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## Positive and negative transfer in analogical problem solving by 6-year-olds.

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# FIVE COLLEGE DEPOSITORY



POSITIVE AND NEGATIVE TRANSFER IN ANALOGICAL PROBLEM SOLVING  
BY 6-YEAR-OLDS

A Thesis Presented

by

Zhe Chen

Submitted to the Graduate School of the  
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of the requirements for the degree of

MASTER OF SCIENCE

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Psychology

POSITIVE AND NEGATIVE TRANSFER IN ANALOGICAL PROBLEM SOLVING  
BY 6-YEAR-OLDS

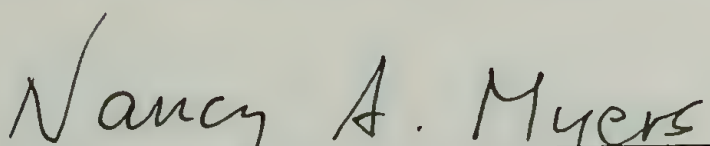
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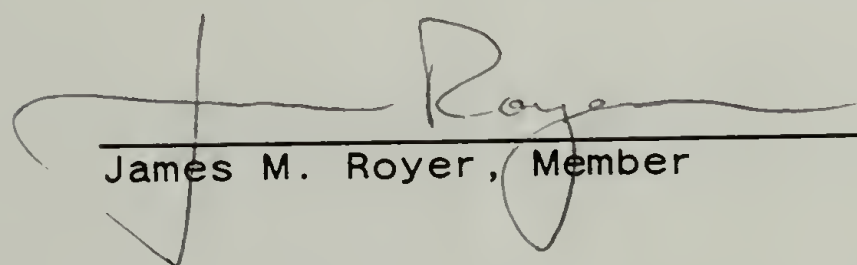
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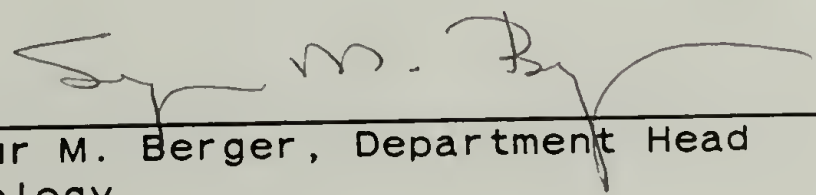
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## ABSTRACT

The present study of analogical transfer examined patterns of positive and negative transfer, the relationship between level of representation (specific or abstract schema) and transfer, and the effects of abstract schema training on problem solving in 6-year-olds. A total of 116 first grade subjects were assigned to five conditions: Schema Training Positive, Schema Training Negative, Story Analogue Positive, Story Analogue Negative, and Control. Six-year-olds are able to spontaneously transfer analogous solutions when base and target problems share few surface similarities. An abstract representation of the source analogue is an important determinant of transfer; however, specific representations do not seem sufficient for transfer. Negative transfer was obtained when the transfer task involved a solution principle different from the base problems. Schema training could effectively improve positive transfer; however, such training did not improve the ability to discriminate the effectiveness of a solution in the negative training condition. Developmental and educational implications are discussed, and future studies on children's analogical transfer are outlined.

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## C H A P T E R I

### INTRODUCTION

The present study examines whether first-grade children are able to spontaneously transfer an analogical solution when few surface features are shared between base and target problems. This study also examines how level of representation influences analogical transfer. Based on the findings of prior research it was predicted that an abstract representation would be more effective in transfer than a domain-specific representation. If so, instructions encouraging and guiding children to construct an abstract schema might also increase the likelihood of analogical transfer, and so the effects of training are also of interest here. Finally, the issue of children's negative transfer is addressed. The impact of a solution principle that is not appropriate for solving the transfer problem is studied, along with the effects of training this principle, and the consequences for discriminating applicability to the transfer situation. Is problem solving impaired when base and target problems require different solution principles?

## Traditional Transfer Theories

Modern research and theories on learning transfer have their historical roots in the works of Thorndike and Woodworth in 1901 and 1903 and Judd in 1908. Thorndike and Woodworth proposed that transfer from one task to another occurs only when the two tasks share a set of common stimulus features or elements. For example, Thorndike's theory of identical elements stated that for transfer to occur, there must be some elements of identity or similarity between the influencing and influenced "mental functions". When two tasks shared similar elements or features, a response learned to one task could facilitate or inhibit the second task. However, this identical-elements theory came under attack as a result of studies by Judd (1908) and his colleagues. Judd argued that the important condition for transfer was that the subject be able to abstract general rules or principles. He called this a theory of generalization, by which he meant that a subject must be able to "generalize" his or her experiences from one situation to another in order for transfer to take place.

These early theories of transfer represent historical viewpoints which guided much of early research on this topic. Actually, identical elements and generalization are not mutually exclusive theories, nor are they diametrically opposed. Rather, they may be regarded as different ways of

trying to explain the processes contributing to transfer. Thorndike's theory focused attention on the elements in common between learning material or activities in which transfer was expected to occur, while Judd emphasized the learner's competence in generalizing from one situation to another. It was the similar elements theory, however, which dominated the early research literature concerned with transfer.

The findings of early studies comparing the effects of the similarity of stimuli and responses were summarized several decades ago by Osgood (1949). He presented a theoretical integration of available empirical data in the form of a figure which became known as a transfer surface, and which claimed to show the relationship between response and stimulus similarity in two tasks and the transfer effects that could be expected. The Osgood model showed that if two tasks shared similar stimuli and required the same responses, what was learned about the stimuli in one task would generalize to the similar stimuli provided in the second task. Thus, what was learned from one task was to some degree transferred to performance on the second task. This described the operation of stimulus generalization. On the other hand, if two tasks called for different responses to similar stimuli, the response learned to the first task



would interfere with the response to be learned on the second task. The consequence would be negative transfer.

### Background Research And Theoretical Issues

The Influence of Thorndike's and, subsequently, Osgood's views concerning transfer can be seen in a great number of early studies which focused on the conditions that influence transfer (e.g., Wittrock, 1963; Martin, 1965; Anderson, 1956). Nearly all were concerned with stimulus and response relationships that enhance or decrease transfer performance. However, a few of these studies also attempted to evaluate mechanisms of transfer and their development, or gave consideration to the cognitive processes involved in the more creative and productive sense in which transfer is known to occur in problem solving. Recently, however, several programs of research have been initiated investigating the mechanisms of transfer in realistic problem solving situations with a particular focus on the important roles of rules, principles, and cognitive processes. One specific type of problem, that of analogical transfer, and the factors that seem to influence performance on this type of task, are especially relevant to the research conducted in this study.

#### Studies on Analogical Transfer

In recent years, analogy has come to be viewed as a major heuristic for solving problems. Analogy requires that

the problem solver use the solution concerning a problem in one domain to solve a problem in another domain. Glick and Holyoak (1983) argued that there are two essential elements for studying analogical transfer in problem solving. First, information which is analogous to the target problem must be provided. That is, a subject must understand the solution to a prior problem or comprehend the story before receiving the target problem. Second, the transfer problem must be new and sufficiently difficult so that the analogy can be potentially effective in arriving at a solution.

Several recent studies have been carried out to investigate the processes by which adults solve analogical problems. Reed, Ernst and Banerji (1974) used the missionary-cannibal and jealous husbands problems to investigate the effect of transfer between two tasks having similar (isomorphic) problem states. This type of problem is viewed as a "well-defined" problem (see Minsky, 1961; Reitman, 1964; Simon, 1973) since the initial conditions, acceptable procedures and goal to be reached are explicitly specified. These two problems are similar because both involve a river crossing. In both problems, subjects need to transport three missionaries and three cannibals (or husbands and wives) across a river on a ferry which is so small that it can contain no more than two persons. Moreover, the missionaries on either bank or in the boat

must not be outnumbered at any time and similarly, no wives shall be left in the company of any men, unless her husband is present. In both cases, subjects are required to move people and evaluate the legality of their moves. Someone who knows the solution to the missionaries problem can solve the Jealous husbands problem by substituting husbands for missionaries and wives for cannibals. In addition, in the Jealous husbands problem, subjects must pair men and women who are on the same bank of the river. If people make use of the analogy, it should be easier to solve the second of these two problems if they have already solved the first. However, the results indicated that people were, in fact, not better at solving the target problem after they first solved the other problem than subjects with no prior experience with the analogous problem.

One explanation for why people did not improve their performance on the second of these two similar problems is that they did not perceive the relationship between the two problems. In a second study, the experimenter encouraged subjects to use the solution for the first problem to solve the second problem. They informed subjects that husbands corresponded to missionaries and wives corresponded to cannibals. The information indicating that the problems were related did help subjects solve the missionaries and cannibals problem when it was the target problem but it did



not help them to solve the Jealous husbands problem when it was the target problem.

The results of this study indicated that the successful use of analogy by adults does not occur as readily as researchers might expect. The fact that subjects needed to be informed about the correspondences between the two stories indicated that subjects had difficulty in "noticing" that there is some relationship between one problem and another. But even when the instructions emphasized the exact relationship between the two problems, arriving at the solution for one problem did not guarantee solution of the other. One explanation for this latter finding is that it is difficult to remember the correct solution (exact steps) when it consists of a long sequence of moves. This hypothesis suggests that the use of analogy should be more effective when the solution is easier to remember.

Several other investigations of analogical transfer have adopted relatively "ill-defined" types of problem to study transfer between base and target problem. Such ill-defined problems often require only one creative or insightful step and allow multiple solutions. An example of such a problem is the tumor or radiation problem which was first used by Duncker (1945). In this problem, a doctor needs to use a kind of ray to destroy a malignant tumor in a patient's stomach. However, if the ray is of sufficiently high

Intensity to destroy the tumor, the healthy tissue that the ray passes through will also be destroyed. An acceptable solution involves dividing the ray into many less intense rays so they will have a high intensity only when they converge on the tumor (dispersion solution). Although this is an effective solution, Duncker found that very few people solved the problem in this way.

Glick and Holyoak (1980) investigated whether more people would discover the dispersion solution if they were first exposed to an analogous story. Their subjects (college students) read an attack-dispersion story associated with a military problem in which the army had to be divided in order to converge on and capture a fortress. The instructions indicated that this story might prove insightful for solving the radiation problem. The results showed that most people did make use of the analogue. Over half of those who read the attack-dispersion story included a radiation dispersion solution among their proposed solutions compared to only 8% of the people who did not read the base story before attempting to solve the radiation story. But when Glick and Holyoak omitted the hints to use the military story, many subjects again failed to notice the relevance of it for the medical story, and hence the frequency of use of the dispersion solution to destroy the tumor decreased. Their findings provided further

confirmation that college students can generate an analogous solution when prompted, but they often fail to spontaneously recognize or notice it.

Several experiments, then, have shown that people often fail to notice the relation between two problems unless the instructions describe the relation, or at least suggest that some relation exists (e.g., Reed et al, 1974; Duncker, 1926; Glick & Holyoak, 1980). Several factors, such as the complexity and type of problems, degree of similarity between base and target problems, degree of original-task learning and variety of previous tasks could influence noticing and therefore analogical transfer. The possibility is that these factors facilitate performance through increasing cue or surface similarity, a factor that would not extend our understanding of transfer processes much beyond earlier conceptions of identical elements. But another answer to the problem of "noticing" has been given in terms of the induction of a schema (Glick & Holyoak, 1983), a generalized representation of the initial state, solution plan and outcome of a problem. Glick and Holyoak (1983) argued that when a schema is abstracted, this relationship can be effectively mapped from one problem to another. Furthermore, analogous information in the form of an abstract schema might be more accessible than information in concrete forms when subjects encounter the target



problem. Thus, an important issue for Gick and Holyoak has been to determine how a problem is represented since it is these representations that govern the likelihood of noticing an analogy and mapping the correspondences between base and target problems.

Gick and Holyoak (1983) attempted to encourage subjects in several ways to abstract a general (convergence) schema when exposed to only a single analogous story. These included (1) asking subjects to summarize the story rather than recall details; (2) asking them to read a sentence at the end of the story which abstractly described the solution to the problem; and (3) providing subjects with a diagram to represent the underlying solution principle after subjects read the story. None of these attempts were successful.

In contrast, subsequent experiments by Gick and Holyoak (1983) demonstrated that if two prior analogs were given, subjects often developed a convergence schema and hence, improved transfer. Under these circumstances, subjects given analogs with an additional abstract sentence summarizing the solution principle or with a diagram depicting a figure characterization of the solution principle, achieved even higher levels of transfer than subjects in the analog only condition. Furthermore, the quality of the induced schema was highly predictive of subsequent transfer performance. Summaries by the subjects were categorized into three

levels, good, intermediate and poor, based on the degree to which subjects produced the solution principle, that is, "to use many small forces together to add up to one large force necessary to destroy the object" (p.23). A much higher percentage of subjects who produced good schemas achieved transfer (91%) than those who produced intermediate (40%) or poor schemas (30%). This finding was obtained whether analogs came from the same domain (both were military stories) or from dissimilar domains (a military vs. a fire-fighting story).

The investigations briefly reviewed here examined the mechanisms of transfer or conditions which influence analogical transfer. Several other related studies (e.g., Welsberg et al 1978, Perfetto et al 1983, Stein et al 1986) have also indicated that individuals usually do not spontaneously access useful prior information while solving "insight" problems.

#### Developmental Research on Analogical Transfer

While a great deal of work has been done on how subjects solve formal analogies (see Sternberg & Rifkin, 1979; Sternberg, 1982), relatively little has been done on the use of analogy in solving realistic problems, especially by children. Many studies of analogical thinking and its development have been carried out using the form  $A:B::C:?$ . Such problems emphasize how the relationship between A and B

is generalized so that an item is selected to match C. The fact that subjects are informed that A and B have a relationship and that it is useful for deriving the answer, precludes gaining information about developmental differences in how children "notice" analogical relationships.

Holyoak, Junn and Billman (1984) investigated young children's ability to transfer a common solution heard in one story to an analogous problem. Preschoolers and fifth and sixth graders were asked to solve a problem that allowed multiple solutions. The transfer problem required children to move small balls from a nearby bowl to an empty bowl farther away and beyond the children's reach. They could solve the problem by using a hollow cardboard tube long enough to reach the farther bowl or by rolling up a heavy paper to form a tube or by using a cane to pull the distant bowl nearer.

Before attempting to solve the transfer problem, subjects first read a story that involved an analogous problem. The mapping between the analogous and target problems was fairly straightforward, in that the corresponding instruments were perceptually and functionally similar. Even preschoolers were able to use this analogy to derive a solution to the target problem. However, a high degree of perceptual and functional similarity between the



instruments in the base and target problem seemed neither sufficient nor necessary for success by preschool subjects. When the story analog mapped well onto the transfer problem, 4-year-olds were often able to transfer a solution, although there was little perceptual or semantic similarity between the base and target problems. In this study, children demonstrated considerable ability at analogical problem solving, although this ability was relatively fragile, especially for younger children. For example, young children typically required hints to consider the prior problem. otherwise, they frequently failed to notice that the two situations might be analogous. Younger children tended to rely on the surface features shared by base and target problems to "notice" the analogy.

Crisafi and Brown (1986) examined the ability of even younger children (2-4 years old) to transfer responses in a similar task. They found that by 3-years of age, children were able to perform analogical transfer. They also found that analogical transfer can be facilitated either by directly informing children that the target problem is an appropriate occasion for the application of the old responses, or by encouraging children to talk about the rule underlying the solution to two analogical base problems that were presented. For example, after they completed the two problems, the experimenter described the rule common to each

version. The subjects were able to repeat the rule after it was stated by the experimenter although few of them could state the rule in abstract terms without aid. Nevertheless, when the rule was explicitly described by the experimenter and repeated by subjects, there was a great improvement in subsequent transfer, compared to when subjects received no such training.

Brown, Kane and Echols (1986) have performed additional studies to assess how representation influences young children's analogical transfer. In their study Brown et al. explored whether subjects are more likely to achieve transfer when they spontaneously recall or are prompted to form a common goal structure for the base and target problems than when they fail or are not required to form such a schema. The goal structure includes a character (Who has a problem?), goal (What did the character want to do?), obstacle (What is stopping him?), and a solution (How did he do it?). When subjects were encouraged to concentrate on the essential elements of the analogous story by being asked four questions about these elements, 93% of five-year-olds and 63% of four-year-olds showed transfer. However, only 75% and 56% of the respective age groups in the spontaneous recall condition, and only 56% and 44% of subjects in the control group showed transfer.

In another study, subjects who spontaneously focused on the goal structure in their recall (68% for 5-year-olds) or who did not recall the goal structure but were prompted to achieve such a structure (71% and 64% for 5- and 3-year-olds respectively), evidenced transfer. But only 14% of the 5-year-olds who did not represent the problems at the level of the underlying goal structure, and instead reported only irrelevant surface features, showed transfer. The data provide strong support for the claim that the common goal structure allows for analogical transfer.

Brown et al.'s findings also indicated that children as young as 3 years of age have the underlying competence to flexibly transfer a common problem solution. Based on these findings, Brown et al. went on to conclude that transfer is not a simple function of age but depends on the level of analysis afforded the base analogy. That is, level of representation rather than age determines transfer efficiency. However, it should be noted that since age and representational efficiency might be highly positively correlated, transfer ability could be age sensitive.

#### Major Issues Related to the Present Study

Level of Representation. The representation of an analogy may occur at different levels of abstraction. Brown et al.'s common goal structure seems to be relatively more specific than Gick and Holyoak's abstract convergence



schema. A goal structure is abstract in that it includes four major elements of a story problem: a goal, a protagonist, an obstacle and a solution. Nevertheless, the goal structure is represented or manifested in relatively concrete form since it is still tied to the particular character, goal, obstacle and solution of a story problem (e.g., "the genie transfers jewels from bottle 1 across wall into bottle 2 by using his magic carpet") rather than to a more abstract schema or generalized principle. Brown suggested that such a goal structure is "an optimal mental model" of the base analog and "the most advantageous level of representation". However, a common goal structure and a convergence schema can be viewed as two different levels of representation in terms of abstraction. The former is relatively specific while the latter is more abstract and generalized than the former.

A knowledge structure that still retains featural commonalities between domains can be expected to maximize the likelihood of noticing the analogical relationship and this should be beneficial to subsequent transfer. The results in Brown et al.'s study suggested that subjects who form a goal structure achieved a very high level of transfer. However, the relative efficiency of a specific representation vs. an abstract, domain-independent schema can only be directly addressed by comparing transfer

performance between subjects who form a goal structure (specific representation only) with those who summarize a domain-free principle as well. Children who produce an abstract schema would be more likely to achieve analogical transfer than those who just construct the specific representation.

Processes of Analogical Transfer. Almost all studies of analogical transfer in problem solving have focused only on "noticing" and "mapping" processes. Actually, problem solving by analogy is a complex cognitive activity. Several researchers have described and analyzed these processes (e.g., Holyoak, 1984; Gentner In press). Holyoak argued that there are four components involved in analogical transfer: (1) forming a mental representation of the base and target problems; (2) noticing the potentially analogous relationship between the problems; (3) mapping the correspondences between the elements of the base and target; and (4) extending the mapping to construct a solution appropriate for the target problem. Gentner described several subprocesses of analogical learning. According to her view, learning by analogy involves accessing the base problems; mapping the base and the target; judging the soundness of the mapping and extracting the general principle. Thus, a theoretical analysis of how analogies are used to solve problems has suggested that both analogous

problem and target problems must be represented, similarities between the problems must be noticed, and the representations of the problems must be mapped. Yet an additional important process is concerned with evaluating the appropriateness of using the solution, or in the case of multiple potential sources for analogical transfer, discriminating that which is best or most appropriate.

In essence, success in using an analogy in problem solving depends on representing, noticing, mapping and applying. Recognizing the analogous relationship between the base and target, or noticing the "problem isomorph" (Newell, 1979; Rumelhart & Norman, 1981, and Simon, 1979) is an essential prerequisite, while eventual application involves transforming the relatively abstract or generalized principle into a concrete form in the target problem situation, and simultaneously, evaluating its applicability to the novel situation. When the solution principle is exactly the same, application seems trivial. However, when the analogous solution requires elaboration in order to suit the principle to the target problem situation, or the solution rule is inappropriate to the target problem, or the most effective solution principle must be discriminated from multiple analogical situations, the process of applying is crucial for appropriately solving the problem. Negative



transfer is especially problematic in situations involving the application of an analogous solution.

Brown (Brown & Camplone, 1984; Brown et al, 1986) has pointed out that effective transfer involves discriminating the appropriateness of a solution to a situation rather than blind application. She implied that the process of transferring information across task boundaries should include a component of evaluation. Failure to transfer can be a consequence of many factors. On the one hand, information available in one situation, though appropriate, may not be readily used. The inability to flexibly use available information for appropriate occasions may be largely due to failing to notice the similarities among the situations. On the other hand, knowledge may be applied in inappropriate contexts. Subjects may rely on similarity in the surface features of task situations and fail to realize such features may not be relevant or can be misleading. Mistaken or inefficient application is the product of failure to discriminate the functional differences between the problem situations. Thus, flexible and appropriate transfer of a known solution principle requires noticing and also evaluating the applicability of the solution to a new occasion.

The "Set" Problem and Negative Transfer. When a person repeats a mental activity, there is some tendency for it to persist in a new situation although in some cases the rule or strategy is no longer suitable to the situation. The classic study of the "set" or "sequence cue" was reported by Luchins (1942) who studied the effect of giving subjects a series of "water-jar problems" in which subjects were shown a set of jars of various capacities and an unlimited water supply. The subject's task was to measure out a specific quantity of water. Of ten problems presented to subjects, all but the eighth could be solved using the B-2C-A method, that is, by filling B, pouring B into C twice, and then pouring B into A. For the first 5 problems, this solution was the only solution, but for problems 7 and 9, and problem 6 and 10, a simpler solution existed (A+C and A-C, respectively). Problem 8 could be solved using only a simpler solution (A-C). After doing problems 1 through 5, 83% of the subjects continued to use the B-2C-A method to solve problem 6 and 7, 64% failed to solve problem 8, and 79% used B-2C-A for problems 9 and 10. The performance of subjects who worked on all problems was compared with the performance of control subjects who only saw the last five problems. Fewer than 1% of the control subjects used the B-2C-A solution on problems 6 through 10, and only 5% failed

to solve problem 8. Thus, the first five problems created a powerful bias for a particular solution.

Problem-solving set has been described in negative terms. Actually, whether a set will facilitate or impair solving problems depends on the applicability of the set to the problem. Set effects occur when some information or certain rules become more available at the expense of others. If the available knowledge is what the subject needs for solving the problem, his or her problem solving will be facilitated. If the available knowledge is not what is needed, problem solving will be inhibited. A set usually involves a fairly specific solution rule which will aid in solving some problems but impair solving others.

Negative transfer is related to the "set" problem. A major impediment to flexible learning is often not the lack of transfer across domains, but rather "inappropriate transfer" (Brown & Camplone, 1984), including functional fixedness and set. Since positive and negative transfer are aspects of the same process, consideration of issues of application may tell us a great deal about the process of analogical transfer. In several studies we described above, once the analogy was noticed, the application of the rule was fairly trivial. But in a few cases, the "analogous" solution was not useful to the target problem, the "analog" was a trap, and inhibited other better solutions, as Luchins



(1942) has shown so dramatically. Investigating both positive and negative transfer in problem solving might shed more light on the mechanisms of flexible and appropriate transfer and provide a better and more comprehensive understanding of transfer in new contexts.

A large number of studies of learning have tested for both positive and negative transfer, but few have been carried out using analogical transfer. The heuristic value of analogies is often the key to creative solutions to a problem. However, people do not always take advantage of this type of transfer. Not only do principles sometimes fail to generalize, but they may transfer to situations where they are inappropriate.

Brown and Kane (in press) examined young children's negative transfer. They considered both functional fixedness (where the typical function of a tool is reinforced and is thereby rendered unavailable for a novel use) and cognitive embeddedness (where a potential solution tool is not seen because it is embedded in a familiar context) as impediments to cognitive flexibility and learning to learn. In a pretraining task, children were engaged in using a certain object (e.g., string) in typical ways (hanging, tying, pulling), or in atypical ways: measuring, sewing and stuffing. Thus, the function of the string was a usual one (functional fixedness condition) or an unusual one

(flexibility condition). Children showed less transfer in the functional fixedness condition than in a baseline condition. But, the flexibility condition yielded a great increase in transfer presumably because the unusual uses of the string led to its being freed from its typical function and made it more available as a problem solution tool.

A replication was also carried out in which biological themes served as the domain for the analogy. In the "flexible group", young children benefited from the multiple examples of how animals defend themselves by various mechanisms. Although the learning phase did not cause them to learn a particular rule, it did prepare them to look for novel solutions suitable to the new situation. In contrast, children in "fixedness group" attempted to apply a particular rule learned from several examples. The particular rule blocked the subjects from considering alternative possibilities.

When the base and target problems require the same solution rule, a more abstract level of representation of analogs should be beneficial to and yield positive transfer across different domains (Glick & Holyoak, 1983). But will it be harmful to problem solving when the two situations require different solutions? Or can increasing abstraction -- from a more detailed or specific representation to a schema -- enhance both positive and negative transfer? Level

of representation of analogs may only influence noticing and mapping processes, and may not be instrumental in facilitating evaluation or discrimination of the solution to new situations.

Developmental Differences. Several studies have indicated that transfer ability in problem solving is developmentally sensitive. Young children's acquired knowledge tends to be closely tied to specific situations, and "flexible access to information" (Brown and Campione, 1981) is often assumed to be uncharacteristic of young children's thinking (Rozin, 1976; Brown & Campione, 1984). Under suitable circumstances, young children may well be able to display a whole variety of logical competencies. For example, several studies have demonstrated that young children are able to transfer prior knowledge to novel contexts or domains to a certain extent. Crisafi and Brown (1986) found that 3-year olds transferred readily across dissimilar problems if they first "taught" the base solution to a puppet learner, and hence had been prompted to use the common solution to the target problems. Holyoak et al's findings (1984) demonstrated that even preschoolers can use analogies to solve problems under optimal circumstances (e.g., when hints are provided to encourage subjects to find the similarity or when the similarity between task contexts is pointed out). Brown et al (1986) have obtained



results which are also consistent with these findings. However, young children's competence may be relatively limited and more restricted in range than these studies first suggest when we consider that flexible and appropriate transfer is affected not only by the ability to notice problem isomorphs, but also by an ability to discriminate the appropriateness of prior information in a novel situation. Difficulty in transfer arises just as readily from inappropriate application of rules as from a failure to utilize available information (Brown et al, 1986). We can not be certain from these prior experiments whether very young children have effectively demonstrated transfer or are blindly applying the solution principle that immediately dominates their thinking about a problem.

Current investigations of transfer in problem solving have focused on positive transfer, either with simple analogical problem solving in young children (e.g., Crisafi & Brown, 1986; Holyoak et al, 1983; Brown et al, 1986) or with more complex problems using adults (e.g., Reed et al, 1974; Glick & Holyoak, 1980; 1983). In these studies, researchers have focused on the process of noticing and mapping. That is, recognizing problem isomorphs or recognizing that a new situation is similar to one encountered previously. In these cases, as Glick and Holyoak have pointed out, the "gap" between initial noticing and

eventual application of the analogs has been very small. Once one recognizes the similarity, he or she can directly apply the solution to the new situation without considering the appropriateness. However, when the base and target do not share a common solution rule, children might tend to inflexibly apply the rule if they recognize the similarities of the surface features ("blind application"). Studies have explored whether children have difficulty noticing a potentially useful analogy, but few have explored children's ability to decide whether an analogue is appropriate or not.

In summary, although relatively few studies have been conducted examining the problem of analogical transfer, particularly with children, a number of investigations on this topic have shed some light on the mechanisms or processes of transfer in problem solving. Data from adults and children suggest that 1) individuals do not usually spontaneously use prior analogous problem solutions in solving the isomorphic problem, 2) analogies are often a valuable heuristic for solving problems, even to young children, although in many cases various hints are required; 3) prior information might impact negatively, rather than positively, when base and target problems require different solution rules, and 4) abstract schemas produce superior analogical transfer for adults, and specific representations (common goal structure) facilitate children's transfer. How

differential levels of representation of story analogs influence children's positive and negative transfer performances, and whether instructions guiding children to achieve an abstract representation improve transfer performance serve as the major question to be addressed in the present investigation.

The present study, then, attempts to focus on 1) the patterns of children's positive and negative transfer in problem solving; 2) the relationship between level of representation and positive and negative transfer, and 3) the effects of schema training on positive and negative analogical transfer. The transfer task employed in the present study involves two analogous story problems which share a common solution principle at a deep level but few surface similarities with a practical target problem. Thus, base and target problems share neither superficial features nor context cues. In this case, effects of "set" or "sequence prompts" is minimized, and remembering the base story problems might not be sufficient for transfer; an abstract representation might be required.



## C H A P T E R   I I

### METHOD

#### Subjects

A total of 116 first grade subjects from one elementary school in each of two cities, Pittsfield (62) and Chicopee (54), Massachusetts were included in this study. There were 57 males and 59 females (mean age= 6 years, 9 months). Approximately equal numbers of boys and girls were included in each group and condition.

#### Materials

##### Transfer Problem

The transfer problem used in this study required subjects to retrieve a bead from the bottom of a tall cylinder. There were two versions of the problem:

1. The "Adding" Problem. Subjects in this version of the problem were provided with a glass cylinder 12 inches tall containing a small amount of water with a bead floating on the surface. The cylinder was only 2 inches in diameter and subjects could not simply reach in to obtain the bead. The cylinder was located on a child-size table along with a number of other common items. These included (1) a glass measuring cup containing water, (2) two sticks of different

colors (tinkertoys), and (3) Irrelevant props. Irrelevant props consisted of a piece of heavy paper, paper clips, small toy bricks, a toy scissors, a toy hammer, pliers, rubber bands and a scarf. The task was to retrieve the bead without turning the cylinder upside down. In this version of the problem, each stick was too short to reach the bead by itself. Moreover, if the two sticks were joined, it was still not possible to get the bead out. However, there was a sufficient amount of water in the measuring cup so that when poured into the cylinder, the water level rose and the floating ball could be reached.

2. The "Combining" Problem. This version of the problem was exactly the same as the first except that 1) only a small amount of water was present in the measuring cup and when poured into the cylinder failed to raise the water level sufficiently for the child to reach the bead, and (2) a toy spoon with a tinkertoy connector on the handle replaced one of the two sticks, and when attached to the end of the other stick, could be used to lift the bead out of the cylinder.

#### Story Analogs

Two different sets of two stories were used as story analogs for the experimental groups. Each of these four stories included a goal, obstacle, solution and irrelevant information (extra details).

Set 1. Both of the stories used in this set included a problem in which the solution was similar to version 1 of the transfer problem described above. The two stories described different situations and protagonists, but the solution rule was the same, that is, "reaching an object that can not be directly retrieved by adding something to make it rise". The first story described a bird trying to drink water from a bottle but she could not reach the water. The solution was to use her beak to pick up and put some pebbles into the bottle so that the water level was elevated. In the second story, a ping pong ball rolled into a narrow hole. The hole was too deep for the boy to reach the ball. The solution was to fill the hole with water so that the ping pong ball floated to the top. The complete stories are presented in Appendix A.

Set 2. The two stories used as base analogs in this set utilized solutions appropriate for Version 2 of the transfer problem. The first story described a monkey who was able to combine two short poles together so that it was now long enough to reach the food outside its cage. The second story described a boy who was able to get a ball from the roof by tying two bats together so that the ball could be reached. See Appendix A for these stories.

Table 1 summarizes the goal, obstacle, and relevant solution principles for the transfer problems and outlines



Table 1

SUMMARY OF TRANSFER PROBLEM AND BASE STORIES

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Transfer Problem

GOAL: To get the bead out of the cylinder

OBSTACLE: The bead is too low to reach

RELEVANT SOLUTION: Version 1. Add Water  
Version 2. Combine Items

---

Base Stories

SET 1:

Specific Representation --

"The Thirsty Bird"

"The Fallen Ball"

Goal: Get a drink of water Get pingpong ball in hole

Obstacle: Water too low to reach Ball too deep to reach

Solution: Put stones into bottle Pour water into hole

Abstract Schema -- Reaching something that can not be  
directly obtained by adding something  
to make it rise.

---

SET 2:

Specific Representation --

"The Hungry Monkey"

"The Caught Ball"

Goal: Get food outside the cage Get ball from the roof

Obstacle: Food too far away to reach Ball too high to reach

Solution: Join two sticks together Join two bats together

Abstract Schema -- Reaching something that can not be  
directly obtained by combining two items.

---

the specific representations and the abstract schema or more generalized representation that captures the essential solution principle for the sets of stories.

An additional set of two neutral stories was used in a control condition. These stories, also presented in Appendix A, were about a visit to the zoo and moving into a new house, irrelevant to the target problem.

### Design and Procedure

There were ten groups in this study: four Story Analogue groups, four Schema Training groups and two Control groups, are summarized in Table 2. These groups differed in which version of the transfer problem they received ("adding" or "combining" solution principle), which base stories they were presented (Set 1 or Set 2 or Control) and whether the solution principle introduced in the base stories agreed with or differed from the solution principle for the target problem (positive or negative transfer). The experimental procedure consisted of two phases. First, two base stories were provided. Second, the transfer problem was presented.

### Presentation of Base Stories

Story Analogue Groups. In these groups, the subject was instructed that he/she would hear two stories. After listening to each story the subject was asked to recall it. After both stories were read and recalled, the subject was

Table 2  
SUMMARY OF CONDITIONS

<u>Condition</u>	<u>Base Problem</u>	<u>Transfer Solution</u>	<u>Type of Transfer</u>
Story-Analogue	Set 1	Add Water	Positive
Schema-Training	Set 1	Add Water	Positive
Story-Analogue	Set 2	Add Water	Negative
Schema-Training	Set 2	Add Water	Negative
Control	Irrelevant	Add Water	n/a
Story-Analogue	Set 1	Combine Items	Negative
Schema-Training	Set 1	Combine Items	Negative
Story-Analogue	Set 2	Combine Items	Positive
Schema-Training	Set 2	Combine Items	Positive
Control	Irrelevant	Combine Items	n/a



also asked to indicate the ways in which the two stories were similar (e.g., "Are these two stories alike?"; "Can you tell me how they are alike?" "Was there anything that happened in the two stories that was alike?"). The answers to these questions and the recall protocols were subsequently scored to determine whether the child had abstracted and generalized the solution principle common to both problems. Responses were classified as following into one of four levels of comprehension of the stories:

- Level I: Irrelevant Recall -- Irrelevant surface details of the stories were remembered.
- Level II: Incomplete Representational Recall -- Only the solutions, but no other key elements (goal and obstacle) of the problems were remembered, and these were recalled in the form of story-specific features of the problems.
- Level III: Complete Specific Representational Recall-- All three key aspects of the goal structure for each story were remembered but in the form of story-specific features.
- Level IV: Abstract Representational Recall -- A schema integrating the key elements and solution principle for both stories was reported.

Examples of recall and response protocols scored at each of the four representation levels are presented in Appendix B.

Schema Training Groups. Because not many subjects in the Story Analogue Groups were expected to be able to spontaneously generate abstract schemas when comparing the two stories, four schema training groups were also included in this study. The story recall phase for these groups was identical to that in the Story Analogue Condition. After the

stories had been presented, the subject was also instructed to compare the two stories. If he/she failed to provide an abstract representation (Level IV), he/she was then explicitly instructed concerning the generalized principle. The following concrete questions were asked depending on the response produced. "In both of the two stories, (the characters) had a problem and tried to solve the problem. How are the problems alike?" "They could not get the objects (e.g., water and ping-pong ball), why?" "How did they finally get the objects they wanted?" "How were the ways of solving their problems alike?" After the subject answered these questions, he/she was asked a general question: "Now, can you tell me how the two stories are alike?". After the subject summarized the stories, or was provided an explicit verbal statement of the generalized schema. If he/she failed to do so, the problem solving phase was introduced.

The two sets of stories were combined with the two versions of the problem to balance conditions for positive and negative transfer. Subjects who solve the "adding" problem after hearing story Set 1 (or solved the "combining" problem after receiving story Set 2) were expected to demonstrate positive transfer. In contrast, negative transfer might be expected when subjects solved the "adding" problem after receiving the second set or solved the "combining" problem after hearing the first set.

Control Groups. Subjects in the two Control Groups were asked to solve the transfer problem after hearing two neutral stories. The two control groups differed only with respect to which version of the transfer problem they received.

#### Introduction of Transfer Problem

During the problem-solving phase, the table and the apparatus were moved to the front of the child. The subject was then shown a tall cylinder containing a little water with a bead floating on the surface. The props which could be used to solve the transfer problem as well as the several irrelevant items were scattered around the cylinder. The experimenter directed the child's attention to the cylinder and instructed: "Now, Let's do something else. Someone dropped this bead in here. Can you get it out without turning the cylinder upside down?" Subjects were encouraged to think about the problem and to use the objects on the table freely. If a subject had not begun to attempt a solution after 20 seconds, he/she was told: "Now, use anything you want on the table to show me how to get the ball out." Up to 200 seconds was allowed to solve the problem.

If the child produced an analogous solution, the experimenter asked the child how he (she) arrived at it ("How did you think of pouring the water - or attaching the



spoon and stick?"; "Did you find the stories helpful in solving the problem?"; "How did the stories help you?")

### Predictions

Four major sets of predictions can be outlined:

1). In the Story Analogue Conditions, the frequency of using analogous solutions in the positive transfer groups should be higher than the base rate produced by the control groups. Time taken to solve the target problem might also differ between subjects in the Story Analogue and Control Conditions.

2). Subjects in the Story Analogue Positive Transfer groups who are able to create abstract schemas (Level IV) should solve the transfer problem more effectively than those who form irrelevant or specific representations. In other words, transfer performance should be positively correlated with the level of schema abstraction that subjects demonstrate.

3). The predictions for the Story Analogue groups receiving a negative transfer task are more complicated. Subjects could try to solve the target problem by using the "faulty" analog provided in the stories. If so, few would solve the problem successfully and such a finding would suggest that subjects notice or access a solution principle but fail to discriminate its appropriateness for the transfer problem. This blind application should also hinder

subjects from arriving at potentially better solutions. On the other hand, use of appropriate and faulty attempts to solve the transfer problem may not differ from baseline performance in the Control Condition for two possible reasons. First, subjects may not perceive the relationship between the negative base story analog and the target problem so that no interference occurs. Alternatively, children may notice the negative solution principle but also recognize that it is inappropriate, and be able to reject it so that another solution is sought, much as in the Control Groups.

4). Finally, it is predicted that a greater percentage of subjects in the Schema Training Positive Transfer groups will achieve an abstract schema and hence produce superior transfer performance than subjects in the Story Analogue Positive Transfer Condition who have not been trained to represent the solution principle at an abstract level.

## C H A P T E R   I I I

### RESULTS

The present study addresses the following questions: (1) Do first grade children spontaneously utilize the story analogue to solve the target problem? (2) What role does representation level of the base problems play in analogical transfer? (3) Can children be effectively encouraged and guided to achieve an abstract representation of prior story problems in order to improve transfer performance? and (4) Does an acquired inappropriate solution principle interfere with solving a problem?

Five dependent measures were analyzed to address the questions. First, the proportions of subjects in each condition that were successful in solving the target problem within 200 seconds were calculated. The proportions of subjects who produced "appropriate" attempts to solve the target problem were also calculated. Appropriate attempts refer to those structurally similar to the correct solution principle for the transfer problem, regardless of whether they yielded success. For example, attaching items (i.e. stick and spoon; clothes pin and stick; hammer and clothes pin) in the "combining" problem, or pouring water or



dropping other items into the water in the "adding" problem, were considered appropriate attempts whether or not such attempts led to successful problem solving.

Another measure was the proportion of subjects who produced "faulty" attempts to solve the problem. Faulty attempts refer to those structurally similar to the incorrect solution principle. For example, using water or dropping other items into the water in the "combining" problem or combining items in the "adding" problem were scored as faulty attempts. Faulty attempts do not include picking up and using the irrelevant items on the table. In the negative condition, children could be misguided by the inappropriate solution principle, and the proportion of subjects who incorrectly attempt to solve the target problem would increase.

In addition to these dependent measures, a 6-point scale was established to assess the relative efficiency and success with which subjects approached and solved the transfer task. This scale took into consideration whether or not subjects successfully solved the problem, if and when they made appropriate or faulty attempts to solve the problem, whether any irrelevant solution attempts were produced. The criteria for each scale assignment was as follows:

### Solution Behaviors:

### Assigned Score:

No solution; No Appropriate attempt.	1
No solution; Appropriate attempt; Faulty attempt.	2
No solution; Appropriate attempt; No faulty attempt.	3
Solution; Appropriate attempt after faulty attempt.	4
Solution; Appropriate attempt; No faulty attempt.	5
Immediate solution without any Irrelevant activity.	6

The final dependent measure was time required by the subjects to solve the problem. Response time has been shown to be an important index of many types of cognitive processing. For this analysis, problem solving time for subjects who did not solve the target problem was scored as 200 seconds.

### Preliminary Analyses

Preliminary analyses performed on the proportion of subjects successful in solving the target problem and in time taken to solve the problem yielded no reliable difference between subjects from the two schools and between boys and girls in any of the five conditions. Therefore, the data were collapsed over school and gender.

The data have also been summarized over target problem versions. The two versions of the target problem ("adding" and "combining") were assumed to be the same level of difficulty and, indeed, the proportions of subjects successful in solving these two versions in the Control Condition was approximately the same (33% and 25%, respectively). There was also no significant difference in the proportion of subjects successful in solving these two

versions in either the Story Analogue or Schema Training Condition.

The scores for each of the five dependent measures for each of the conditions are presented in Table 3. Differences among these conditions were reliable for proportion of subjects successful in solving the problem ( $\chi^2(4)=49.9$ ,  $p<.0001$ ); proportion of subjects making appropriate attempts ( $\chi^2(4)=24.2$ ,  $p<.0001$ ); and proportion of subjects attempting faulty solutions ( $\chi^2(4)=25.98$ ,  $p<.0001$ ). A One-way-analysis of variance showed a highly significant difference in subjects' scores on the success-efficiency scale ( $F(4,111)=20.29$ ,  $p<.0001$ ) and in time taken to solve the problem ( $F(4,111)=17.63$ ,  $p<.0001$ ). Further analyses were carried out to examine specific issues of concern in this study, and are presented in the following sections.

#### The Pattern of Positive and Negative Transfer

As Table 3 reveals, seven of the 24 children in the Control Condition solved the target problem, compared to 15 of 25 in the Story Analogue-Positive Transfer Condition, and only two of 24 in the Story Analogue-Negative Transfer Condition. The difference between the positive transfer and control conditions was reliable at the .05 level ( $\chi^2(1)=3.71$ ). The proportion of subjects successfully solving the problem in the Story Analogue-Negative Transfer



Table 3

SCORES ON VARIOUS DEPENDENT MEASURES  
AS A FUNCTION OF CONDITION

Dependent Measure	Schema Training Positive Transfer (N=21)	Story Analogue Positive Transfer (N=25)	Control (N=24)	Story Analogue Negative Transfer (N=24)	Schema Training Negative Transfer (N=22)
Percentage of Subjects Successfully Solving the Problem	91% (19)	60% (15)	29% (7)	8% (2)	5% (1)
Percentage of Subjects Attempting Appropriate Solutions	91% (19)	68% (17)	50% (12)	25% (6)	36% (8)
Percentage of Subjects Attempting Faulty Solutions	0% (0)	16% (4)	17% (4)	58% (14)	46% (10)
Mean Success-efficiency Score	5.09	3.80	2.50	1.50	1.59
Mean Time (seconds) to Solve Problem	86	118	169	195	195

Condition was lower than that in the Control Condition, and the difference was marginally significant ( $\chi^2(1)=3.42$ ,  $p<.1$ ).

The pattern of findings was similar for the proportion of subjects initiating appropriate attempts although these differences were not statistically significant. As presented in Table 3, the proportion of subjects initiating faulty attempts was very high in the Story Analogue-Negative Transfer Condition (58%). A reliably lower proportion of subjects produced faulty attempts in the Control group (17%,  $\chi^2(1)=8.9$ ,  $p<.01$ ), and in the Story Analogue-Positive Transfer Condition (16%).

Reliable differences were also found among all three conditions on the success-efficiency scale. The mean score for subjects in the Control group was 2.5, compared to 3.8 in the Story Analogue-Positive Transfer, and 1.5 in the Story Analogue-Negative Transfer Condition,  $t$ 's=2.25, 2.35,  $p$ 's<.05. Mean time to solve the target problem was also found to be reliably different between Control and Story Analogue-Positive Transfer (169 vs. 118 secs.,  $t(42)=-2.6$ ,  $p<.05$ ), and between Control and Story Analogue-Negative Transfer Condition (169 vs. 195 secs.,  $t(29)=-2.26$ ,  $p<.05$ ).

A two-way analysis of variance evaluating transfer type (Positive vs. Negative) and training type (Story Analogue vs. Schema Training) was also performed on the success-efficiency score. As expected, this analysis showed a

significant main effect for transfer type,  $F(1,88)=79.6$ ,  $p<.0001$ . Further discussion of the results of this analysis will be presented later.

Taken together, it is obvious that transfer performance by subjects in the Story Analogue-Positive Transfer Condition was substantially higher than transfer performance of subjects in the Control Condition. The reliable differences indicate that children are able to access the prior analogous problems and utilize the solution principle without any specific hints to do so. In contrast, subjects in the Story Analogue-Negative Transfer Condition produced significantly fewer appropriate solutions to the target problem, and were misled by the prior story problems. These results indicate that solutions from prior story problems are used by children and can lead to either better or poorer performance depending upon the appropriateness of the solution principle to which they are exposed. There is little evidence that children were able to discriminate the effectiveness of the solution principles offered in the base problems. The proportion of subjects attempting appropriate solution in the positive transfer condition (68%) was very close to the proportion of subjects attempting faulty solution in the negative condition (58%). Similarly, the proportion of subjects attempting appropriate solutions in the negative transfer condition (25%) did not differ very



much from the proportion of subjects attempting faulty solutions in the positive transfer condition (16%). The mirror-like pattern reflected in these data suggests that subjects in the negative transfer condition had difficulty ignoring the solution principle in the base problems that they received, and tried to apply this faulty solution principle nearly as readily as the subjects in the positive condition tried to apply the appropriate solution. If subjects were able to reject the inappropriate rule before applying it, performance on problem solving would not be reliably lower than in the Control Condition.

It had been expected that subjects who did not receive the source analogs would solve the problem in essentially a trial-and-error manner, and that problem solving for children who initially received positive analogous problem solutions would tend to be insightful. The time to retrieve, translate and apply the analogous information should be less than the time to carry out the same activity without using information from the previous solutions (see Reed, 1985). Thus, time taken to solve the problem and the number of irrelevant items used before successfully solving the problem should be substantially less in the analogue condition. The mean time to solve the problem for successful subjects in the Story Analogue-Positive Transfer Condition (N=15) was 64 seconds. However, the mean time for

successful subjects in the Control Condition ( $N=7$ ) was 92 seconds. This difference was not significant ( $p>.1$ ). Moreover, the mean number of irrelevant items picked up by these successful subjects before correctly solving the problem (3.7 vs. 5.3 for Story Analogue-Positive Transfer and Control conditions, respectively) did not differ significantly.

#### Effects of Representation Level on Analogical Transfer

A 4-point scale based on subjects' recall and understanding of the two analogous story problems was created to examine the effects of representation level on analogical transfer. Subjects who recalled only the extraneous, irrelevant information of both stories were scored as Level I. Children who remembered the specific solutions (or at least one solution) were classified as Level II. Those who were able to recall all critical aspects of each story problem were rated at Level III. Finally, the criteria for Level IV was either successful summary and comparison of the two sets of key elements, or construction of an abstract schema or principle.

Subjects' recall and understanding of the two story problems were rated independently by the author and two other scorers. The agreement between pairs of judges varied between 94% and 96%. Disagreements in range never exceeded

Table 4

REPRESENTATION LEVEL AND ITS RELATIONSHIP TO PERFORMANCE  
ON TRANSFER TASK FOR SUBJECTS IN  
THE STORY ANALOGUE, POSITIVE CONDITION

Dependent Measure	Level IV: Abstract Schema (N=9)	Level III: Specific Representation (N=6)	Level II: Specific Solution (N=4)	Level I: Irrelevant Details (N=6)
Percentage of Subjects Solving the Problem	100% (9)	50% (3)	50% (2)	17% (1)
Percentage of Subjects Attempting Appropriate Solutions	100% (9)	67% (4)	50% (2)	33% (2)
Percentage of Subjects Attempting Faulty Solutions	0% (0)	50% (3)	25% (1)	0% (0)
Mean Success-Efficiency Score	5.56	3.50	3.25	1.83
Mean Time	74	132	118	170



Table 5

PERFORMANCE ON THE TRANSFER TASK AS A FUNCTION  
OF ABSTRACT VS. OTHER LEVELS OF REPRESENTATION  
FOR STORY ANALOGUE AND SCHEMA TRAINING POSITIVE CONDITION

Dependent Measure	<u>Story Analogue</u>		<u>Schema Training</u>	
	Level IV	Level I II & III	Level IV	Level I II & III
	(N=9)	(N=16)	(N=4)	(N=17)
Percentage of Subjects Solving the Problem	100% (9)	38% (6)	100% (4)	88% (15)
Percentage of Subjects Attempting Appropriate Solutions	100% (9)	50% (8)	100% (4)	88% (15)
Percentage of Subjects Attempting Faulty Solutions	0%	25% (4)	0%	0%
Mean Success-Efficiency Score	5.56	2.80	5.75	4.94
Mean Time	74	143	29	99

one level of the scale. Scores involving disagreement were resolved by consensus.

Since so few subjects in the Story Analogue-Negative Transfer Condition solved the transfer problems, the relationship between representation level and transfer performance was not examined in this condition. The performance on the problem solving task as a function of representation level for subjects in the Story Analogue-Positive Transfer Condition are presented in Table 4. All twenty-five subjects in this condition were classified into one of the four levels, based on their memory and understanding of the two story problems. For the subjects who constructed an abstract schema (level IV), the proportion successfully solving the problem was extremely high: All nine children (100%) produced a correct solution. In contrast, only 50% (three of six) children who formed a specific representation (level III) achieved successful solution, and 50% (two of four) in level II solved the problem. Only 17% (one of six) of children in level I solved the problem. Because of the small cell frequencies, a Fisher Exact test was used rather than  $\chi^2$ . This test revealed that subjects in level IV performed significantly better than those in level III, II, and I ( $p < .05$  for each comparison). Obviously, there were no differences in performance between subjects in levels III and II. Differences between levels II

and I were not statistically analyzed because of the small samples.

A similar pattern was obtained for the proportion of subjects initiating appropriate attempts. All subjects who achieved Level IV produced appropriate attempts, compared to only 67% of subjects who formed a specific representation (Level III). The difference was marginally significant ( $\chi^2(1)=3.46$ ,  $p<.1$ ).

None of the subjects in level IV produced any faulty attempts, compared to three of six (50%) children in level III (Fisher  $p<.05$ ). Further analyses were carried out using scores on the success-efficiency scale and time to solve the problem. A marginally-significant difference in scale was obtained between level IV and level III (5.56 vs. 3.50),  $t(5)=2.28$ ,  $p<.10$ . Problem-solving time did not differ significantly between level IV and III (74 vs. 132 secs,  $t(13)=-1.55$ ,  $p>.10$ ).

The results for subjects in the Story Analogue-Positive Transfer Condition who scored at Levels I, II and III on the representation scale were combined and compared with the results for subjects who scored at Level IV. The results are illustrated in Table 5 (first two columns). As can be seen in this table, there is a highly reliable difference in proportion of subjects achieving success in these two groups (100% vs. 38%),  $\chi^2(1)=9.38$ ,  $p<.01$ . More subjects in level IV



also produced appropriate attempts (100%) than those in lower levels (50%),  $\chi^2(1)=6.62$ ,  $p<.01$ . Similarly, subjects who achieved an abstract schema performed significantly better than those who did not, in terms of the success-efficiency scale (5.6 vs. 2.8,  $t(18)=4.7$ ,  $p<.001$ ). Mean time to solve the problem (74 vs. 143) also differed reliably ( $t(23)=-2.36$ ,  $p<.05$ ).

It is clear that performance is different for subjects who coded at different representational levels. Children who constructed an abstract schema of the analogous story problem performed better than those who encoded only specific or incomplete or irrelevant representations. Remembering complete but specific goal structure is not sufficient for analogical transfer.

#### Effectiveness of Schema Training

Since superior transfer performance was found for children who constructed an abstract schema, a natural question is whether the instructions given to subjects in the Schema Training Condition encouraged and helped children to perceive the underlying principle and to improve transfer. Subjects in the Schema Training-Positive Transfer Condition should display relatively greater facilitation, whereas subjects in the Schema Training-Negative Transfer Condition might or might not show more interference

depending on whether an abstract schema permits them to discriminate its effective application.

The transfer performance of the subjects in both the Story Analogue-Positive Transfer and Negative Transfer Conditions and Schema Training Positive Transfer and Negative Transfer Conditions are illustrated in Table 3. As predicted, the proportion of subjects successful in problem solving in the Schema Training-Positive Transfer Condition (91%) was reliably higher than the proportion in Story Analogue-Positive Transfer Condition (60%),  $\chi^2(1)=5.5$ ,  $p<.05$ . The differences in percentage of subjects initiating appropriate attempts (91% vs. 68%) and faulty attempts (0% vs. 16%) between these two conditions were marginally significant,  $p<.10$ .

The mean success-efficiency scores (5.1 vs. 3.8 respectively) also differed significantly ( $t(42)=2.38$ ,  $p<.05$ ). In addition, a significant main effect for training type (Story Analogue vs. Schema Training) was obtained in the 2X2 ANOVA on this score ( $F(4,88)=4.54$ ,  $p<.05$ ). The interaction between training type and transfer type was also marginally significant ( $F(4,88)=3.43$ ,  $p<.10$ ). This interaction indicates that schema training played different roles for positive and negative transfer. The difference in mean solving time between the Schema Training Positive Transfer and the Story Analogue-Positive Transfer Condition

(86 vs. 118 secs), however, was not significant ( $t(44) = -1.45$ ,  $p > .10$ ).

Taken together, these results demonstrate that subjects in Schema Training Positive Transfer Condition outperformed those in the Story Analogue-Positive Transfer Condition. The superior performance in solving the target problem demonstrated the effectiveness of the schema training method.

There were no reliable differences for any of the dependent measures between the schema-trained and untrained subjects in the Negative Transfer Conditions (see Table 3). One possibility is that while training improves positive transfer performance, it does not affect problem solving when problem situations involve different solution rules. Alternatively, such absence of greater negative effect for schema-trained groups might be simply the result of the extremely poor performance of the Negative Transfer groups (the floor effect).

Another way to address the effects of schema training is to compare the performance of children who did not form an abstract representation in the Story Analogue-Positive Transfer Condition with those who did develop such a schema only after receiving the training instructions in the Schema Training Positive Transfer groups (see Table 5). Seventeen of 21 children in the Schema Training Positive Transfer



Condition did not evidence Level IV representation before being instructed. It is interesting to note that those 4 subjects who did spontaneously achieve Level IV representation prior to training performed very similarly to those 9 who achieved level IV in the Story Analogue Positive Transfer Condition. The one noticeable difference between these two level IV groups was problem-solving time (29 vs. 74,  $t(18)=2.07$ ,  $p<.10$ ).

Receiving the instructions to prompt schema construction did significantly improve such representation and transfer. Eighty-eight percent of subjects in the training condition who initially failed to demonstrate level IV representation but did so after training, successfully solve the target problem, compared to only 38% of subjects who did not receive instructions and did not achieve level IV ( $\chi^2(1)=9.17$ ,  $p<.01$ ). The difference in appropriate attempt between these two groups (88% vs. 50%) was also reliable ( $\chi^2(1)=5.7$ ,  $p<.05$ ), as was the difference in the success-efficiency score (4.9 vs. 2.8,  $t(27)=-3.16$ ,  $p<.01$ ). However, mean time (99 vs. 143 respectively) did not approach significance ( $t(31)=1.69$ ,  $p>.10$ ).

Additional comparisons were carried examining the difference in performance between the subjects who spontaneously constructed level IV representations in the Story Analogue Positive Transfer Condition and those

subjects who required training to achieve such a level of representation. If subjects who spontaneously form an abstract schema perform better than those who required aids to develop such a schema, it would suggest that a spontaneously-formed abstract schema is more effective than a prompted one. However, positive schema-training for those subjects who did not spontaneously achieve Level IV yielded a profile of performance quite similar to that of the subjects who produced the abstract schemas spontaneously. The results are summarized in Table 5. Although the former achieved slightly higher scores than the latter, the differences in the various measures were not reliable. It was appropriate and effective to instruct children by encouraging and guiding them to discover the underlying principle in order to improve transfer performance.

## CHAPTER IV

### GENERAL DISCUSSION

Data obtained from subjects' performance on problem solving enables us 1) to examine the pattern of positive and negative transfer, 2) to assess whether 6-year-old children are able to extract an abstract principle as a vehicle to cross the "gap" between problems which share identical rules but different surface formats, 3) to examine the function of different levels of representation in terms of transfer value, and 4) to determine whether children who did not spontaneously construct an abstract schema can be trained to do so and improve subsequent analogical transfer.

The results revealed that 6-year-olds are able to spontaneously transfer analogous solutions and that an abstract representation of the source analogs is an important factor in analogical transfer. Once children constructed a relatively abstract representation, the likelihood of transfer greatly increased. The data also showed a negative transfer effect. Prior story problems could hinder, rather than facilitate, problem solving when problems involved different solution principles. Moreover, schema training effectively improved transfer performance in



the positive condition although it did not improve ability to discriminate the effectiveness of a solution in the negative transfer condition.

### Representation Level and Processes of Analogical Transfer

As noted in the Introduction, "accessing" or "noticing" and mapping are often theorized as the critical processes in analogical transfer. Before an analogous problem can be applied to solve a target problem in another domain, the source or base analog must first be accessed, and then correspondences must be mapped from base to target (e.g., Brown & Camplone, 1981; Holyoak, 1984; Bransford et al, 1987; Gentner, In press). Several studies of transfer (e.g., Glick & Holyoak, 1980; Reed et al, 1974; Reed, 1987) have demonstrated that people often fail to spontaneously access prior analogous information and therefore fail to map the underlying structures.

One important factor which influences analogical transfer is the similarity shared by base and target problems. There is a widespread claim that transfer would never occur if the problem situations did not share any commonality (e.g., Thorndike, 1903; McGeoch, 1932; Simon, 1980; Holyoak, 1984; Brown & Camplone, 1984; Gentner, In press). However, there are two kinds of similarity, superficial and structural, which play different roles in accessing and mapping processes. It is widely accepted that

superficial similarity, that is, surface commonality is very important in accessing, and that transfer tends to occur when problems share certain superficial similarities. This is true for both adults and children (e.g., Holyoak et al, 1984; Gentner, 1984, 1987; Stein et al, 1986; Holland et al, 1986; Reed, 1987; Holyoak & Koh, 1987). Surface commonality plays a role by providing a "hint" or "cue". However, once problems do not involve the same underlying principle or structure, such superficial features might interfere with solving the target problem. In addition, what should be transferred is the principle, rather than the specific surface features. Therefore, whether superficial similarity plays a positive or negative role would depend on whether the base and the target problem involve the same structure or rule. Thus, underlying structural similarity will play a crucial role in mapping, but may also be a significant element in noticing, as well.

Absence of transfer most frequently occurs when there is failure to perceive the underlying common structure. The results of the present study demonstrated that although subjects in the positive transfer condition who received two analogue stories performed better than those who did not, only the subjects who were able to extract the principle from two source analogs (i.e., achieve Level IV representation) could consistently access and apply the

generalized principle to the target problem. This finding is consistent with the results of several other studies (e.g., Glick & Holyoak, 1986). Thus, successful transfer greatly depends on whether subjects create an abstract representation of the two source analogs.

An abstract representation has more impact on successful solving than the accuracy for specific memory of either the irrelevant details or even the key points of the story problems. The present study directly compared the effectiveness of an abstract schema and a specific representation in terms of transfer. The failure of transfer for subjects characterized as attaining only Level I representation would suggest that absence of transfer might be due to the fact that an analogous solution was not available in memory. In addition, data also showed that subjects who scored at representation levels II or III did not differ from those at the baseline level in their performance. This finding suggests that accurate memory for key elements is not sufficient, although it may be necessary, for transfer to occur. The findings that there were significant differences in performance of subjects at levels IV and III, and no reliable difference between those subjects scoring on level III and those at baseline, indicate that remembering more specific key aspects does not seem critical to transfer. Solutions embedded in specific



representations are hard to separate from particular contexts; therefore, transfer performance was not improved. Once the representation was relatively domain-independent, it yielded better transfer.

The results of this study may or may not be consistent with Brown et al's findings (1986) which suggested that memory for key points of the story problems ("goal structure") is critical for transfer. One possibility is that subjects who formed a goal structure also achieved abstract representations, although their study did not address this issue. However, the "gap" between base and target problems was relatively narrow; remembering the key elements of the base stories was sufficient for transfer to occur. Once the gap increases, transfer may require a more abstract schema which is more "generally accessible" (Brown & Camplone, 1982) to a variety of domains. Domain-specific representations become ineffective because accessibility is limited to a restricted set of contexts. Thus, transfer performance depends on whether the subjects' understanding is characterized as abstract or simply memory for specific solutions. Success in accessing, mapping and eventually applying, involves a great deal more than simply having context-dependent information. Transfer often requires being able to flexibly, resourcefully and efficiently manipulate and utilize information. The level of representation or the

depth of processing of the story problems is an important determinant of analogical transfer.

Investigations have found that structural similarity plays an important role in mapping and also influences accessing to some degree (e.g., Gentner, In press, Holland et al., 1986). It is not always useful and appropriate to emphasize the surface attributes shared by problems. Consider the situation in which one of two source analogs shares the identifying principle, but does not share surface features with the target problem. In another case, the target shares superficial attributes, but does not share underlying structure. The process of subjects' spontaneous selection of source analogs can be directly addressed.

One way to increase the ease with which such deep level information is accessed and mapped, is to prompt subjects to generate a relatively abstract representation of the solution principle. The present study demonstrated that abstract schemas can be trained effectively. Schema training in this study encouraged and guided children to focus on the key points and to compare these two sets of key elements, that is, to extract the underlying solution principle and draw attention away from the surface features. Such schema training improves the flexible use of the base story problems in the positive transfer condition. Children who did not spontaneously create an abstract schema but then

received instructions helping them to do so, performed much better than those who did not receive such instructions. There was no difference in the performance of subjects who spontaneously formed the abstract schema and who were prompted to achieve such a level. This finding provided a further confirmation that representation level is a major factor and main determinant of subjects' capacity to generalize.

But once a general principle is accessed and mapped onto the new problem, subjects must discriminate whether the principle is applicable in the target problem situation. Difficulty in solving the target problem might be due to either the absence of transferring an appropriate solution, or application of an inappropriate solution principle. Brown and Camplone (1984) have pointed out that "a major impediment to flexible learning is often not the lack of transfer across domains but rather inappropriate transfer. Efficient learning involves discriminating when, where and what to transfer rather than blind application of known information" (pp.185). Blind application might occur if subjects fail to evaluate the general principle in the new problem situation. This seems to have occurred in the present study. In the negative transfer conditions, a low proportion of subjects successfully solved the problem, and a high proportion of subjects made misguided attempts. When



the problem required a different principle, subjects were not able to evaluate the appropriateness of the learned rule in the new problem situation, and to avoid interference. The failure to discriminate the problem situations in the negative transfer conditions led to a decrease in performance on problem solving compared to the control group. Difficulty in applying knowledge arises when either the available information can not be accessed when needed, or different problem solutions can not be distinguished.

It is often assumed that to achieve flexible and appropriate transfer across task boundaries, it is important to construct a relatively abstract, domain-independent structure or deep-level principle. Efficient learning and understanding also involves acquiring information about the conditions under which the abstract principle can be applied. The importance of acquiring "conditionalized knowledge" or the "constraints and conditions" of the use of available knowledge have been emphasized by several theorists (e.g., Glaser, 1984; Simon, 1980; Sternberg & Caruso, 1985; Bransford et al., 1987). Schema training in the negative transfer condition in the present study focused on helping children discover the general principle, but did not emphasize the constraints governing its use. Thus the instructions did not help subjects evaluate whether the general principle could be applied in the new problem.

Further work is needed to explore the conditions and instructions which facilitate positive transfer and simultaneously avoid blind application.

### Developmental Implications

Data from the present study revealed that first grade children are capable of spontaneously producing a relatively abstract representation from two story problems and of transferring the analogous solutions to solve a target problem. Although this study did not directly assess developmental differences, the findings do have some implications for explanations of developmental differences in analogical transfer.

Several psychologists (e.g., Gelman, 1978; Rozin, 1976; Fodor, 1972) have argued that the older child tends to be able to transfer his or her knowledge across a variety of domains, while the young child needs to be tested with a particular set of stimuli, in a particular setting, with a particular task. They also argue that with age cognitive structures which initially serve in a restricted way can be accessed and applied to a wider and wider range of tasks.

Several investigations have shown that older children are more likely to use analogous solutions to solve a problem (e.g., Holyoak, et al., 1984; Crisafi & Brown, 1986). Although the popular claim concerning young children is that they tend to acquire knowledge in a way that is

closely tied, or restricted to occasions of learning (Brown & Campione, 1984; Brown, In press), evidence has been provided that children as young as three years are capable of solving analogical problems if the tasks and the distance between base and target problem are age-appropriate. A transfer task can be viewed as a problem in discovering how previously acquired information can be applied to a novel situation. Most developmental studies can not be directly compared because of the different transfer tasks that have been employed. However, pieces of findings have significant implications for the picture that emerges concerning the development of analogical transfer.

It is a widespread belief that younger children are less likely to transfer because they tend to rely on superficial similarity among problems. Such surface commonality includes (1) physical or perceptual features of objects in problems; (2) semantic domains or themes reflected by the characters and their activities; and (3) the modality in which base and target problems are presented. What young children learn might tend to be restricted to the domain or context in which it was originally learned, and transfer of such knowledge would depend on whether the new problem involves superficial cues. Such knowledge might gradually become free from the specific context with age.



There is evidence in the developmental literature showing a tendency for children at different ages to be influenced by surface similarity of problems. Crisafi and Brown's series of experiments (1986) have shown no transfer in 2-year-olds, some transfer in 3-year-olds if two problem versions shared physical similarities, and transfer in four-year-olds even when the problems were perceptually dissimilar. The failure of 3-year-olds can be interpreted to suggest that younger children are more perceptually-bound than older children. However, the superior performance of the 4-year-olds does not necessarily mean that children at this age level are capable of extracting an abstract rule from different problems. The gap or distance between base and target problems in the Crisafi and Brown study can be seen as very narrow because they shared some surface commonalities such as the context cues. All the problem situations involved inserting a coin to earn a gumball or candy. Four-year-olds may view these different versions of a problem as the same theme since they involve the same type of activity. Other developmental studies have demonstrated the importance of superficial similarity in children's analogical learning (e.g., Holyoak et al., 1984; DeLoache, 1985). For example, Gentner and Toupin (1986) suggest that younger children (5-7 years old) rely on surface features rather than relations, but that by 8-10 years old, children

begin to possess the capacity to perceive and utilize the underlying structure or "higher-order-relations".

So far, It can be seen that although young children are able to transfer analogous problem solutions to solve a target problem, their ability to perform analogical transfer is fragile. Young children's analogical transfer can occur only under optimal conditions in which source analogs and target problem share some surface commonality, or where explicit hints are provided to inform them that the information is relevant to the problem they confront.

The transfer task in the present study required children to remember story problems, and more importantly, to extract and generalize an abstract principle from the problems in order to flexibly apply this information. Young children's difficulty in analogical transfer might be due largely to their deficiency in deep processes of understanding. Younger children, given the present transfer task, might rely more on the superficial information and have more difficulty in selecting the key elements and connecting them into a coherent organization, and as a consequence might be less likely to show transfer. This task was assumed to be suitably difficult and challenging for 6-year-old children. Although target problems did not involve surface cues such as similar objects, semantic domain or context, many children at this age were capable of spontaneously

constructing an underlying structure of the two story problems.

It has been traditionally thought that summarizing and abstracting requires an awareness of text or story structure and that this kind of analysis is beyond the skill of young children. Deep processing involves selecting the critical constituents while deemphasizing the extraneous information, and condensing those units into an coherent structure or schema (Van Dijk & Kintsch, 1983; Hayes & Simon, 1976; Greeno, 1977; Johnson, 1978; Mandler, 1983). In the present study, an ability to extract and generalize the underlying principle from different specific story problems was evident in first graders at least in a rudimentary form. The learned principle can be used to guide problem solving in different contexts, rather than remain tied to the particular context in which it was learned.

What is responsible for the greater efficiency of older children in analogical learning? Two popular alternative explanations offered for why younger children are less likely to transfer their knowledge to a broad range of tasks are lack of specific knowledge and differences in mental capacity (Brown, in press; Gentner & Toupin, 1986). Data from the present study indicated that children's capacity to generalize and abstract is responsible for transfer performance. Although specific problem solutions were



available in memory, they were not flexibly used because of lack of generality.

The major mediating factor for developmental improvement in transfer might be the growth of capacity to generalize and abstract, which influences how deeply children can process and understand the analogs and target problems, and at what level they perceive the relationship between them. The level at which children can process materials or problems and construct a representation of problems would determine the accessibility and applicability of the representation. It seems appropriate to explain children's frequent failure to transfer information, as being the result of difficulty in processing and understanding problems at a deeper level. It is because of the lack of capacity to generalize and abstract that young children's ability to perceive structure commonality or the principle underlying certain specific domains or contexts is fragile.

Since younger children have been assumed to be more perceptually-bound, and to lack the ability to perceive deep-level structures, negative transfer such as functional fixedness, cognitive embeddedness and negative learning set (Brown, in press) would be more likely to occur when problems share similar surface format but not underlying structure. In this case, although children are able to transfer, it is not appropriate, and therefore prior

knowledge impedes rather than enhances flexible use of the knowledge acquired. Brown and Kane (In press) have found that information gained from a pretraining phase where a certain function of an object was emphasized, or a particular rule learned, had an impact on young children's target problem solving when it required an alternative solution. Results from the present study indicated that negative transfer occurs even when base and target problems share few surface features. This study also demonstrated the lack of ability of children to discriminate conditions under which the learned principle can be suitably applied. Such blind application interferes with selecting alternative possibilities.

Further studies need to be designed to examine age differences in both positive and negative transfer. On the one hand, children's ability to flexibly transfer knowledge increases with the improvement of capacity to abstract and generalize. Younger children tend to restrict what they learn to a narrow set of contexts, while older children are able to process and understand materials more deeply and transfer the information to a broad set of tasks. On the other hand, negative transfer might decrease with age because older children tend to be able to build knowledge structures including information about the conditions and constraints of its use. Older children might be less

perceptually-bound, therefore, able to avoid the interferences of surface features, and more capable of evaluating the appropriateness and seeking other potential solutions in a new problem situation.

### Implications for Education

Much research on transfer in problem solving in recent years has shown that people do not often spontaneously transfer prior information from one situation to another. One popular method used to improve adults and children's transfer has been to provide certain kinds of hints or to directly inform subjects that the problems are isomorphic. Research has shown that providing hints to subjects dramatically increases transfer (e.g., Glick & Holyoak, 1980, 1983; Holyoak et al, 1983; Crisafi & Brown, 1986; Welsberg et al, 1978; Perfetto et al, 1983; Stein et al, 1986). This fact provides supportive evidence for the claim that "noticing" and "mapping" are critical or major aspects of using analogies, particularly in those cases in which the "gap" between noticing and applying is narrow. In such cases, once the insight has been achieved, the problem is basically solved, and hints often help to gain such insight. When hints are provided, it can not be firmly concluded that children at a certain age are able to flexibly use analogies, since discovery of a hidden analogy is often the key to finding a suitable solution to a problem.



Although explicit hints increase the likelihood of transferring information from one domain to another, such aids do not always seem appropriate. In applied and practical problem situations, it is not often the case that a teacher can directly inform students what knowledge is suitable or inappropriate to the novel problem situation. Knowledge use outside of school or within classrooms (e.g., Royer, 1979) requires students to flexibly and appropriately apply information independently. The problems that are encountered often give little suggestion as to what knowledge may be relevant to solving the problems. Thus, whether students are able to notice the link between prior problems and the solutions and the current problem will depend greatly on how deeply they process and understand the problems.

One major reason for failure to discover the isomorphic link between problems is that prior problems are understood in a specific fashion and such information is welded to a particular context. The danger of "inert knowledge" has been widely recognized (Whitehead, 1929; Bransford et al, 1987). Such inert knowledge can not be accessed and applied to a variety of domains where it is potentially applicable. One major purpose of education is to help students build basic knowledge which can be widely used, rather than inert facts, and to develop students' ability to flexibly transfer the

knowledge acquired. Results from the present study suggest that one limitation to transfer is the failure to process information at a sufficiently abstract level. Abstract representation can be accessed more flexibly when an isomorphic problem is encountered, while specific information in prior problems often remains inert and passive, although still accurate. "Bare facts in memory do not solve problems" (Simon, 1978).

Brown (in press) has discussed various methods of enhancing young children's analogical transfer. Aids include hints, instructions, such as explicitly informing subjects that two base problems are the same, prompting children to discuss the similarities between problems, and encouraging children to teach the specific solution to others enhance subsequent transfer. Abstract schema training in the present study provided evidence that a method which encourages and guides students to process materials more deeply, to discover the underlying structure, and to construct an abstract schema, is effective in prompting broader transfer. Instructions stating the essential rule (Brown & Camplone, 1984) appear to be more appropriate and valuable in terms of transfer than instructions which emphasize bare facts and details.

In the present study, the performance of subjects who spontaneously formed abstract schemas and the performance of

subjects who were prompted to do so, did not differ significantly. This finding bears upon issues concerned with discovery versus expository methods of teaching and learning. In rule-induction experiments, discovery learning has often been found to facilitate transfer more than expository learning (e.g., Katona, 1940; Guthrie, 1967). While discovery methods require students to process materials deeply and search for generalizations, expository methods may reinforce only specific facts (see Andre, 1986). The real issue then, may not be discovery or expository learning, but rather the cognitive activities students use during the processes of understanding (Andre, 1979; 1986). The instructions in the schema training conditions in the present study focused on understanding the underlying structure and generalizing the solution principle from the source analogs. Such schema training was effective in facilitating analogical transfer.

Although the failure to spontaneously transfer information in problem solving has been consistently reported in the research literature, scientists and inventors in various domains often do use relevant information without explicit prompts (e.g., Okagaki & Okagaki, 1987; Gordon, 1979; Knorr, 1980). One explanation is that they possess more effective and higher levels of knowledge structure in terms of abstractness and



applicability. Thus, while solving problems, experts tend to be able to process the materials more deeply and perceive the deep structure whereas novices attend to the surface characteristics of the problem situations (e.g., Chi et al., 1981; Chi et al., 1982; Larkin et al., 1980; Larkin, 1980).

Much of traditional and recent research has also shown the positive effects of a variety of examples on subsequent transfer in problem solving (e.g., Grether & Wolfle, 1936; Adams, 1954; Morrisett & Hovland, 1959; Glick & Holyoak, 1983; Gholson, 1987). Here, too, a major reason for the superior transfer performance may be that the multiple source analogs provide opportunities for subjects to extract the common underlying principle and to realize that the same abstract principle can be used in problems with different surface formats. A principle extracted from problems with similar superficial features might tend to be tied to problems with the same format. Only principles extracted and generalized from problems with different superficial characteristics can be highly accessible and effective in terms of applicability.

#### Further Studies on Children's Analogical Transfer

Two kinds of similarity, surface and structural, have been theorized to play an important role in accessing and mapping processes. Additional studies need to be conducted to explore the ways in which surface features and structural

similarity of story problems influence children's active search and selecting processes. Questions such as how semantic domain and modality of problems influence level of representation in term of abstraction and subsequent transfer also need to be addressed.

Surface similarity includes several aspects. Three primary features are 1) major character; 2) goal object, and 3) theme (story context). These superficial features might play different roles as activation cues in accessing the base story problems. In order to evaluate the influence of various aspects of surface and structural similarity, and explore the processes of searching and selecting an analogue, experiments may need to be included in which a set of base story problems in the experimental condition bear a specific relationship to the target problem, and every subject is exposed to all the stories. For example, in one planned experiment, three base problems share some surface feature with the target problem, such as major character, goal object, or theme, respectively. Another base problem does not share surface features, but only the solution principle is isomorphic. Each of these four story problems provides a solution principle (e.g., "raise water level", "combine lengths", "pierce object", or "use sticky substance") for the target problem which requires subjects to get a bead out of a cylinder. A fifth base problem shares

no similarity with the target problem. Subjects's problem solving behavior after receiving these base story problems will allow us to examine the effects of superficial similarities on positive transfer.

In another experiment, the superficial feature of the target problem and each of the five base problems will be the same as those in the first experiment, but only the isomorphic problem shares the same solution principle with the target and will work for the target. The effects of superficial features on negative transfer can be explored in this experiment.

Children at different ages will be included. In these experiments, we can begin to understand how surface features influence the choice of an isomorphic solution in positive and negative conditions at different age levels.

The effects of similarity in the semantic domains of base problems, and between base and target problems and how modality of problems influences representation level and transfer are also of interest. For example, experiments need to be carried out to compare performance by subjects who receive two base problems (A' and A'') from the same domain as the target problem (A) with subjects who will be presented two base problems from a similar domain (B' and B'') but that differs from the transfer problem (A) and subjects who will be presented base problems from two



different domains (B and C) that also differ from the target domain (A). A key goal in this experiment is to determine how similarity in semantic domain affects noticing and representing the solution principle and how this affects transfer in children at different ages.

Effects of modality of problems could be examined in other experiments. In prior studies on analogical transfer, base and target problems have involved the same modality. For example, with adults, base and target tasks have typically been story problems (e.g., Glick & Holyoak, 1980; 1983) and with children, story problems in which physical props have been added to demonstrate the solution to the problems (Brown et al., 1986; Holyoak et al., 1984), or physical problems only, with the same theme (e.g., "Candy game" in Crisafi & Brown, 1986). Such modality identity might provide "context cues" which may greatly influence children's analogical transfer.

The major issue addressed is the relation of transfer performance to base and target problem modality presentation. The effects of different modalities such as practical, pictorial and verbal problems, could be investigated. In some conditions, the modality would be the same for the base and target problems, but in others, they could differ. It is predicted that transfer performance should be higher when the modalities are the same, and

younger children might benefit more from modality identity than older children do.

Transfer performance is greatly determined by whether subjects construct a schema with the key elements at an abstract level. Transfer performance also depends on the structural features of the story problems. Problem components such as goal, obstacle, solution and the causal relationship between these and the problem solution constitute the coherent structure or complete structure of a problem. An incomplete structure exists when the goal and obstacle are deemphasized and the casual relationship among these key elements is violated.

Experiments could also be conducted to examine the effects of complete versus incomplete structure on children's analogical transfer. Children might have considerably difficulty in using the solution principle from an incomplete-structure base story compared to a complete-structure story, if structural similarity is an important component in analogical transfer. Age differences will also be explored.

The effects of superficial features and structural similarity on children's searching and selecting an analogous solution and developmental differences in analogical transfer can be systematically explored in these studies.

## APPENDIX A

### BASE STORIES

#### Story Set 1: "Adding" Solutions

##### Story 1: The Thirsty Bird

Once upon a time there was a bird who lived on a forest. She was pretty and smart. Some of her friends often told her about the people, buildings and other things in the city. One day, in the summer, she decided to go to the city. She got up before sun-rise and flew for several hours, miles and miles, because the city was far away. It was very hot. She became very thirsty but could not find anything to drink. Finally, she landed in a field and found a bottle half full of water. She put her beak into the bottle and stretched her neck, but the water was too low in the bottle for her to reach it. After thinking a bit, she came up with a good idea: She picked up a pebble in her beak and dropped it in the bottle. Then she picked up another and another... She continued to put pebbles into the bottle, one by one, and each time a pebble fell in the bottle, the water got a little bit higher, until finally she could reach the water with her beak and got a long, cool drink. Refreshed after



drinking the water, she sang and flapped her wings, and flew on to see the city.

### Story 2: The Fallen Ball

Eddie was in second grade. He liked to swim, play baseball and ping-pong, and go fishing with his grandfather. Eddie was very good at these things. One day, during a summer vacation, he was playing a game of ping-pong in the back-yard of his house. Eddie and his friends had a wonderful time playing together. Suddenly, the ball bounced across the lawn and rolled into a small but deep hole. The hole was too deep for the boys to reach the ball with their hands. They had to think of a different way to get the ball out. After a few minutes of thinking, Eddie came up with a great idea: He went to the house, brought out a long hose. He connected the hose to a water tap and filled the hole with water from the hose. The boys were very happy because the ping-pong ball floated to the top. After getting the ball, they went on playing the game.

### Story Set 2: "Combining" Solutions

#### Story 1: The Hungry Monkey

Once upon a time, there was a monkey who lived in a beautiful forest with his friends. He was very smart and worked hard. He and his friends had a little house and planted many flowers around their home. Every day, they

walked several miles looking for food. One day, he and his two friends were caught by some hunters and were sent to the zoo. From then on, he had to live in a big cage. He was always very hungry in the zoo. He often tried to get food outside of his cage or from other cages. One day, people put some bananas outside the cage, but they were too far away for him to reach. He looked around and saw two poles lying right outside his cage. He picked up one of the poles and tried to reach the banana with it. However, the pole was too short. He was very hungry indeed. After thinking a bit, he came up with a good idea: He grabbed both poles and stuck two together by putting one inside the other to make a pole long enough to reach the banana. He finally got the food and was very proud.

#### Story 2: The Caught Ball

Eddie was in second grade. He liked to swim, play baseball and ping-pong, and go fishing with his grandfather. Eddie was good at these things. One day, during a summer vacation, he was playing baseball in the back-yard of his house. Eddie and his friends had much fun together. Now it was time for Eddie to bat. When the ball was pitched, Eddie hit it. Up, up, went the ball to the top of the roof of the house, and it got stuck in a corner. The boys could not reach the ball and could not find a ladder to climb on top of the roof either. They had to think of a different way to

get the ball down. They thought and thought. Finally, Eddie came up with a great idea. He combined two bats together with a thick string so that the bats were long enough to reach the ball. The boys were happy. After getting the ball, they went on playing their game.

### Control Stories: Irrelevant to solution

#### Story 1: The New House

Nancy was moving into a new house. It was white, with red porches. It was much bigger than her old house. She was going to have her very own room. Before, she had to share with her big sister. On moving day, the movers carried the beds and chairs and rugs out the old house and into the truck. When everything was in the truck, they closed it up, and drove to the new house. Nancy and her family got into their car and also drove to the new house. As soon as the door was unlocked, Nancy ran into the new rooms. She found the kitchen, and the bathroom, but she didn't stop until she found her very own bedroom. There she sat, waiting for the movers to bring her things. "I will put them where I want," she thought. "My sister can't tell me what to do in my very own room." Nancy was sure to be happy in this new house.

#### Story 2: The Zoo Visit

Jennifer and her grandparents were going to the zoo. They parked in the big parking lot, and then rode in a fancy



trolley to the gate. They bought tickets and gave them to the gatekeeper. Now they were inside. "Where do you want to go first?", asked Grandma and Grandpa. Jennifer told them that she always liked to go to the elephants first because they were closest. They watched the elephants and then there was a big noise from the seals, so they went over there, and watched the keeper throw them fish. Watching the seals eat made them hungry, so Grandma and Grandpa and Jennifer ate lunch, too. Then they looked at the monkeys and hippo and the giraffe, and so many other animals that they all got too tired to walk anymore. They rode the trolley back to their car. On the way home Jennifer fell asleep, and dreamed of a fun new animal - A mix of a giraffe and a bear!

## APPENDIX B

### Examples of Four Levels of Representation

#### Level I. Irrelevant Recall:

(1) Recall: "A monkey...once he lived in the forest. He found some food...The zoo keeper caught him in the forest. He got put in the zoo, and he always hungry." (subject #48)

(2) Comparison: (Experimenter: "Do you think the two stories are alike?"). "No. Well the boy was not an animal..." (subject #8)

(3) Comparison: "They were alike because some of them are kind of funny. Maybe one of them is a make believe story and one of them is a real story." (subject #79)

#### Level II. Incomplete Recall:

(1) Recall: "That he lived in the forest with his friends. He planted many flowers... Some hunters came and then caught him and brought him to the zoo... He put two poles together and got the banana" (subject #23)

(2) Comparison: (similar to that in level I)

#### Level III. Complete Specific Recall:

(1) Recall: "...He was very hungry but the banana was too far away. He could not reach the banana. He got two short poles. He found an idea. He put two poles together to

reach the banana." (subject #101)

(2) Comparison: (similar to that in level I or II)

Level IV. Abstract Representation:

(1) Recall: (similar to that in level III)

(2) Comparison: "Yes... In the monkey story, the monkey put two poles together, and the other story, the boys were playing baseball, They put two bats together, and it was longer, to get the ball down... the two stories are alike."  
(subject #17)

(3) "Yes, because both of them could not reach something... They thought for a few minutes. They both put two things together to reach something... and got what they were looking for." (subject #64)



## BIBLIOGRAPHY

- Adams, J. A. (1954) Multiple versus single problem-solving. Journal of Experimental Psychology, 58, 52-55
- Anderson, R. C. (1965) Can first graders learn an advanced problem solving skill? Journal of Educational Psychology Vol. 54.
- Andre, T. (1979) On productive knowledge and levels of questions. Review of Educational Research 49, 280-318
- Andre, T. (1986) Problem solving and education. In G. D. Phye, & T. Andre (Eds.) Cognitive Classroom Learning: Understanding, thinking, and problem solving. Academic Press, INC.
- Bransford, J., Sherwood, R., Vye, N. & Rieser, J. (1986) Thinking and problem solving. American Psychologist 1078-1089
- Brown, A. (In press) Analogical learning and transfer: What develops?
- Brown, A. L & Campione, J. C. (1981) Inducing flexible thinking: A problem of access. In M. Friedland, J. P. Das, & N. O'Connor (Eds.), Intelligence and learning, New York: Plenum, 1981

- Brown A. L. & Camplone, J.C. (1984) Three faces of transfer: Implications for early competence, Individual differences and Instruction. In M. Lamb, A. Brown, & B. Rogff (Eds) Advances In developmental psychology (vol.3) Hillsdale, NJ: Erlbaum.
- Brown, A. L. & Kane, M. J. (In press) Cognitive flexibility In young children: learning to learn and learning by examples.
- Brown, A. L., Kane, M. J., & Echols, C. H. (1986) Young children's mental models determine analogical problems with a common goal structure. Cognitive Development, 1, 103-121
- Chi, M. T. H., Fetlovich, P. J., & Glaser, R. (1981) Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152
- Chi, M. T. H., Glaser, R., & Rees, E. (1982) Experts In problem solving . In R. J. Sternberg (Ed.), Advances In the psychology of human Intelligence, (Vol. 1, pp. 7-75). Hillsdale, NJ: Erlbaum.
- Cox, J. R. & Grigg, R. A. 1982 The effects of experience on performance In Wason's selection task. Memory and cognition, 10, 496-502
- Craik, F. J. M. & Lockhart, R. S. (1972) Levels of processing: A framwork for memory research. Journal of Verbal Learning and Verbal Behavior, 11, 671-684

- Crisafi, M. A. & Brown, A. L. (1986) Analogical transfer in very young children: Combining two separately learned solutions to reach a goal. Child Development, 57, 953-968
- DeLoache (1985) Memory-based searching in very young children. In H. Wellman (Ed.), The Development of Search Ability. Hillsdale, NJ,: Erlbaum, 151-183
- Duncan, C. P. (1959) Recent research on human problem solving. Psychol. Bull., 56, 397-429
- Duncan, C. P. (1961) Attempts to influence performance on an insight problem. Psychological Reports, 9, 35-42
- Duncker, K. (1962) A qualitative (experimental and the theoretical) study of productive thinking (solving of comprehensible problems). Journal of genetic psychology. 33, 642-708
- Duncker, K. (1945) On problem solving. Psychological monographs, 58, (5, whole No.270)
- Fodor, J. A. (1972) Some reflections on L. S. Vygotsky's "Thought and Language". Cognition, 1, 83-95
- Gelman, R. (1978) Cognitive development. Annual Review of Psychology, 29, 297-332
- Gentner, D. (In press) The mechanisms of analogical learning.
- Gentner, D. (1983) Structure--mapping: A theoretical framework for analogy. Cognitive Science, 7, 155-170



- Gentner, D. & Toupin, C. (1986) Systematicity and similarity in the development of analogy. Cognitive Science, 10, 277-300
- Gholson, B., Eymard, L. A., Morgan, D., & Kamhi, A. G. (1987) Problem solving, recall, & isomorphic transfer among third-grade and six-grade children. Journal of Experimental Child Psychology, 43, 227-243
- Gick M.L. & Holyoak K.J. (1980) Analogical problem solving. Cognitive psychology 12, 306-335
- Gick M.L. & Holyoak K.L. (1983) Schema induction and analogical transfer. Cognitive psychology 15 1-38
- Glaser, R. (1984) Education and thinking: the role of knowledge. American Psychologist, 39, 93-104
- Gordon, W. J. J. (1961) Synectics New York: Harper & Row
- Gordon, W. J. J. (1978) Some source material in discover-by-analogy. The Journal of Creative Behavior, 8, (4) 239-257
- Greeno, J. G. (1980) Trends in the theory of knowledge for problem solving. In D. T. Tuma & F. Relf (Eds.), Problem Solving and Education: Issues in Teaching and Research. Hillsdale, N.J. Erlbaum
- Grether, W. F. & Wolfle, D. L. (1936) The relative efficiency of constant and varied stimulation during learning. Journal of Comparative and Physiological Psychology, 22, 365-374

- Guthrie, J. T. (1967) Expository Instruction versus a discovery method. Journal of Educational Psychology, 58, 45-49
- Hayes, J. R., & Simon, H. A. (1979) Psychological differences among problem isomorphs. In N. J. Castellan, Jr., D. P. Pisoni, & G. R. Potts (Eds.), Cognitive theory (Vol. 2). Hillsdale, N. J: Erlbaum
- Holland, J. H., Holyoak, K. J., Nisbett, R. E., & Thagard, P. R. (1986) Induction: Processes of Inference, Learning, and Discovery. Cambridge, Ma.: MIT Press
- Holyoak K.L. (1984) Analogical thinking and human Intelligence. In R.J. Sternberg (Ed.) Advances in psychology of human Intelligence (vol.2). Hillsdale, N.J. Erlbaum
- Holyoak, K.L., Junn, E.W., & Billman, D.O. (1983) Developmental analogical problem solving skills. Child Development, 55 (6), 2042-2055
- Holyoak, K. J. & Koh, K. (1987) Surface and structural similarity in analogical transfer. Memory and Cognition 15, 332-340
- Johnson, N. S. (1978) A structural analysis of the development of story recall and summarization. Unpublished doctoral dissertation, Univ. of California, San Diego

- Judd, C.H. (1908) The relation of special training and general intelligence. Educ. Rev., 36 42-48
- Katona, G. (1940) Organizing and memorizing. New York: Columbia University Press.
- Knorr, K. D. (1980) The scientist as an analogical reasoner: A critique of the metaphor theory of innovation. Communication & Cognition, 13, 183-208
- Larkin, J. H. (1980) Teaching problem solving in physics: The psychological laboratory and the practical classroom. In D. T. Tuma & F. Relf (Eds.), Problem solving and education: Issues in learning and research (pp. 111-126). Hillsdale, NJ: Erlbaum.
- Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980) Expert and novice performance in solving physics problems. Science, 208, 1335-1342
- Luchins, A.S. (1942) Mechanism in problem solving. Psychological monographs, 54, No. 248
- Maier, N. R. F. (1930) Reasoning in humans I: On direction. Journal of Comparative Psychology, 11, 115-143
- Maier, N. R. F. (1931) Reasoning in humans II: The solution of a problem and its appearance in consciousness. Journal of Comparative Psychology, 12, 181-194
- Maier, N. R. F. (1945) Reasoning in humans III: The mechanisms of equivalent stimuli and of reasoning. Journal of Experimental Psychology, 12, 181-194



- Martin, E. (1965) Transfer of verbal paired associates.  
Psychological Review, 72 327-334
- Mandler, J. M. (1983) Representation. In J. H. Flavell & E. M. M. Markman (Eds.), Handbook of Child Psychology vol. III Cognitive Development
- McGeoch, J. A. (1932) Forgetting and the law of disuse.  
Psychological Review, 39, 352-370
- Minsky, M. (1961) Steps toward artificial intelligence.  
Proc, IRE, 49, 8-29, 148
- Morrisett, L., & Hovland, C. I. (1959) A comparison of three varieties of training in human problem solving. Journal of Experimental Psychology, 58, 52-55
- Newell, A. (1979) One final word. In D.T. Tuma & F. Relf (Eds.) Problem solving and education: Issues in teaching and research. Hillsdale N.J. Lawrence Erlbaum.
- Okagaki, L. & Koslowski, B. (1987) Another look at analogy and problem solving. The Journal of Creative Behavior, 15-21
- Osgood, C.E. (1949) The similarity paradox in human learning: A resolution. Psychological Review, 56, 132-143
- Perfetto, G. A., Bransford, J. D., & Franks, J. J. (1983) Constraints on access in problem solving context. Memory & Cognition, 11, 24-31

- Reed, S.K. Ernst, G.W. & Banerji, R. (1974) The role of analogy in transfer between similar problem states. Cognitive psychology, 6, 436-450
- Reed, S. K. (1987) A structure-mapping model for word problems. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13, 124-139
- Reitman, W., (1964) Heuristic decision procedures, open constraint, and the structure of ill-defined problems. In M.W. Shelley and G.L. Bryan (Eds.) Human Judgments and Optimality. New York: Wiley.
- Royer, J. M. (1979) Theories of the transfer of learning. Education Psychologist, Vol. 14, 53-69
- Rozin, P. (1976) The evolution of intelligence and access to the cognitive unconscious. Progress in psychobiology and physiological psychology, 6, 245-280
- Rumelhart, D.E., & Norman, D.A. (1981) Analogical processes in learning. In J.R. Anderson (Ed.) Cognitive skills and their acquisition. Hillsdale, N.J. Lawrence Erlbaum Associates.
- Simon, H.A. (1978) Information-processing theory of human problem solving. In: Estes, W.K. (Ed.), Handbook of learning and cognitive processes vol. 5: Human information processing. Hillsdale, N.J, Erlbaum, 271-296
- Simon, H., (1973) The structure of ill structured problems. Artificial Intelligence 4: 181-202

- Simon, H. A. (1979) Problem solving and education. In D.T. Tuma & F. Reif (Eds.) Problem solving and education: Issues in teaching and research. Hillsdale, N.J. Lawrence Erlbaum Associates.
- Stein, B. S., Way, K. R., Benninsfield, S. E. & Hedgecoush, C. A. (1986) Constraints on spontaneous transfer in problem-solving tasks. Memory & Cognition, 14, (5), 432-441
- Sternberg, R. J., & Caruso, D. R. (1985) Practical modes of knowing. In E. Eisner & K. J. Rehaeg (Eds.), Learning and Teaching: The ways of knowing, Chicago: Univ. of Chicago Press.
- Thorndike, E.L. & Woodworth, R.S. (1901) The Influence of Improvement in one mental function upon the efficiency of mental function of other functions. I;II. The estimation of magnitudes; III. Function involving attention, observation and discrimination. Psychological Review, 8, 247-261, 553-564
- Van Dijk, T. A. & Kintsch, W. (1983) Strategies of discourse and comprehension. New York: Academic Press.
- Weisberg, R. W., DiCamillo, M., & Phillips, D. (1978) Transfer old associations to new problems: A non-automatic process. Journal of verbal learning & verbal behavior, 17, 219-228



Whitehead, A. N. (1929) The aims of education. New York:  
Macmillan.

Wittrock, M. C. (1963) Verbal stimuli in concept formation:  
learning by discovery. Journal of Educational Psychology  
vol. 54





