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ABSTRACT

This study examined how learning a problem-solving strategy or schema in one or two distinct content areas with copying or explaining of the strategy affected students' ability to transfer that strategy to a new content area. Eighty-one regular and 56 honors junior high school students (grades 6 and 7) were presented with story problems and their solutions in one or two content areas. Students also completed plan worksheets in which they copied or explained the underlying strategy. In a transfer task, students were asked to solve a new story problem and to complete a questionnaire about metacognitive strategy use. They were then given a hint to use the previously learned story problems and a second chance to solve the problem. Copying or explaining the strategy had no effect on subsequent transfer. For regular students, exposure to a strategy in two content areas significantly enhanced pre-hint, but not post-hint, performance. Two-content honors students performed better on the post-hint task than did one-content students, but there were no differences in pre-hint transfer. Honors students reported more metacognitive strategy use. A direct relationship was found between transfer and metacognitive scores, with higher-performing students reporting more metacognitive strategy use. Plan worksheets and the questionnaire are appended. (Contains 32 references, 1 figure, and 2 tables.) (SLD)

Transferring Critical Thinking Skills across Content Areas: The Effects of Multiple Content Areas and Summary Generation on the Analogical Problem Solving of Regular and Honors Students

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Running Head: ANALOGICAL PROBLEM SOLVING

Abstract

This study examined how learning a problem solving strategy or schema in one or two distinct content areas with copying or explaining of the strategy affected students' ability to transfer that strategy to a new content area. Regular and honors junior high school students were presented with story problems and their solutions in either one content area or two content areas. In addition, students completed plan worksheets in which they either copied or explained the underlying strategy. The transfer task was a new story problem in a different content area. Students were asked to solve the new story problem, then to complete a questionnaire addressing their metacognitive strategy use; they were then given a hint to use the previously learned story problems and given a second chance to solve the problem. Copying or explaining the strategy had no effects on subsequent transfer performance. For regular students, exposure to a strategy in two content areas significantly enhanced their pre-hint performance over their one-content counterparts, but did not affect post-hint scores. In contrast, two-content honors students were found to perform significantly better on the post-hint task than one-content honors students, but no differences were found in pre-hint transfer. Honors students reported significantly more metacognitive strategy use than did regular students. In addition, a direct relationship was found between transfer performance and metacognitive scores, with higher-performing students reporting more metacognitive strategy use. Results have practical implications for transfer facilitation and achievement level instruction.

The Effects of Multiple Content Areas and Summary Generation on the Analogical Problem Solving of Regular and Honors Students: Is Transfer Fostered?

Cognitive theorists teach us the importance of relating new information to students' previous knowledge (Bransford & Vye, 1989; Wittrock, 1978, 1990; Wittrock & Alesandrini, 1990). Fractions are taught by reminding students that a pie can be sliced into pieces, or sections. The heart is likened to a water pump, the behavior of gases to billiard balls. As these examples demonstrate, successful analogies can compare two very different types of information; as long as the connection between the two examples is clear in the students' minds, the analogy can be understood. But what happens if students learn similar concepts in different content areas without the guidance of a teacher to help them make the connections? How difficult is it to make these connections alone?

The literature has much to say on the difficulty in obtaining transfer and the challenge involved in training for it (Brown & Campione, 1984; Campione, Brown, Ferrara, Jones, & Steinberg, 1985; Crisafi & Brown, 1986; Ennis, 1989; Gick & Holyoak, 1980, 1983; Holyoak, Junn, & Billman, 1984; Holyoak & Koh, 1987; Holyoak & Thagard, in press; King-Johnson, 1992; Perkins & Salomon, 1989; Resnick, 1987; Salomon & Perkins, 1987; Sternberg & Ketron, 1982).

The term transfer as used in the literature generally involves the flexible use of information across task boundaries (Brown & Campione, 1984) or the use of knowledge gained in one known domain to solve a problem posed in a new different domain (Gick & Holyoak, 1980; Perkins & Salomon, 1989). More generally, it can be defined as the effect of previous problem solving experience on learning or performance in a new problem solving situation (Mayer & Wittrock, in press). Regardless of its exact definition, transfer is an important goal. Industry complains that high school graduates are unable to function well in the workplace because they lack the problem solving skills necessary for success, and conditions of employment are now likely to change several times during one's life (Resnick, 1987; Resnick & Resnick, 1992). In this environment, it is clear that the ability to transfer skills and concepts from one domain to another can significantly affect an individual's likelihood of success.

Types of Transfer

The literature describes many types of transfer. Researchers differentiate between near transfer and far transfer (Brown & Campione, 1984). Near transfer is the use of knowledge acquired from one domain in a second, similar domain. Far transfer involves relating knowledge to a very different domain. The transfer of a concept from one particular math problem to another similar type of math problem would be considered near transfer; using that concept in a physics context could be categorized as far transfer.

Gagné (1970) discusses vertical and lateral transfer. He characterizes vertical transfer as the spontaneous assembly of learned subskills into an integrated whole. Vertical transfer thus entails the creation of a generalized approach from specific examples. Lateral transfer is defined as the application of skills broadly across content areas. Using the same knowledge or skills in math, and science, and language arts could therefore fall into the category of lateral transfer.

Salomon and Perkins (1987) differentiate between low road transfer and high road transfer. They define low road transfer as that transfer which occurs "when a performance practiced to near automaticity in one context becomes activated spontaneously by stimulus conditions in another context" (p. 151). For instance, an individual who knows how to drive a car can transfer that knowledge to the operation of a truck, without much serious cognitive effort. Low road transfer is characterized by: (a) extensive practice until the original behavior becomes automatic and (b) a reflexive response in the transfer situation. In contrast, high road transfer involves intentional generalization or abstraction from one domain to another. High road transfer is natural for spec ic problem solving strategies or principles. This type of transfer occurs when the individual is consciously attempting to integrate past experiences to solve current problems. Self-monitoring and metacognition are key components of high road transfer. Thus, whereas low road transfer is directed by automated performance and varied practice is needed for far transfer of this type, high road transfer is directed by conscious decontextualization; personal motivation and self-monitoring are necessary to achieve this road to far transfer.

Another view of transfer focuses on the metacognitive processes involved in attaining transfer, such as assessment of the requirements of a problem, construction of a plan to solve the problem, selection of the appropriate solution strategy, and the monitoring of progress (Mayer & Wittrock, in press). In this view of transfer, transfer occurs when the above processes lead people to manage the way they use their prior knowledge to create new solutions to a novel problem.

Analogical transfer is a particular type of transfer involving the transfer of knowledge from one domain to another by a mapping process, in which the individual attempts to find a set of one-to-one correspondences between portions of each domain (Brown, Kane, & Echols, 1986; Gick & Holyoak, 1983). The most familiar analogical problems are proportional analogies of the form A:B :: C:? ("A is to B as C is to ?"), often found on standardized tests. More interesting research, however, focuses on real-life types of analogies, termed analogical problem solving.

Research in the area of analogical problem solving and transfer generally involves two components. First, students are given at least one problem and its solution as an example. Then, they are presented with a problem to solve, whose solution they can arrive at by using the problem solving strategy from the previous problem. Most of these types of studies have been conducted either with preschool children (Brown & Campione, 1984; Brown et al., 1986; Crisafi & Brown, 1986; Holyoak et al., 1984, for example) or with adults (Gick & Holyoak, 1980, 1983; Phye, 1989, for example). By varying the tasks, conditions, and number of trials, transfer outcomes can be manipulated.

Analogical transfer consists of representation of the known and novel problems, recognition of the potential for transfer, mapping of the known problem onto the novel problem, and application of the known problem solution to the novel problem. Holyoak postulates that, in order to solve an analogical problem, four requirements are needed (Holyoak et al., 1984; Holyoak & Koh, 1987). Individuals need to: (1) construct mental representations of the known problem and of the novel problem, (2) notice the potential for transfer between the known and novel problems, (3) construct an initial partial mapping between the elements of each problem, and (4) extend the mapping to find a solution for the new problem.

Representation

Schema theory attempts to describe how individuals organize and represent the knowledge they acquire and how cognitive structures facilitate the use of knowledge (Glaser, 1984; Rumelhart, 1980). A "schema" is a structure that represents knowledge stored in memory. People use their schemata of previously experienced situations to interpret new, related experiences. By integrating and assimilating new information with prior knowledge, people make sense of new objects, situations, and relationships.

The creation of a schema can be viewed as learning a general problem solving strategy or concept. If an individual processes only one example of a problem solving strategy or problem approach, the representation in memory of that example is isolated and disconnected. The example stays context-dependent, not allowing for a general schema to evolve. However, as the individual encounters more examples of the same or similar strategies, he or she can construct a more general schema for this new problem solving strategy. Holyoak et al. (1984) refer to this construction as a "more abstract knowledge structure that describes the commonalities between the two domains" (p. 2053). Brown et al. (1986) discuss the representation of problems in terms of "a generalized mental model" (p. 105). Whether termed schema, abstract knowledge structure, or generalized mental model, this representation contains information such as when the strategy is useful, how to use the strategy, and in what contexts the strategy has been applied. It is less context-dependent than singular examples in memory and more available for future retrieval (Gick & Holyoak, 1983). In addition, a schema is easier to apply than an example, because of its closer similarity to the novel problem: A schema shares underlying features with the novel problem without having a divergent surface structure (Holyoak & Thagard, in press). Thus, an individual may be better equipped to transfer a concept from one domain to another if an associated schema exists. The construction of mental representations of the known and novel problems about which Holyoak writes is strongly tied to the existence of a problem schema or mental model.

Recognition

Research suggests that one of the major blocks to successful transfer is the failure to spontaneously notice transfer potential (Brown & Campione, 1984; Gick & Holyoak, 1980, 1983). Even in studies in which subjects are given a problem and solution to review and are then immediately presented with a new problem whose statement and solution are analogous to the first problem, a large number of subjects (generally 80%, as cited by Brown and her colleagues) fail to transfer (Brown et al., 1986; Gick & Holyoak, 1980, 1983). In order to transfer a general problem solving strategy to a specific domain, individuals must notice the relevance between previous examples, general schemata, and the current problem. Facilitating this recognition has been the subject a numerous studies (Brown & Campione, 1984; Crisafi & Brown, 1986; Gholson, Dattel, Morgan, & Eymard, 1989; Gick & Holyoak, 1980, 1983; Phye, 1989).

The first and most direct approach to facilitating recognition is to tell the subjects that two problems are similar (Crisafi & Brown, 1986; Gick & Holyoak, 1980, 1983). For instance, Gick and Holyoak (1980) found that giving subjects a "hint" to use a previously presented story problem resulted in higher rates of transfer over the non-hint condition. However, questions regarding the authenticity of such an approach arise. In real-life situations, individuals often do not receive assistance, or "hints," regarding the usefulness of one example in the solution of another problem.

A second approach is to give subjects more than one example problem and solution before presenting them with the transfer task (Brown & Campione, 1984; Crisafi & Brown, 1986; Gick & Holyoak, 1983). Schema theory suggests that an individual can construct a schema by abstracting the common elements of two examples. This construction clearly relies on the provision of at least *two* prior examples, which can be mapped to induce the schema. As Gick and Holyoak (1983) state: "Indeed, the schema is defined by the correspondences between two analogs" (p. 12). By providing subjects the opportunity to create a schema, rather than relying solely on one known example, easier retrieval and less context-dependence are expected (Gick & Holyoak, 1983). For example, Crisafi and Brown (1986) found greater recognition and subsequent transfer when children were given two examples prior to the transfer task as compared to just one previous example.

A third approach to facilitating recognition is to actually give subjects a schema or problem solving strategy to use (Crisafi & Brown, 1986; Gick & Holyoak, 1983; King-Johnson, 1992). In these studies, the relevant schema is presented as part of the problem, implicit within its representation. Subjects are then asked to summarize the basic strategy or rule or, with younger children, to explain to someone else how to solve the problem. Gick and Holyoak (1983), for instance, found that subjects who were given general strategy statements at the end of the story problems transferred significantly better than the no-strategy-statement subjects. Since the construction of a schema is thought to aid in the representation and recognition process, giving subjects the general "rule" or problem solving strategy can help facilitate transfer.

Both of these last two approaches—giving subjects more than one example problem or giving subjects a schema or problem solving strategy--aid in the recognition of a potential transfer situation. However, in addition to recognition, having a schema also facilitates transfer by simplifying the mapping and application processes.

Mapping and Application

Mapping entails the construction of a network of correspondences between the elements of the known problem and the elements of the novel problem. The application process uses the mapping to solve the new problem by applying the solution of one problem to the mapping onto the new problem. Brown and Campione (1984) argue that a successful intervention to facilitate mapping and thus enhance transfer should emphasize underlying similarities and minimize surface structure differences. Mappings can also be defined at multiple levels of abstraction; finding the optimal level of abstraction—that level which maximizes the correspondences between two analogous problems—is a crucial part of the mapping process (Gick & Holyoak, 1983).

Holyoak argues that there are two ways in which mappings are created (Gick & Holyoak, 1983; Holyoak & Thagard, in press). "Reasoning from an analog" refers to the mapping of a new problem directly with a known problem, bypassing an explicit, separate schema. In contrast, "reasoning from a schema" describes the process of mapping a new problem with an existing schema stored in memory. Brown and her colleagues (Brown et al., 1986) found that children who understood the underlying goal structure of the presented stories performed better on an analogous transfer task than did children who did not grasp the goal structure of the stories. As this example illustrates, the use of a problem schema or underlying structure simplifies the mapping and application process. As is the case for representation and recognition, mapping from a schema and applying the schema's solution to the novel problem better facilitates transfer than mapping and application from an example (Gick & Holyoak, 1983).

Constructing Meaning

Schemata, then, help foster transfer at all levels: Representation, recognition, mapping, and application processes all benefit from the availability of a schema. Thus, giving individuals a schema or problem solving strategy to use, or aiding in its creation, should be a worthwhile strategy. But current learning and cognition theory sees students as active participants who construct meaning from the information they gather (Bransford & Vye, 1989; Wittrock, 1978, 1990). Students do not merely absorb all new information given to them; rather they learn new concepts by actively processing that information.

Students can process information in a variety of ways. One approach to fostering the construction of meaning is to have students summarize information (Doctorow, Wittrock, & Marks, 1978; Palincsar & Brown, 1989; Wittrock, 1990). This is seen as a way to facilitate learning by stimulating generative processes; students will construct relations between their knowledge and new information they are summarizing, allowing them to "make the information their own." Wittrock and Alesandrini (1990) have found that students who generated either summaries or analogies performed better in a reading comprehension test than did students in a control group who simply read the text twice. This finding is consistent with other research: As learners relate what they are reading to their knowledge, their learning increases.

Just as summary creation aids students in reading comprehension, so does summarizing stories or strategies help students in analogical transfer. This makes intuitive sense: Students actively processing a strategy should comprehend its underlying structure better than students who are simply presented with that strategy. Researchers have found that instructing students to summarize the basic underlying strategy or rule or—with younger students—to explain to someone else how to solve the problem does indeed enhance transfer (Crisafi & Brown, 1986; Gick & Holyoak, 1983).

Achievement Level

Research has also been conducted to examine the relationship between achievement level and transfer (Brown & Campione, 1984; Franks et al., 1982; for example) and achievement level and strategy use (Zimmerman, 1986; Zimmerman & Martinez-Pons, 1990; for example). Findings indicate that transfer flexibility increases with achievement level. Franks and his colleagues (Franks et al., 1982) found evidence in fifth graders of a relationship between achievement level and transfer, with higher-achieving students able to transfer better than lower-achieving students. Day (1980, as cited in Brown & Campione, 1984) investigated similar issues with junior college students. She also found that, following instruction, higher-achieving students transferred better than other students. With respect to metacognitive strategy use, Zimmerman (1986) reported an interview study in which he found that high school students' use of metacognitive strategies was significantly related to their achievement level, with higher levels of strategy use coupled with higher achievement. Finally, Zimmerman and Martinez-Pons (1990) examined differences in self-regulated learning strategies in fifth-, eighth-, and eleventh-grade students. They found that gifted students displayed significantly higher levels of strategy use than regular students. Thus, achievement level, metacognitive strategy use, and transfer potential are clearly correlated.

Analogical Transfer Research

Given the facilitators of transfer presented above, we can now explore a few notable studies in the area of analogical transfer to examine more specifically how transfer outcomes have been manipulated. Although the following studies have focused on many different aspects of transfer across ages and content domains, all of them can be analyzed within the framework of the four requirements for transfer discussed above.

Brown et al. (1986) looked at analogical transfer in three- to five-year-old children. Using three similar stories suited for this young age group, researchers told the children the first story and then had the children try to solve the problems in the next two stories. By using an analogous solution, both additional problems could be solved. They found that children who understood the goal structure of the stories and could ignore trivial details transferred the solution across stories better than children without a clear goal structure in mind. Understanding the underlying structure of the stories and committing surface differences to a secondary position facilitated children's mapping and application.

Crisafi and Brown (1986) also studied transfer in young children. They chose to use a problem solving approach departing slightly from many analogical studies, involving the ability to combine two separately learned strategies to reach a goal. They conducted five separate studies, using a number of analogous tasks. In the first task, the children learned that a purse or piggy bank held coins and that inserting the proper coin into a gum ball machine produced a gum ball. The second task required the same solution in a different context: Children learned that coins, which were located either in a milk container or in a saucepan, could be inserted into a dump truck to obtain a piece of candy. The third and final task involved a box apparatus with drawers containing various pieces of hardware. The apparatus produced a candy if the correct hardware item was inserted into the top of the apparatus.

Crisafi and Brown looked for conditions that would facilitate transfer. They found that telling children that analogous tasks are the same increases the probability that the children will transfer the solution from one problem to the next. This approach clearly shows the effect of direct intervention on the recognition of a relevant analogous problem.

Next, the researchers tried to help the children see the similarities between the tasks without actually telling them the tasks were the same. They did this by stating the general rule underlying all tasks and by having the children explain the general solution rule to Kermit the Frog after solving each task. Because the children explicitly stated the rule, their attention was focused on the similarities of the problems without being directly told of the similarities. These children performed significantly better on the transfer task than did the non-explanation group. However, it took the children until the third analogous task to realize that they could transfer the problem solving strategy; children did not transfer any better in the above conditions on the second transfer task. Two issues are at work in this example. First, the rule statement and explanation to Kermit allowed the children to represent and recognize the novel problem, by using the underlying schema. However, the fact that the children did not transfer the strategy until the third task is evidence that, in addition to the explicit strategy statement, the children also needed two examples before they could transfer. This bolsters Gick and Holyoak's (1983) argument that the creation of a general schema with two examples enhances transfer over the one example case.

Gick and Holyoak conducted a number of studies, which they report on in two journal articles (Gick & Holyoak, 1980, 1983). Many of their studies used stories analogous to Duncker's "radiation problem" (1945, as cited in Gick & Holyoak, 1980), which is explained as follows:

> Suppose that you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue? (pp. 307-308)

One solution to the radiation problem is to direct numerous low-intensity rays towards the tumor simultaneously from different directions. In this way, the healthy tissue is left unharmed, while the effects of multiple low-intensity rays will sum to a high intensity, thus destroying the tumor. Other analogous problems used in Gick and Holyoak's studies include "The General," a story about a general whose army cannot capture a fortress by using a full-scale direct attack down one road, and "Red Adair," a story about an oil well fire so massive that the fire hoses available are too small to individually shoot enough fire retardant foam to put out the flames. All these problems have analogous solutions. The underlying strategy, termed the "convergence" solution, is this: If you nee ' a large force to overcome a central target and you are unable to apply the full force along one path, apply weak forces along multiple paths simultaneously. In this way, the central target will be overcome by a combined large force (Gick & Holyoak, 1983).

Gick and Holyoak (1980) conducted five studies with college students, each study building on the previous one. In Experiment I, students were divided into four groups. Students in each group were given one of three versions of "The General" story; each version consisted of the same initial problem, but three different "solutions" existed. The control group was given no story. Then students were presented with the radiation problem, told they could use the previous problem to solve the current problem if they so desired, and asked to suggest possible solutions to the current problem. The researchers' hypothesis was confirmed: The previous analogy colored students' solutions to the transfer problem. Students who were first presented with the convergence solution were more likely to suggest an analogous solution to the radiation problem; the same was true for both other types of solutions.

The most tenable explanation for these results is that the "hint" given to the students to use the previous problem to solve the radiation problem affected how they constructed their solutions. Once a hint is given, recognition of the transfer potential is simplified.

In Experiment IV, Gick and Holyoak began investigating the differences in student responses dependent upon hint availability. Students were asked to memorize three stories—"The General" and two unrelated distracter stories—in the guise of a recall experiment. Students were then required to write down as much of the stories as they could recall. Following a three to five minute break, students were presented with the radiation problem and asked to suggest possible solutions to the problem. Half of these students were given a hint to use the memorized stories and half received no hint.

In the hint condition, 92% of the students produced the correct solution and most said the relevant story was "very helpful" in solving the radiation story. However, the researchers found a dramatic difference in the no hint condition: only 20% of the students produced the correct solution and almost all the students in this group indicated that it had not occurred to them to use the relevant story, which they had read less than a half hour before. Based on these findings, Gick and Holyoak (1980) suggest that "analogical problem solving is neither automatic nor invariably applied by college students as a conscious strategy" (p. 343).

Gick and Holyoak conducted further studies in 1983 to investigate factors that might aid in the recognition of an available analogy and in the induction of a problem schema. First, they examined the effect of multiple analogs on transfer. "The General" was modified to create "The Commander," a story involving an attack on an island using multiple bridges (instead of the fortress and multiple roads in the original story); "Red Adair" was modified to create "The Fire Chief," a story about a wood shed fire and a bucket brigade (instead of a huge oil well fire and small fire hoses). All students initially read two problems. Those students in the similar-analog condition received two problems in the same domain, those in the dissimilar-analog condition received two problems in different domains, and those in the one-analog condition received one problem from the four above and one irrelevant control problem. Students were asked to write brief summaries of each story and to rate the comprehensibility of each story. Most critically, students were asked to describe the ways in which the stories were similar. This task was meant to elicit a mapping and possibly the creation of a convergence schema. Students were given the radiation problem in the usual two-pass (no hint followed by hint) manner.

No differences were found for the similar or dissimilar-analog conditions, although cell frequencies were too low to perform valid statistical tests for the description analysis. However, other clear differences emerged: students in the two-analog conditions were significantly more likely to demonstrate transfer ability, both before and after the hint. In addition, schema analysis of the similarity descriptions yielded significant results: the better the description, the better the transfer. Over 90% of the students who wrote "good" descriptions solved the radiation problem using the convergence solution without a hint. An appropriate schema can significantly simplify the recognition, mapping, and application processes. How else, then, can we facilitate good schemata?

In one final study I will report, Gick and Holyoak (1983) added verbal strategy statements to attempt to aid schemata creation further and boost transfer performance. College students were randomly assigned to either the principle or no-principle condition. The verbal principle consisted of a paragraph explaining the convergence solution; the paragraph was added to the end of both "The General" and "The Fire Chief" stories. Students were asked to read the two stories, summarize each story, rate the comprehensibility of each, and—most importantly—describe similarities between the two stories. Following these tasks, students were presented with the radiation problem, first with no hint, then with a hint.

As the researchers hypothesized, the addition of the verbal strategy statement with the two analogs improved students' transfer. Furthermore, similarity descriptions scored for schema quality showed that the addition of the verbal statement elicited better schemata than the no-principle condition. By summarizing the similarities between the stories, students constructed their own understanding of the analogy. The results Gick and Holyoak found are also in line with their theory that a better schema results in easier recognition and more straightforward mapping between the known and novel problems.

Synthesis

Examining these studies in combination, the various researchers found that students will be substantially more likely to transfer if: (1) they are given hints to use an analogous story with which they are already familiar, (2) they are presented with multiple analogous stories, (3) they are told the strategy underlying the stories, and (4) they understand the goal structure or underlying strategy of the stories. Although the first element—hint giving—is less applicable to the real-world, multiple analogies, strategy presentation, and understanding of the underlying strategy are approaches that could be used in classrooms to enhance students' transfer.

In this study, I investigated analogical transfer with 12- to 13-year-olds, an age group that has not been targeted in the previous research. Since school children often learn similar concepts in very different contexts, I examined how learning a problem solving strategy or schema in two distinct content areas affects both regular and honors students' ability to transfer that strategy to a new content area. Positive effects in this area could help inform classroom instruction in fostering transfer. Although Gick and Holyoak (1983) investigated the issue of multiple content areas, they did not attempt to use this approach together with all the other transfer-facilitating approaches. Following previous research, some students in the present study were given all the opportunities for transfer: two initial problems with solutions, multiple content areas, underlying strategy presentation, generation of summaries of the underlying strategy, and an eventual hint regarding use of the previous problems.

Prior to conducting this study, my three hypotheses were that: (1) students exposed to a strategy in two content areas would perform better on an analogous problem in a new content area than students exposed to the strategy twice in the same content area, (2) students who processed the strategy by explaining that strategy to a friend in writing would perform better on the transfer task than students who simply copied the strategy verbatim, and (3) honors students would transfer better than regular students in all situations.

Methods

Subjects

One hundred and thirty-seven students participated in this study, 81 students taken from two regular sixth- and one regular seventh-grade English class and 56 students taken from one honors sixth- and one honors seventh-grade English class. Parental informed consent and student assent were obtained for each participant. The students all attended a junior high school in the Los Angeles area. Students were middle-class SES and of mixed ethnicity (African-American, Asian-American, Latino, and White). Within each class, the subjects were randomly assigned by sex and ethnicity to one of the four treatments.

Materials

Materials were created or revised for use in this study. Four analogical problem solving tasks were revised from the problems described above (Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987) to be more suitable for junior high school students. Each of the two initial tasks used consisted of a story problem followed by its solution, using the convergence problem solving strategy. The third and final task included only the transfer story problem, with no given solution. To control for reading level, all story problems were reviewed by teachers for grade level appropriateness prior to their use. In addition, all story problems were distributed to students as well as being read aloud by the teacher. There were two social studies tasks, "The General" and "The Pharaoh," one science task, "The Light Bulb," and one language arts transfer task, "The Fire Chief." These story problems are presented in Appendix A (within the teacher scripts).

Scripts for all teacher presentations (included in Appendix A) contained teacher directions, story problems, and solutions, and were created with input from the teachers whose classrooms were used in this study. Two plan worksheets were used which allowed the students to either: (1) copy the strategy directly, or (2) explain the strategy to a friend in writing. The plan worksheets are included in Appendix B. An answer sheet provided a standardized way for the students to respond to the transfer task.

A questionnaire was used to obtain information about how the students solved or tried to solve the transfer task. The questionnaire (presented in Appendix C) was administered following the first transfer task pass; it asked students to explain how they arrived at their solutions and also included five items related to students' thought processes and the metacognitive strategies they may have used in solving the transfer task. The Likert-scale strategy use questions were modified from the Self-Assessment Questionnaire (O'Neil, Baker, Jacoby, & Wittrock, 1990). All five questions from the *cognitive strategy* subscale on the original questionnaire were used. Previously conducted principal components analysis found that all items within this subscale loaded on only one factor; Cronbach's Alpha for the set was calculated to be .61.

Design and Procedure

A 2 x 2 x 2 x 2 factorial design was used. Independent variables were the number of content areas (one or two), the type of strategy processing (copy or explain), the student's achievement level (regular or honors), and the availability of a hint (pre-hint and post-hint trials). Students in each class (where achievement level covaried with class) were randomly assigned by sex and ethnicity to one of four treatment groups: (1) one content area, copy strategy; (2) one content area, explain strategy; (3) two content areas, copy strategy; and (4) two content areas, explain strategy. Hint availability was a repeated measures variable.

The teachers involved in this study included three female teachers (each with one class) and one male teacher (with two classes). All teachers were given a copy of the teacher script and were briefed on the details of the study prior to the study's commencement. Students were told they were participating in a study investigating problem solving and transfer issues in junior high school students.

Day one. The study was conducted with pairs of classrooms for four of the classrooms; the final classroom was studied separately. Procedures for each portion of the study were identical. For each pair of classrooms (or individual classroom), students were divided into four groups: one content area, copy; one content area, explain; two content areas, copy; and two content areas, explain. The one-content groups were taken to one area, while the two-content groups were taken to another. Thus, for four of the five classrooms, students were in a room with students from their own class and from another class. Within each group, students received copies of and were read "The General" problem and solution. The presenter was either a classroom teacher or the researcher; in all cases, the presenter was counter-balanced such that each group was read one story problem by each of the two presenters.

Following presentation of the first story problem, students completed the appropriate plan worksheets according to group assignment; worksheets instructed students either to copy the general underlying strategy presented or to explain the presented strategy to a friend in their own words. The presenters then switched groups. The one-content group received and was read "The King" problem and solution. The two-content group received and was read "The Light Bulb" problem and solution. Plan worksheets were again distributed and students again copied or explained the general underlying strategy presented. All materials were then collected and students returned to their normal classrooms. Day one activities took about 40 minutes to complete.

Day two. Day two activities were carried out the following day within each classroom; the researcher was not present so as to prevent cueing effects. The normal classroom teacher distributed "The Fire Chief" written task to students, read the story problem aloud, and asked students to write down their solutions to the problem. After the solutions were collected, a questionnaire was handed out asking students whether other problems were helpful in solving "The Fire Chief" and addressing students' general cognitive strategy use. Like Gick and Holyoak's (1980, 1983) two-pass studies, the teacher then reminded the students to think about the story problems they learned the previous day in order to solve the current problem. New worksheets were then distributed and students were given a second chance to solve the transfer problem. Day two activities took about 20 minutes to complete.

Results

Both pre- and post-hint transfer tasks were evaluated using a set scoring criterion. One point each was given for mentioning each of the following three factors: (1) simultaneous forces, (2) low intensity/small amounts, and (3) several directions/multiple paths. Scores ranged from zero to three and reflected how many aspects of the underlying problem solving strategy students included in their solutions to the transfer problem.

In addition, the questionnaires were coded. On the first part of the questionnaire, only 20% of the students reported having used any other stories to help them solve the transfer task. An additional 20% misunderstood the first part of the questionnaire: Rather than explaining how they used *another* story problem to help solve the transfer task, these students either explained why the transfer task was useful or interesting to them or presented their original solutions to the problem again. Finally, 60% of the students reported not using other stories, although it appeared that many of these students may have been confused by the question, as evidenced by the often-present cross-outs and eraser marks. Thus, although the characteristics of the 20% of students who clearly understood the first part of the questionnaire were examined, only the metacognitive strategy use portion of the questionnaires were analyzed.

Finally, plan worksheets were examined. All students in the copy condition followed the directions and copied the strategy directly.

Thus, plan worksheets were coded only for those students instructed to explain the strategy to a friend. Clearly, generating explanations of the general strategy should only enhance transfer if the generation is actually accomplished. Students were considered to have written an explanation if at least one of their two plan worksheets was complete. Explanations were coded very generously, with only blank or completely incomprehensible explanations deemed "missing." Thirteen students were missing *both* explanations, distributed as follows: (a) Of the 21 one-content regular students, six were missing both explanations; (b) Of the 13 one-content honors students, one was missing both explanations; (c) Of the 22 two-content regular students, six were missing both explanations; (d) Of the 14 two-content honors students, none were missing both explanations. Thus, non-completion was more likely for regular than honors students. No other characteristic differences were found.

Since these thirteen students were considered either to have found the task too difficult or to have made no effort whatsoever to write an explanation, they were dropped from the analyses. In addition, a small number of students who were absent on Day two of the study were obviously omitted due to lack of transfer data. With the remaining students, groups of equal size were randomly chosen for statistical analyses. Thus, twelve students per cell were chosen, totaling 96 students in all.

Preliminary statistical analyses found no effect of gender on transfer scores. Tests for the effect of ethnicity on transfer scores did yield significant results. However, it appeared that ethnicity was confounded with achievement level: Latino students were under-represented in the honors classes. Statistical tests of the effect of ethnicity, when achievement level was included, showed that the variance in transfer scores was accounted for by achievement level, with ethnicity having no significant effect on transfer scores when achievement level was taken into account.

Repeated measures analysis of variance statistical tests were performed on the transfer scores to examine possible differences both within and between each group. CONTENT (one or two content areas), WORKSHEET (copy or explain strategy), HONORS (regular or honors), and TRIAL (pre-hint or post-hint) variables were analyzed. Group means are presented in Table 1. A significant between subjects effect was found for HONORS, $F\ (1, 88) = 8.95, p < 004$, with honors students performing significantly better than regular students on the transfer task, regardless of other factors (1.53 and 0.98, respectively). In addition, a significant main effect was found for TRIAL, $F\ (1, 88) = 5.81, p < .02$, showing—as expected—that post-hint scores were significantly higher than pre-hint scores (1.35 vs. 1.16). No significant differences were found for WORKSHEET. Most interesting, however, was the finding of a significant within subject three-way interaction for TRIAL*CONTENT*HONORS, $F(1, 88) = 11.74, p < .001$. This interaction is visually displayed in Figure 1.

Insert Table 1 about here

In order to examine the interaction effect more closely, a test of simple main effects by HONORS was performed. For *regular students*, no significant between subjects differences existed; however, a significant within subject interaction effect for TRIAL*CONTENT was found, $F(1, 44) = 8.36, p < .006$. For pre-hint scores, a significant main effect for CONTENT existed for regular students, $F(1, 44) = 4.04, p = .05$, showing that regular two-content students had higher pre-hint scores than regular one-content students (1.21 and 0.625, respectively). Post-hint scores for regular students revealed no significant differences between content groups. In addition, a paired-comparison t-test was then performed to examine differences *across trials* for one-content regular scores. Significant differences were found, $t(23) = 2.32, p < .03$; one-content regular students performed significantly better on the transfer task after a hint was given than prior to that hint (0.625 pre-hint; 1.04 post-hint). A paired-comparison t-test for two-content regular students showed no significant differences across trials, indicating that two-content regular students performed the same on the transfer task regardless of the hint.

For *honors students*, a different pattern was found. The test of simple main effects showed no significant between subject effects, but did reveal a significant main effect for TRIAL, $F(1, 44) = 4.37$, $p < .05$ (1.40 pre-hint; 1.67 post-hint), as well as a significant within subject interaction effect of TRIAL*CONTENT, $F(1, 44) = 4.37$, $p < .05$. No significant effects for CONTENT for honors students were found either for pre-hint scores or for post-hint scores. However, a paired-comparison t-test did reveal a significant difference between pre-hint and post-hint scores for two-content honors students, $t(23) = 2.41$, $p < .03$ (1.25 pre-hint; 1.79 post-hint). Thus, two-content honors students were significantly aided by a hint. No comparable differences were found for one-content honors students (1.54 pre-hint; 1.54 post-hint).

Insert Figure 1 about here

Looking at the same three-way interaction from another perspective, in a test of simple main effects by CONTENT, for *one-content students*, a between group main effect for HONORS was found $F(1, 44) = 7.58$, $p < .01$, with one-content honors students performing significantly better than one-content regular students, regardless of trial (1.54 as compared to 0.83). No other significant between groups or within group effects for one-content students were found.

For *two-content students*, the main effect for HONORS was not significant. However, a significant within group TRIAL*HONORS interaction effect was found for two-content students, $F(1, 44) = 8.09$, $p < .007$. Significant differences were found for two-content, post-hint scores between regular and honors students, $F(1, 44) = 7.33$, $p < .01$ (1.04 regular, 1.79 honors). Two-content pre-hint scores did not differ significantly between regular and honors students.

Turning to the questionnaire data, the first part of the questionnaire was found to be unusable (see discussion above). However, an examination of the characteristics of the students who understood the intent of the first questions and reported using another story to solve the transfer task showed that honors students were much more likely than regular students to give this response (57% of these responses were from honors students, whereas honors students comprised only 41% of the student population). In addition, males were found to respond in this manner over females (71% of these respondents were male, whereas only 55% of the student population was male). The honors distinction is explained by the other metacognitive measure discussed below. The gender difference is probably a side effect of the larger enrollment of males in honors classes (64% males vs. 36% females in the honors classes), rather than an effect of gender itself. No other characteristic differences were found.

For the second part of the questionnaire, responses to the five Likert-scale strategy use questions (each response score ranging from one to four) were summed to obtain a general metacognitive strategy use score. This was deemed valid, since previous research using this subscale indicated that all items center on one dimension. Preliminary analyses revealed no significant effects for gender or ethnicity. Since the students' metacognitive strategy use was only measured once, the TRIAL variable was irrelevant. Group means are shown in Table 2.

Results from the 2 x 2 x 2 analysis of variance test indicated a main effect for HONORS, $F(1, 85) = 15.28, p < .001$, with honors students reporting significantly more metacognitive activity (13.73 vs. 11.67). No other main or interaction effects were found. Means were also examined on each individual question to investigate similarities across questions. Questions 1, 2, 3, and 5 had similar results, with honors students reporting *moderate* use of metacognitive strategies use (means equal to 2.87, 3.07, 2.93, and 3.00 respectively) and regular students reporting *some* use of such strategies (means equal to 2.23, 2.56, 2.48, and 2.40 respectively). Question 4 yielded different results: both regular and honors students reported lower usage of "multiple ways to solve the story problem" (1.87 for honors students, 2.00 for regular students).

Insert Table 2 about here

Question 2 was examined in more detail as it reflected students' awareness of their use of prior knowledge in solving the transfer task. As with the summed data, a main effect for HONORS was found, F (1, 85) = 5.93, $p < .02$, with honors students significantly more likely to report relating the transfer task to what they already knew (3.07 vs. 2.56). In addition, a main effect for CONTENT approached significance, F (1, 85) = 3.58, $p = .06$, showing two-content students may have been more likely to report awareness of the relationship than one-content students (3.00 as compared to 2.61).

Finally, a new variable was created to indicate high or low transfer performance; TSCORE's value was set to zero if a student scored low (zero or one) on the pre-hint transfer task and one if the student scored high (two or three) on the task. In order to examine the direct relationship between pre-hint transfer performance and metacognitive strategy use, a 2 x 2 x 2 analysis of variance test was performed utilizing HONORS, CONTENT, and TSCORE as independent variables and the summed metacognitive score as the dependent variable. Results were consistent with previous findings, showing a main effect for HONORS, F (1, 85) = 15.48, $p < .001$, with honors students reporting significantly more metacognitive activity than regular students (13.73 vs. 11.67). In addition, a main effect for TSCORE was found, F (1, 85) = 4.04, $p < .05$, with students who performed better on the transfer task reporting more cognitive strategy use (13.49 vs. 11.90). No other main or interaction effects were found.

Discussion

Comparing transfer at its best to transfer at its worst, one notices that even the two-content honors students received an average pre-hint score of only 1.25 out of a total possible score of 3. Regular students in the one-content condition scored an abysmally low pre-hint score of 0.63 on average. Post-hint scores ranged from 1.79 for two-content honors students—who gave the best responses on the transfer task—to 1.04 for one-content regular students. These numbers show that even students receiving the highest transfer scores grasped only 60% of the correct response, indicating that transfer is indeed an elusive goal.

A discussion of the lack of effect for the copy/explain manipulation is appropriate. Based on previous research an effect should have been found. However, possibly due to the relatively small size of the sample, such an effect was not found. Future research will hopefully clarify this issue.

Transfer Task

Looking first at regular students, when initially presented with the transfer task regular students who had been exposed to story problems in two content areas were found to transfer significantly better than regular students exposed to only one content area. When given a hint to use the previous story problems, one-content students were then able to perform on a par with their two-content counterparts. Although not directly supported by the data, it is hypothesized that presentation of story problems in two content areas may have fostered recognition of the similarities across tasks that on the surface looked different; one-content students needed the hint in order to recognize the opportunity to use analogical reasoning. Once given a hint to use the previous story problems, the recognition demands may be minimized. This interpretation is further bolstered by the finding that, in metacognitive question two, two-content students reported more awareness of the connection between the transfer task and the previous stories than did one-content students. Since no differences between one-content and two-content regular students were found in performance on the post-hint task, it is hypothesized that their mapping and application skills were not affected by the number of content areas in which story problems were presented.

With honors students, a different pattern emerged. No differences were found between one-content and two-content students upon first presentation of the transfer task. Likewise, no differences were found between one-content and two-content students following a hint to use the previous story problems. However, whereas one-content honors students did not transfer better after the hint, two-content honors students were able to improve their performance given the clue to use prior information. Thus, perhaps we can think of honors students as already being on a higher "recognition level" than regular students so that it is the mapping and application process that was made easier for the two-content honors students.

These patterns may be explained by the distinction drawn by Gick and Holyoak (1983) between reasoning from an analog and reasoning from a schema. Since the two distinct problems—very different on the surface—may have helped students in the two-content condition to form a general schema, following the hint these students could have been reasoning from a schema when solving the transfer task. Thus, the mapping and application process for two-content students following a hint would have involved mapping from a schema onto the transfer story problem. This is consistent with the finding that two-content students reported higher awareness of the relationship between the transfer task and other stories. In contrast, students in the one-content condition may have had a more difficult time forming a schema, since the two story problems they received had more surface similarities. Thus, one-content students may have been reasoning from an analog, mapping the transfer story problem directly to one of the known story problem and bypassing an explicit, separate schema. Since use of a problem schema is hypothesized to simplify the mapping and application process, students presented with story problems in two content areas performed better once recognition was bypassed (i.e., following a hint), whereas students presented with story problems in only one content area did not significan 'y improve their pre-hint performance.

It is also interesting to note that although in general honors students performed significantly better than regular students, when either group was *given the two content areas*, pre-hint transfer scores did not differ between groups. Thus, the presentation of the story problems in two content areas elevated the regular students to an "honors students" level. Logically, this advantage could be due to an increase in the regular students' ability either: (a) to recognize the analogy or (b) to map and apply the analogy. Since two-content regular students did not do as well as two-content honors students *following a hint* (that is, when recognition requirements were minimized), it is hypothesized that the advantage for regular students—consistent with the analysis of one-content and two-content regular students above—lies in the *recognition* rather than the mapping or application processes. Thus, initially, two-content regular students did as well as two-content honors students because the presentation of story problems in two different content areas helped them to more easily recognize the similarities between the known problems (or their associated schema) and the target problem. But once the connection was made explicit for all, two-content regular students did not perform as well as two-content honors students. One-content regular students at no time reached the levels of performance of the one-content honors students, with scores falling far below the honors students both before and after the hint was given.

To summarize these results, it is suggested that when regular students are presented with story problems in multiple content areas, their ability to *recognize* a novel story problem as analogous to the previously presented problems is enhanced. It seems that the number of content areas has no effect, however, on the *mapping and application* phases of their problem solving. In contrast, it is thought that multiple content areas do not affect honors students' *recognition*, but do allow these students to *map and apply* known to novel story problems better than do one-content honors students.

Metacognitive Strategy Use

A direct connection was observed between transfer performance and metacognitive scores, with higher-performing students reporting more metacognitive strategy use. In addition, honors students reported using more metacognitive strategies when trying to solve the transfer task than did regular students. Honors students are thus either better prepared to use these types of strategies or are more aware that such strategies are helpful in solving problems. Finally, presentation in multiple content areas may help to facilitate an awareness of the relationship between the current task and prior knowledge.

Conclusion

Research has shown that transfer is neither easily elicited nor simply explained. Study after study has found individuals not able to recognize obvious—to the investigator at least—parallels. Yet research has also shown children as young as two and three years of age able to transfer if the circumstances are geared towards transfer.

Gick and Holyoak (1983) varied the number of content areas in which they presented problems without finding significant results. However, in that particular study, they did not allow students some of the known facilitators of transfer. The present study summed all the characteristics that have thus far been found to enhance transfer and found that including multiple content areas as an additional variable *did* affect transfer outcomes.

Although not directly supported by the data, in conjunction with theory the results can be interpreted to point to two very different aspects of analogical problem solving: (1) recognition and (2) mapping and application. Whereas multiple content areas help regular students to recognize a source analog, honors students are helped by multiple content areas primarily in the mapping and application phases of analogical problem solving. Future research needs to focus on these differences; practical applications of this research will inform instruction for both regular and high-achieving students.

Students in our schools, as well as adults in the work force, may often find themselves in a situation in which using their previous knowledge from a very different area could help them solve a new problem in the current area. By further investigating what can be added to the growing list of facilitators of transfer, we can increase the chances of attaining that elusive goal.

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Appendix A

Teacher Script

PRELIMINARY NOTE TO TEACHERS:
This study is designed to find out what types of things we can do to help students make connections across subject boundaries without always having to point out similarities. Students often learn concepts in one class, such as social studies, that can be carried over to help them understand a concept in a different class, such as science. Higher-order or critical thinking skills sometimes rely on students transferring such higher-level knowledge over to new domains or situations.

On the first day, students will be taught two story problems, their solutions, and a problem solving strategy or approach that relates to both the stories. On the second day, they will be given a new story problem without a solution and asked to solve the problem. It is critical in this study that students not be told that the new story problem on the second day is related to the first day's activities (i.e., don't tell them it relates to my study until afterwards). After they have an opportunity to try solving the problem, they will fill out a questionnaire that asks how they solved the problem and what, if any, information they used. Then, they will be told to use the first day's story problems and asked to solve the transfer problem again.

At the beginning of the study I will ask students to participate in the study, but that they can decline or can drop out at any time (maybe you can come up with alternative work if they choose not to participate?) Once I collect all the data, all student names will be obscured and no information which identifies the student or the teacher or class will remain. I will also be sure to return to the school once I have completed analyzing the results and report on my findings.

Thank you very much for your participation!

DAY 1 (40-65 min. total)

- [5 min.] Pass out colored copies of the *Information Sheet.* Instruct students to fill in their age.
- [5-10 min.] Split students up into two groups: yellow and blue go with one teacher, pink and green stay with the other teacher. Groups should be out of earshot of one another.
- [5-10 min.] Pass out "The Sumerian General" and teach first lesson to each group as follows:

(BOTH GROUPS GET THE SAME LESSON)

"You should all remember when we learned about Sumeria. Well, I'm going to tell you about a particular Sumerian general and the problem he had. This is a problem solving exercise and we're going to learn how the general solved his problem.

Long ago, one of the cities in Sumeria was ruled from a strong fortress. This fortress was in the middle of the city which was surrounded by mountains. Many roads went through the mountains and led to the fortress. A valiant Sumerian general wanted to capture the fortress and rule the city. He knew that only an attack by his entire army would capture the fortress. He gathered his large army at the head of one of the roads in the mountains, ready to attack the fortress. But, a spy came and told the general that the fortress was protected by patrolling guards. These guards climbed the mountains searching for intruders. The paths through the mountains were large enough that, at night, a small number of people could sneak through without being spotted by the guards. However, any large group of people would be caught. Since the general's army was large, it seemed impossible to capture the fortress!

The general had a problem. He couldn't attack the fortress the way he had planned and needed a new approach to capture the fortress.

The general came up with a plan to solve his problem. He divided his army into small groups and sent each group to the head of a different mountain road. At midnight, each group walked quietly down a different road towards the fortress. They timed each group so that the entire army arrived together at the fortress at the same time. They attacked the fortress together and captured it. The general became ruler of the city and his army celebrated!"

- [5-10 min.] Pass out *Plan Worksheet*. Give students the same color worksheet as the *Information Sheet* they have. Instruct students as follows:

  "Please write your name at the top of the page and then read the Plan Worksheet to yourselves and follow the directions. If you have questions about what you are being asked to do, raise your hand and I'll come over and answer your question."

- [5 min.] Collect worksheets and switch teachers (teacher for yellow and blue groups should go to pink and green group, and vice versa).

- [5-10 min.] Pass out "The Egyptian Pharaoh" (yellow and blue group) **OR** "The Light Bulb" (pink and green group) and teach second lesson to each group as follows:

(EACH GROUP GETS A DIFFERENT LESSON)

YELLOW AND BLUE GROUP:

"This is another problem solving exercise. This time we're going to read a story problem about how an Egyptian solved his problem.

In ancient Egypt, a mean Pharaoh ruled the people and nobody liked him. He built his palace on an island in the middle of a large lake, away from the people. Many small bridges crossed over the lake to the palace. Another Egyptian wanted to capture the palace. The people liked this man. He knew that only an attack by a huge number of people would capture the palace. Therefore, he planned to attack the palace by crossing one bridge with all his followers. He discovered, however, that the bridges were not strong enough to hold all those people at once. It seemed his plan to capture the palace would fail!

The Egyptian had a problem. He couldn't attack the palace the way he had planned and needed a new approach to capture the palace.

The Egyptian came up with a plan to solve his problem. He divided his followers into small groups and sent each group to a different bridge. At midnight, each group crossed a different bridge towards the palace. They timed each group so that all the people arrived together at the palace at the same time. They attacked the palace together and sent the old Pharaoh away. The Egyptian became Pharaoh and his people were happy."

PINK AND GREEN GROUP:

"This is another problem solving exercise. This time we're going to read a story problem about how a group of scientists solved their problem.

A number of famous scientists were working with a very expensive light bulb, used for plant experiments about photosynthesis. One day, they got to the lab to find that the light bulb didn't work anymore. When they examined it more closely, they realized that the two wires that make up the filament inside the light bulb had broken apart. The glass bulb was completely sealed, so there was no way to open it up to fix the filament. One scientist suggested repairing the light bulb by using a strong laser beam to melt the two pieces of wire together in the bulb. There were many lasers in the lab to use, but if they used a strong laser beam, the laser beam's strength would also break the fragile glass. If they used a weak laser beam, the laser beam wouldn't break the glass but it wouldn't melt the wires together either.

The scientists had a problem. They couldn't fix the filament in the light bulb with one strong laser beam and needed a new approach to fix the light bulb.

The scientists came up with a plan to solve their problem. They decided to divide the power of the strong laser beam by using many weaker lasers and aiming each laser from a different direction into the light bulb. At the same time, each beam was turned on from a different direction toward the filament. In this way, a powerful laser was concentrated on the filament at the same instant. The beams arrived at the filament and melted it together. The scientists could use the bulb again and they were very happy!"

o [5-10 min.] Pass out "Plan Worksheet #2" according to color-coding. Again instruct students as follows:

"Please write your name at the top of the page and then read the Plan Worksheet to yourselves and follow the directions. If you have questions about what you are being asked to do, raise your hand and I'll come over and answer your question."

o [5 min.] Collect worksheets and information sheets.

DAY 2 (30-45 min. total)

o NOTE: Please do not mention the previous day's story problems nor the study for the first part of this session!

- [10-20 min.] Pass out "The Fire Chief" worksheet to all students. Instruct the students:

  "Please write your name at the top of the page. I'm going to read the story problem out loud now.

  One night a fire broke out at Debby's house. Debby sounded the alarm. Within minutes, dozens of neighbors were there with buckets to help put out the fire. Luckily, Debby lived right by a lake, so there was plenty of water available. If a large amount of water from the lake could hit the fire at the same time, the fire would be put out. The Fire Chief arrived and thought they could put out the fire with a large bucket of water from the lake. But the neighbors' buckets were too small. Pouring bucket after bucket on the fire didn't help. It looked like the house was doomed.

  The Fire Chief had a problem. They couldn't put out the fire with one small bucket and needed a new approach to extinguish the fire.

  Can you come up with a plan to solve their problem? If you were the Fire Chief, how would you save Debby's house?

  Think about the Fire Chief's problem and write down your solution to the problem."

- [2 min.] Collect sheets.

- [5 min.] Hand out "Short Questionnaire" to students. Instruct students as follows:

  "Turn the Questionnaire to the page that has a place for your name. Please write your name and then read the first page of the questionnaire to yourselves and follow the directions. When you're done, turn it over to page 2 and follow the directions. If you have questions about what you are being asked to do, raise your hand and I'll come over and answer your question."

- o [2 min.] Collect questionnaires.

- o [10-15 min.] Hand out new "The Fire Chief" worksheets to all students. Tell students:

  > "Please write your name at the top of the page. You should all remember the story problems we learned about yesterday. Some of you may have used those problems to solve the Fire Chief's problem and some of you may not have. Either way is okay, but I want you to try to think about those story problems now. This time when you solve the Fire Chief's problem, I want <u>ALL OF YOU</u> to try using yesterday's story problems. If you did that the first time, just do it again. If you have questions about what you are being asked to do, raise your hand and I'll come over and answer your question."

- o [2 min.] Collect sheets.

Appendix B

Plan Worksheets

<Copy condition>

MASTER PLAN:

If you can't bring in all your force from one location, divide the force at the beginning and combine the force at the end.

DIRECTIONS:

Copy the master plan from above to the lines below.

____

____

____

<Explain condition>

MASTER PLAN:

If you can't bring in all your force from one location, divide the force at the beginning and combine the force at the end.

DIRECTIONS:

Pretend you're talking to a friend in another class. <u>In your own words</u>, how would you explain the master plan to your friend? Write your short explanation below.

____

____

____

Appendix C

Questionnaire

Did you think about or try to use any other problems or stories to help you solve the Fire Chief's problem? o Yes o No

IF YES, answer the following two questions:

1. How helpful was the problem or story you used?

o Not at all helpful o Somewhat helpful o Very helpful

2. Which problem or story did you use and how did you use it?

____

____

____

____

____

IF NO, answer the following question:

1. How did you solve the Fire Chief's problem?

____

____

____

____

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How true are the following statements? For each question, circle the number that best describes you.

	Not at all	Somewhat	Moderately so	Very much so
1. I tried to discover the main ideas in the story problem.	1	2	3	4
2. I asked myself how the story problem related to what I already knew.	1	2	3	4
3. I thought through the meaning of the story problem before I began to solve it.	1	2	3	4
4. I used multiple ways to solve the story problem.	1	2	3	4
5. I selected and organized important information to solve the story problem.	1	2	3	4

Table 1

Mean Pre-hint and Post-hint Transfer Scores by Number of Content Areas, Copy/Explain Manipulation, and Student Achievement Level (n = 12 per cell)

	One Content Area		Two Content Areas	
Group	Copy	Explain	Copy	Explain
Regular Students				
Pre-hint	0.83 (0.83)	0.42 (1.00)	1.17 (1.19)	1.25 (0.97)
Post-hint	1.00 (0.95)	1.08 (1.00)	0.92 (1.00)	1.17 (1.03)
Honors Students				
Pre-hint	1.67 (1.15)	1.42 (0.79)	1.08 (1.00)	1.42 (1.08)
Post-hint	1.75 (1.06)	1.33 (0.89)	1.50 (0.90)	2.08 (0.90)

Note. Standard deviations are shown in parentheses.

Table 2

Mean Summed Metacognitive Questionnaire Scores by Number of Content Areas, Copy/Explain Manipulation, and Student Achievement Level

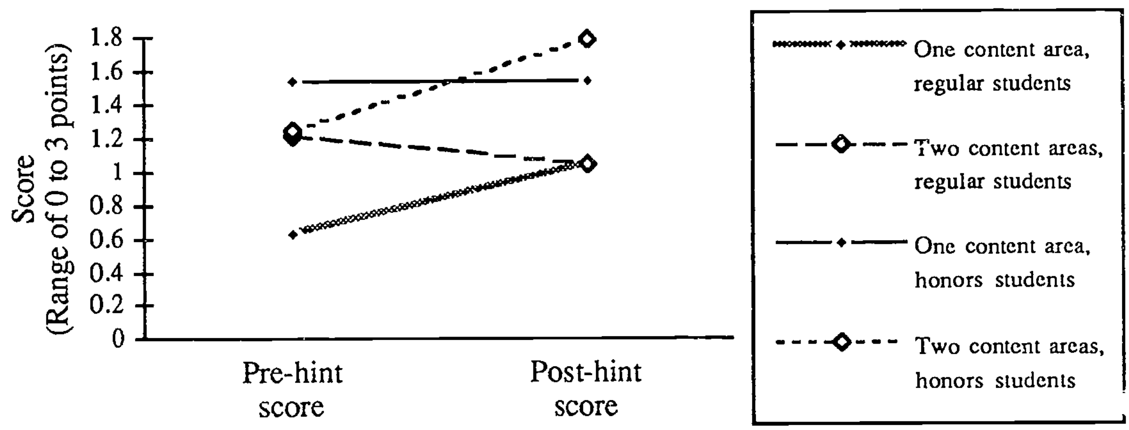
	One Content Area		Two Content Areas	
	Copy	Explain	Copy	Explain
Regular Students	11.75 (3.19)[a]	11.50 (2.20)[a]	10.58 (3.20)[a]	12.83 (2.48)[a]
Honors Students	13.82 (2.96)[b]	13.09 (1.51)[b]	14.17 (2.17)[a]	13.82 (2.09)[b]

Note. Standard deviations are shown in parentheses.

[a] $n = 12$. [b] $n = 11$.

Figure Caption

Figure 1. Pre-hint and post-hint transfer scores by number of content areas for regular and honors students.


Score
(Range of 0 to 3 points)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre-hint score
Post-hint score
One content area, regular students
Two content areas, regular students
One content area, honors students
Two content areas, honors students