a reflection process.

Concluding, Brown and Kane (1988) stated that if knowledge and capacity (mental) are held constant, older children are more efficient problem solvers because of their abilities to reflect on problem solutions and draw analogies which facilitate transfer to new but analogous problem situations.

Novick (1988) studied the effects of analogical problem transfer in novice and expert subjects. The researcher stated that reasons why conflicting results are revealed in the literature regarding a subject's ability to make an anological transfer unless directly told to do so involve the characteristics of the analogical problems. If the two problems are similar in surface features (are perceptually similar), both novice and expert will draw the analogy and be able to solve the problem. If the two problems are similar in structural features alone (are similar in an abstract relationship), the expert may draw the analogy but the novice will not due to lack of knowledge in the domain. The novice, not having sufficient knowledge, will rely on surface features and represent the problem poorly. He will be unable to see or draw the relationships between the analogical problems. A subject's representation of the problem is a source of retrieval cues. If the representation of a source is poor, the retrieval cues will be poor. The subject will not search his memory for the source problem as a means of solving the target problem. Since retrieval cues for novices are perceptually based, they will fail to draw analogies between problems without similar surface features. The retrieval cues for experts have good representations of the source problem and thereby have a variety of retrieval cues for an analogical problem. Novick (1988) studied positive transfer (drawing an analogy between two problems correctly) and negative transfer (making an analogical transfer between two problems incorrectly) in novice and expert subjects through a series of studies. Negative transfer is observed when two problems are alike superficially in surface structure but not in underlying relationships (structural features). She divided the subjects in her study into two groups, a novice and expert group according to the math section of the Scholastic Aptitude Test. Each of these groups were again divided into a baseline group and a remote analogue (analogical problems alike in structural features, but not in surface features) group. In the first of her series of studies, each baseline group solved four unrelated problems to the target problem. The analogical groups (novice and expert) were given three foil problems (unrelated to the target problem) to solve and given a problem which would serve as a source problem to solve a remote analogical target problem given later. All students were assisted in solving the problems. Each student was asked to rate the problems from more to least difficult in an effort to facilitate memory of the procedures used to solve each problem. All students were then given the target remote analogical problem to solve without assistance. The results revealed that experts benefited from the source problem, but novices did not, suggesting that the novice, relying on surface structure, was unable to draw the analogy. The expert, however, with his clear representation of the problem space was able to solve the problem. In the second study, Novick examined negative transfer. The subjects participated in one of two conditions: a distractor or baseline. In the baseline four foils were given to solve. In the distractor condition, the subjects were given three foils and one problem which was superficially but not structurally similar to the target problem. The findings in this study demonstrated that even the experts were influenced by the distractor suggesting that a more complete representation of the problem space did not mediate their ability to see the superficiality of the distractor. In the third experiment, Novick (1988) explored the results of her second experiment. In this experiment a distractor and an remote analogue were given. Negative transfer was significantly less for the expert. In addition, the novice persisted longer in the use of the incorrect procedure of the distractor problem in solving the target problem. In concluding, Novick states that analogical problems do help solve new problems. Level of expertise has a predictable effect on analogical problems particularly when the problems are alike in structural features only. Finally, Novick cites research by others which suggests that experience with analogical reasoning facilitates expertise. This suggests that analogical reasoning may serve as a metastrategic strategy in developing problem solving skills. Thus, there is evidence that an interaction between knowledge and strategy skills exists in analogical reasoning.

Schuable (1990), in studying the effects of the beliefs of children, noted that the beliefs of children can impede transfer of new information to a new problem in that the prior belief may serve as a source of bias. Schauble (1990), suggested that children frequently have difficulty incorporating new knowledge they obtained in problem solving to progress toward more effective strategies, particularly if the new knowledge disconfirms a previous belief.

An interesting observation regarding the transfer of a problem solving strategies noted in several studies (English, 1992; Schauble, 1990), was the regression in the use of a more advanced problem solving strategy to a less advanced solution strategy when solving an increasingly more difficult problem.

Researchers (English, 1992; Schauble, 1990; Brown & Kane, 1988) suggest that the regression may be attributed to an insufficient understanding or knowledge in the application of the solution in more difficult tasks. Peverly (1991) cites other research (Kuhn et al. 1989; Klahr and Dunbar 1988) which supports these same findings in the adult population.

Swanson (1990) investigated the influence of metacognitive strategies and aptitude on problem solving. Swanson (1990) evaluated the influences of general knowledge (as measured by aptitude tests) and metacognitive awareness on problem solving abilities. He first separated a group of children in grades 4 and 5 according to aptitude. High aptitude was judged as gifted and low aptitude was judged to be average to low abilities. Secondly, he divided the children in terms of metacognitive knowledge as measured by a questionnaire which evaluated metacognitive awareness from most efficient to least efficient. The children were to respond to questions such as, "Ryan is 5 years old and knows all about dinosaurs. Ryan's father does not know a lot about dinosaurs. If both Ryan and his father read a book about dinosaurs, who would remember the most? Why?" (p. 308). Finally, problem solving tasks were administered. The children were to solve the problem while using a "think aloud" protocol. The responses were classified in terms of the types of general and specific strategies the children use. The general strategies included components such as defining the problem, organizing and interpreting information.

Specific strategies used were those such as hypothetico-deductive reasoning (if-then constructs) and evaluating (checking the effectiveness of the strategy).

The results of Swanson's (1990) study revealed that students with high metacognitive knowledge and low aptitude outperformed those with high aptitude and low metacognitive knowledge. Swanson concluded that high metacognitive skills can compensate for overall ability by providing certain knowledge about cognition.

In addition, Swanson found that individuals higher in metacognitive skills, irregardless of aptitude, used more advanced strategies in problem solving and took fewer steps to solve the problems. The advanced strategies chosen by those high in metacognitive skills which were most strongly associated with efficient problem solving were hypothetical-deductive and evaluation strategies. Aptitude knowledge appears important only if a student uses lower metacognitive problem solving strategies. Swanson pointed out that students high in aptitude and use of advanced metacognitive strategies have a greater variety of strategies than the other groups making them the most proficient problem solvers.

More recent research conducted by Swanson (1992) further investigated this last finding. Swanson was interested in whether gifted children have a "performance advantage [which] reflects higher metacognitive skills" (p. 43) over children of average intelligence. In addition, he predicted a qualitative difference in metacognitive and problem solving skills between the groups. In this study, he followed the same basic method as in the previously cited research. His findings revealed that gifted children exhibited greater metacognitive skill than children with average intelligence, specifically in their ability to identify "somebody who is an effective problem solver" (p. 47), and in their ability to identify effective strategies for solving problems. In addition, his results revealed that "problem solution, metacognition, creativity and intelligence are weakly correlated" (p. 47) for the gifted, but are significantly correlated for the groups with average intelligence. According to Swanson (1992), these findings suggest that weak metacognitive skills weakens the efficiency of the other constructs. In the gifted, the higher metacognitive abilities allow all the other constructs to operate maximally, and therefore, more independently of one another.

With greater access to computers in the classroom, researchers are also interested in the influence of computer programming knowledge on problem solving strategies, and in whether children can transfer problem solving skills learned in programming to other contexts. Some research (Watson, Lange, & Brinkley, 1992; Clements, Natstasi, & Swaminathan, 1993) suggests that children as young as four and five can gain sufficient mastery of a computer system to learn simple problem solving programing skills. Literature reviews (Clements, et. al, 1993) indicate that knowledge and experience in the use of problem solving software such as Logo, increases strategic, metastrategic, and higher level thinking skills, which in turn produces gains in problem solving behaviors. Gains are particularly noted when the teacher assists in guiding the children's reflective thinking skills through "questioning, modeling, prompting" (p. 60), or or when the children are allowed to work in peer collaboration groups which also encourages the continuous monitoring of their progress toward the goal. Clements, Natstasi and Swaminathan (1993), report research stating that lower ability children prefer drill-type software over problem-solving software; however, teacher assistance in "mediating children's interaction with the computer" (p.60, 62) provides the structure lower ability children need in order to use the problem solving software effectively.

Lehrer & Littlefield (1993) used Logo, a computer language designed to teach problem solving strategies and math concepts, to study the nature of the relationship between cognitive components used in Logo problem solving. In the initial portion of their study, the researchers assessed forty-eight second grade students for (1) mental skills (spatial and verbal working memory, and short-term memory), (2) for domain specific knowledge of Logo programming (3) working memory for Logo, (4) executive control processes or metacognitive abilities evidenced by success in "detecting, describing, and repairing program errors or bugs" (p. 319) which requires the use of metacognitive skills involved in "procedural thinking typical of programming experiences"

(p. 319), (5) problem solving evidenced by performance in Logo relative to the ability to predict and solve Logo problems and (6) the ability to transfer problem solving skills to four contexts related to Logo.

A path analysis revealed that performance in Logo or problem solving skills are significantly influenced both directly by, and through the interaction of, cognitive components of working memory, knowledge, and metacognition. In addition, these components influenced the transfer of knowledge gained from Logo to other related problem solving contexts.

A secondary goal of this study was devoted to evaluating the effects of differential training on transfer of problem solving skills to a complex programming task. The authors were primarily interested in examining the effects of teaching a bridging strategy between problems solving skills used in Logo and the use of these same skills in a non-Logo environment. The researchers assigned forty-eight second grade students to one of two "instructional conditions: macrocontext or microcontext" (p.320). A macrocontext condition is defined as one where children are taught to bridge problem solving skills learned in Logo to novel contexts. In a microcontext, the children only use problem solving skills in the context of Logo programming. The microcontext group served as the control group. In this study, in contrast to others cited by Lehrer and Littlefield (1993), improvements in problem solving efficiency was not noted for the experimental group over the control group following mediated instruction in the use of the strategies learned in Logo when transfered into other problem solving situations.

Influence of Strategies Independent of Knowledge

Peverly (1991) reports that there is a sufficient number of methodologically sound research to support the contribution of strategies independent of knowledge in problem solving. The format conducive to such analysis is a training study (Peverly, 1991). In one such study, Delclos & Harrington (1991) presented the view that although many studies demonstrate the importance of training in general problem solving skills, this training is not sufficient to develop efficient problem solvers. To efficiently use facts and strategies during problem solving activities, students must implement explicit strategy monitoring during problem solving behavior. Students must engage in an ongoing process of evaluation toward their progress in achieving the desired goal. This evaluation is an ongoing process of strategy monitoring. Delclos and Harrington (1991) using a problem solving computer software program called Rocky's Boots (RB; Robinett, 1984), found that for complex problems, students trained in general problem solving skills and self-monitoring training skills (MPS) outperformed those who received training in general problem solving skills only. This finding is consistent with Peverly's (1991) conclusion that strategic competence develops from the ability to reflect upon and to control strategies. The study also demonstrated that the students trained in problem solving strategies outperformed a control group which only received the procedural training in the Rocky's Boots program which was provided to all groups. Results of the study (Delclos and Harrington, 1991) additionally revealed that those MPS subjects performed more complex problems faster than either of the other two groups and, in fact, in less time than they needed to perform the less complex problems. These results suggest that the MPS group had developed a more efficient and a "qualitatively different" (p. 41) level of problem solving. These results are consistent with those found by English (1992). The authors concluded that the monitoring task did not appear to encourage more complex problem solving strategies, but primarily forced the child to reflect on his chosen strategy in view of other possible alternative strategies.

King (1991) reported the effects of strategic questioning on problem solving using a peer interaction technique. Although some research (Ross, 1988), does not demonstrate the benefits of peer interactions in problems solving, many do. King (1991), and others (VanSickle & Hoge, 1991) noted that peer interaction could provide a framework where monitoring of the strategies used in the problem solving process can be continuously presented, considered, reevaluated, and modified in terms of each partner's perspective. Specific strategic questions were designed to clarify/redefine the problem, access prior knowledge and consider a variety of options. These questions were taught to an experimental group to guide students questioning. King's

(1991) results agreed with Delclos and Harringtons's (1991) findings. Training in strategic questioning significantly influenced the students abilities to problem solve and facilitated transfer of the training to novel situations. King reported data revealing that the experience gained through the dyadic problem solving experience transferred to individual problem solving tasks.

The results of King's (1991) study also revealed that there were no differences between the control group's problem solving skills and those of an experimental group instructed to merely engage in questioning when problem solving. King (1991) concluded as others have (Peverly 1991; Delclos and Harrington, 1991) that training in strategic questioning encouraged reflective thinking or elaborated explanations of the problem solving process. She further supposes that the elaborations encourage a change or reconceptualization in the quality of thinking about the problem and even encourages a higher level thinking than the individual ordinarily uses. Others agree (Delclos & Harrington, 1991).

Recent research (King & Rosenshine, 1993), which examines the construction of knowledge using a guided cooperative questioning strategy, continues to support that the "integration-type questioning and explaining" (p. 140) of material facilitates the reconceptualization of information.

Ross' (1988), studies, however, did not demonstrate the benefits of cooperative learning over a whole class approach on improving problem solving. In the study the subjects were divided into three groups: (1) a whole class group which consisted of the teacher taught problem solving strategies and the students worked individually, (2) the cooperative learning group (incentives were given based on group performance) which consisted of teacher instruction in the strategies of problem solving followed by peer interaction solving a problem, (3) the control group which consisted of no explicit direction or encouragement for developing problem solving skills. The students were expected to learn problem solving skills incidentally. Although there was a difference between the control group and the other two, the effects of cooperative learning group over the whole class group was not realized.

Critique of the Literature

Peverly (1991) argues that research supporting a strong knowledge based approach minimizing the influences of the contribution of strategies is problematic. First, Peverly states that there are methodology problems in many studies supporting the knowledge-based position and second, there are sufficient studies to support the influence of strategies independent of knowledge.

Peverly (1991) criticizes single level tasks as a means of determining the nature of problem solving in research supporting a knowledge-based position. If it is agreed that problem solving behaviors only emerge when a task is novel and moderately difficult, then problem solving behaviors in individuals can only be examined when the task is "equally effortful or effortless" (p.75) for individuals with differing expertise in a domain.

On the other hand, Peverly (1991) criticizes those who strongly support domain-general strategies for not eliminating the confounding elements of knowledge/ability as responsible contributors to successful problem solving.

Peverly (1991) praises training studies as suitable for the study of the effectiveness of strategies apart from knowledge. The studies must be systematically controlled for eliminating the effects of knowledge and produce effects of maintenance and transfer in order to be considered worthy of evaluating the contribution the strategy played in problem solving.

Critique of Studies On Interaction of Strategies and Knowledge

English implemented methodology consistent with well designed research in his study. First, his use of a single-level test of increasing difficulty for each age level was considered appropriate because the focus of his study was on development or progression toward problem solving. With age, and hence domain-specific knowledge for combinatorial problem solving, strategies used during problems solving would be different at different levels. Others (Peverly 1991) support this methodological approach. He also made certain that even the youngest came in with the basic domain general information through a familiarization task, but gave no information that could bias their performance on combinatorial mathematics.

Brown and Kane's (1988) study appeared to use sound methodology. Control groups were established. Confounding effects of prior knowledge in a specific domain was controlled by choosing tasks that children could understand but did not have in prior experiences. Lack of the prior experience was established through the control groups and pilot studies. In addition, through subsequent studies, Brown and Kane altered the task demands in examining the interacting effects of new information, reflection, and transfer in order to isolate factors which influenced the results.

Novick's study (1988) was well developed through multiple studies as well. The study was primarily a knowledge based study evaluating the effects of varying levels of expertise and ability to solve problems through analogical reasoning. Although she used a single level difficulty design, Novick's primary concerned with the methodology of other researchers who were showing conflicting results demonstrating that analogical problems do not transfer to new problems. Some research was using remote analogies with novices and then reporting that transfer through analogy did not benefit problem solving. Her research demonstrated that even remote analogical transfer would occur given sufficient expertise in a domain. Her research also used control groups.

Swanson (1990) investigated the relationship between aptitude and use of metacognitive strategies on problem solving behaviors. He used a questionnaire, validated as an appropriate measure of metacognitive awareness in a pilot study, to divide the children into groups of high and low metacognitive knowledge. The questionnaire was reportedly used and developed by Kreutzer, Leonard and Flavell in 1975, and Myers and Paris in 1978 as an appropriate assessment of metacognition (Swanson, 1990). Two items on the questionnaire were not used in the analysis of metacognitive skills because they required actual problem solving skills. The authors argued that such a question type does not directly assess metacognitive skill. Others (VanSickle & Hoge, 1991), however, have reported the use of "think aloud" protocol to assess metacognitive skills. It might be argued that the children could have been equally assessed for metacognitive awareness/abilities by a questionnaire which asked the children how they would solve a specific problem. Swanson himself noted one short coming of his study: that of having a small representative sample in one of his groups. A final problem with the study involves the use of the word "smarter" in the definition of metacognitive abilities. The children were given the word "smarter" to define the person who exhibits greater metacognitive awareness. Even though the authors state that their pilot study suggested that children associate smartness with effective problem solvers, it is still felt that the suggestion of general overall knowledge might be a confounding factor in a child's definition of metacognitive abilities, particularly for those with lower intellectual abilities. A clearer definition might have been "the person who can 'figure out things' more effectively". It is felt that further investigation of the use of the term "smarter" is justified particularly in light of Swanson's (1992) finding of a significant person variable, ie. "knowledge about somebody who is an effective problem solver" (p. 47) when assessing components of metacognitive abilities.

Lehrer & Littlefield (1993) carried out an impressive study to assess the cognitive components influencing and interacting with problem solving skills and the transfer of problem solving skills. Many measures were used to examine this relationship. With the exception of an initial achievement test, the short term memory test, and an analogical reasoning test, the measures were either researcher constructed, or found in previous Logo literature. The reliability reported was high for all measures. The actual validity for each measure was not always reported in the study.

In regard to the study using two instructional approaches (macrocontext and microcontex) to evaluate the effects of transfer of Logo problem skills to other contexts, the authors, noted several possible reasons for the nonsignificant outcome between the two groups. First, the control group spent time interacting with the computers while the experimental group received macrocontext instruction. Working with the computer may have influenced transfer. Secondly, the children may have been too young to fully understand significance of the problem solving strategies themselves apart from the Logo situation. Thirdly, all the children performed many problem solving tasks in the process of learning Logo. These tasks may have facilitated transfer strategies. Another aspect not mentioned by the authors might have been that the final tasks using problem solving skills learned in Logo was a computer programming task. All children had training and a variety of experience in this area. The macrocontext instruction the experimental group received, however, had nothing to do with computers. Instead the children were taught how to apply problem solving skills learned in Logo to solve any type of problem with which an indiviual might be confronted. It seems that it might have been more appropriate to ask the children to use problem solving skills learned in Logo in a task which did not involve computer programming to evaluate transfer of general problem solving skills to everyday problems.

Critique of Studies On Strategies Independent of Knowledge

In the Delclos and Harrington (1991) study which set out to determine the effects of self-monitoring skills and general problem solving skills on the problem solving, it is questioned to what extent knowledge was a factor in comparing the performance of control group with both experimental groups. Both the PS and MPS groups were shown how to use the problem solving techniques of redefining and clarifying a problem with a particular strategic element (knowledge) to solving a problem in Rocky's Boots, ie. Realize a title "un-blue" means eliminate all blues from your solution. The control group was not given this information.

In comparing the PS and the MPS groups, the MPS group was reminded/cued to check the "title of the game". In fact the authors noted that checking the title was one of the most frequently used strategy. Perhaps this research might have been strengthened further in determining the effects of general problem solving strategies and strategies in monitoring the process by (1) eliminating specific references to the Rocky's Boots program when demonstrating exemplars of general problem solving strategies and by (2) eliminating cuing during the monitoring process. In addition, skills might have been validated for transfer to other computer application situations.

On the other hand, the King (1991) article which revealed essentially the same findings as the Delclos and Harrington study (1991), was a carefully designed study. The material used to teach the task was different from the material used to evaluate efficiency of the strategy. Thus, the results were not confounded with the influence of knowledge. Her study demonstrated validity for transfer. The strategic questions were general and transferable to novel situations. Controls for time spent in training were equal for all groups to prevent confounding the results.

Ross (1988) himself critiqued the lack of support for cooperative learning over a direct instruction technique with four main points. First, he stated that the students may not have had sufficient time to master the problem solving techniques facilitated by cooperative learning because of the time required to interact with one another. Second, he stated that some students rely on others to do most of the work in learning/teaching problem solving techniques, and thereby do not learn the techniques sufficiently themselves. Third, since all were learning the technique, perhaps there was not a competent leader to tutor the others in the group. Fourth, perhaps the students were too young to engage competently in elaborative type behaviors characteristic of effective cooperative learning groups.

Concluding Comments

The studies reviewed in this paper, suggest that although knowledge or new information made available to the individual may impede problem solving particularly when the individual does not have complete understanding of the application of that knowledge, it primarily serves to facilitate problem solving. Information may facilitate an individual's ability to engage in higher cognitive levels of reflective thinking or metacognitive strategies. They may have a more complete representation the problem and thereby be able to plan, consider, and evaluate alternative solutions to a problem more efficiently and effectively. In addition, examples of the problem solution facilitate transfer to analogical problems. Indeed, Novick (1988) states that "much of our cognitive activity does depend on our ability to reason analogically." (pg 510)

When new information and domain specific knowledge are held constant, it appears that the reflective thinking processes which encourage elaboration on a problem are instrumental producing the most efficient problem solving. It also appears important that these metacognitive strategies be specifically taught. Research (King, 1991) demonstrates that the use of elaborations encourage a change or reconceptualization in the quality of thinking about the problem.

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Teacher Strategies for Facilitating Problem Solving Behaviors

1. Use examples, practice and feedback on performance on practice examples when learning a new area.

2. Let children explore a problem space giving them feedback regarding their problem solving decisions.

3. Increase knowledge/expertise in an area. This improves the benifit of self-monitoring techniques.

4. Integrate knowledge, domain specific strategies, weak-general strategies (rehersal), importance of the use of the strategy (informedness), and monitoring progress toward goal achievement (executive control processes).

5. Use analogies to help solve new problems
   a. Use analogies that are perceptually similar for the young child and for the novice.
   b. Require children to state the rule learned from the analogy through a reflection process.
   c. Provide a good representation of the problem space (provide background knowledge)

6. Use analogies as a metastrategic strategy to develop problem solving skills.

7. If a child regresses in his problem solving strategy, it may be that he has insufficient understanding or knowledge in the application of the solution in more difficult tasks, so provide the needed information.

8. Provide children with metacognitive strategies to help compensate for a lack of overall ability (intelligence).

9. Help children understand/use hypothetical-deductive (if-then) and evaluation (strategy checking) strategies.

10. Help children monitor their progress (reflect) toward the solution during problem solving behavior.

11. Use peer interaction techniques. They provide a framework where monitoring of the strategies used in the problem solving process can be continuously presented, considered, reevaluated and modified. Be careful that sufficient time is provided for the interaction to take place.

12. Use problem solving programming software with peer collaboration techniques.

Research findings:

1. Success in problem solving reqires the ability to competently use and combine the most efficient strategies while eliminating the less useful ones.

2. Problem solving can be improved solely through use of examples, practice and feedback on performance.

3. Greater knowledge in an area facilitates more efficient metacognitive abilities and more efficient problem solving behaviors.

4. Explicit teaching in organizing knowledge and relating metacognitive knowledge and skills to knowledge improves problem solving.

5. Research supports theoretical integration of knowledge, related strategies, weak-general strategies (e.g., rehersal), informedness, and executive control processes." (Peverly, p.82)

6. Older children use more sophisticated strategies, and more sophisticated general monitoring strategies as they progress toward more difficult problems.

7. The most effective problem solver are those who have sufficient domain specific knowledge to solve the probvlem, but also engaged in teh sophisticated monitoring strategies required for goal attainment.

8. Young children can be taught a problem solution through an example of its use in a source problem (a problem solved in the past); then by transferring the problem solution to an analogous target problem.

9. Young children (3 years) benifit from reflecting on solutions of source problems, but older children make transfers of source problems to target problems just by being told the solution.

10. Examples of solutions to a type of problem are better than learing the abstract rule.

11. Learning a rule and the example is only significantly better than example only when the child is required to state the rule through a reflection process.

12. If knowledge and capacity (mental) are held constant, older children are more efficient problem solvers because of their abilities to reflect on problem solutions and draw analogies which facilitate transfer to new but analoguous problems situations.

13. Anaogical problems do help solve new problems.

14. If two problems are similar in surface features (are perceptually similar), both novice and expert will draw the analogy and be able to solve the problem.

15. If the two problems are similar in structural features alone (are similar in an abstract relationship), the expert may draw the analogy but the novice will not due to lack of knowledge in the domain.

16. A good representation of the problem requires a good knowlege base in a specific domain. Representation of a problem is a source of retrieval cues. If retrieval cues are poor, the child will not search his memory for the source problem as a means of solving the target problem. Since retrieval cues for the novice is perceptually based, they will fail to draw analogies between problems without similar surface features, but the expert will benifit from the analogical source problem.

17. Experience with analogical reasoning facilitates expertise. Analogical reasoning may serve as a metastrategic strategy.

18. Children frequently have difficulty incorporating new knowlege toward more effective strategies, particularly if the new knowledge discomfirms a previous belief.

19. Regression in use of a more advanced problem solving strategy to a less advanced one may be attributed to an insufficient understanding or knowledge in the application of the solution in more difficult tasks.

20. High metacognitive skills can compensate for overall ability (mental) by providing certain knowledge about cognition.

21. Individuals who use advanced strategies in problem solving, take fewer steps to solve problems.

22. Students high in aptitude and use of advanced strategies use hypothetical-deductive and evaluation strategies more frequently than those using less advanced strategies.

23. To efficiently use facts and strategies during problem solving activities, students must implement explicit strategy monitoring during problem solving behavior. Strategic competence develops from the ability to reflect upon and to use control strategies.

24. Training in strategic questioning encourages reflective thinking or elaborated explanations (problems are continuously presented, considered, reevaluated and modified).

25. Elaboration encourages a change or reconceptualization in the quality of thinking about the problem and even encourages a highter level of thinking than the individual ordinarily uses.

26. Problem solving computer improves problem solving behaviors in related contexts.

27. Use of teacher mediated instruction and peer collaboration increases metacognitive skills, and therby, problem solving skills.

28. Even very young children can learn to problem solve using computer programming software such as Logo.