

1993

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THE EFFECTS OF GENERATING INFERENCES
ABOUT A SOLUTION PRINCIPLE ON ANALOGICAL TRANSFER
IN CHILDREN AND ADULTS

A Thesis Presented

by

KAREN L. YANOWITZ

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

February 1993

Department of Psychology

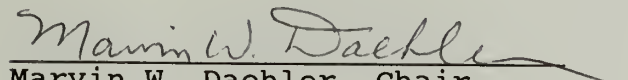
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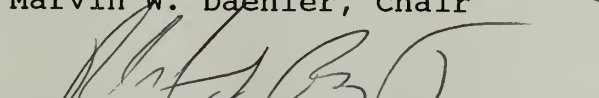
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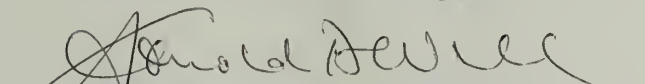
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ACKNOWLEDGEMENTS

I would like to thank Marvin Daehler, my committee chair and advisor, for his support and encouragement throughout this project. I would also like to thank the members of my committee, Dick Bogartz and Arnie Well, for their help and advice.

Christine Donati and Matt Aspin provided invaluable assistance in data collection and reduction. I would like to extend my appreciation to the teachers and students at Mark's Meadow Elementary school, and to all the children and parents who participated at the Child Study Center in Springfield.

Finally, I would like to thank my friends and family, especially my parents and Adrienne and Jennifer, for all their love and support.

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CHAPTER 1

INTRODUCTION

Statement of Purpose

Analogical transfer is the flexible use of previously acquired information in a new context or domain. The mechanisms involved in analogical transfer are often tested by giving subjects source stories that contain a procedure known as a solution principle. Transfer is assessed by ability to use this solution principle to solve a new problem. Traditionally, the solution principle has been given in a complete form in that all of the elements necessary to solve the problem have been explicitly presented. However, it may not always be necessary to provide all of the elements of the solution principle. Other processes, such as the ability to generate inferences, may allow the subject to derive necessary information. This experiment examined whether the requirement to generate an inference about the solution principle affected analogical problem solving performance. The solution principle was varied as to whether the action in the principle was explicitly presented, or only implicit in the source stories. Performance of both adults and 7-8 years-old children, using age appropriate materials, was examined.

Review of Literature Related to Analogical Transfer

Problem solving occupies a great deal of one's life. We are repeatedly confronted with some decision to make or a

problem to solve. One way a person can solve such complex problems is by using the process of analogical transfer: by remembering how he or she had solved a similar problem in the past, deciding if the old problem is somehow similar to the present one, and adapting the old solution to the new problem.

Analogical transfer is used not only to derive solutions to problems, but to make predictions and strengthen arguments (Holyoak, 1984). Anecdotal reports abound of major scientific discoveries, such as the hydraulic model of blood circulation, the planetary model of atomic structure and the billiard ball model of ideal gases, derived as a result of noticing and applying an analogy from a better known area, or domain, to a lesser known domain (Gick & Holyoak, 1980).

As early as the 1900's there were competing theories about processes of analogical transfer. Thorndike and Woodworth (1901) claimed transfer occurred only if identical elements, such as color, shape or size, were shared between the old and new tasks. Judd (1908), on the other hand, believed that transfer between old and new sets of knowledge was determined by the extent to which the learner understood the underlying shared principles between the tasks. Although Thorndike's view was the predominant one for many years, Judd's position is now being championed by many researchers (Brown, 1989).

There has been a resurgence of interest in analogical transfer in problem solving, especially those involving ill-defined problems. Ill-defined problems have more than one solution, as compared to well-defined problems that have algorithmic solution procedures (Gick & Holyoak, 1980).

Gick and Holyoak (1980, 1983) have found that people can use analogical processes to solve ill-defined problems, but they often have difficulty in doing so. In their seminal work (1980) they used Duncker's radiation problem (1945) as the ill-defined problem. The problem is:

A man has a malignant, inoperable tumor in his stomach. He will die if the tumor is not destroyed. There is a ray that will destroy the tumor, but at the high intensity needed, the ray will destroy the healthy tissue it passes through on the way to the tumor. At lower intensities, the rays are harmless to the healthy tissue, but will not destroy the tumor. What can be done to destroy the tumor, using the rays, but not destroy any healthy tissue?

The solution that Gick and Holyoak define as correct is a convergence solution- having several low intensity rays converge on the tumor to destroy it. When adults are given a previous story that describes an analogous convergence procedure, approximately 30% of those people will solve the radiation problem. Since about 10% of subjects in the control condition solve the problem, Gick and Holyoak estimate that only about 20% of the subjects who receive the base story use that story to help them to solve the problem. Gick and Holyoak conclude that one of the major problems in

analogical transfer is the failure to notice the pertinence of the analogy.

According to many theorists (Brown, 1989; Gentner, 1989; Vosniadou, 1989; Gick & Holyoak 1983) several processes enter into analogical problem solving, in addition to noticing the potential analogy. Cognitive processing of the information must take place so that a mental representation of the source, or prior information, and of the target, or new problem, will be formed. Representation involves internalizing the information and transforming it into a mental model. Representation can involve transforming the information and so does not have to be veridical. This representation allows the person to retain the information and then use the information for any purpose (Trabasso, Secco & Van den Broek, 1984).

Mapping is another step that plays a part in the analogical process. Mapping is the construction of a set of correspondences between the representation of the base and the representation of the target. Finally, the solution, with any necessary modifications, must be tried (Brown, 1989; Gentner, 1989; Holyoak, 1984).

Each process is dependent on the other (Holyoak, 1984). For example, level of representation can affect how the mapping is established. Since mental representation of the base and target can be made at many different levels, and in different forms, how the representation is constructed will

affect the likelihood of being able to map any useful correspondences between the base and target (Gick & Holyoak, 1983).

The typical source information in analogical problem solving is a story that relates a sequence of events concerning a protagonist's attempt to solve a problem or reach a goal. This sequence often follows a set pattern that can be decomposed into component parts including an indication of a problem to be solved or more generally, any goal desired, the protagonist's attempt to reach the goal, obstacles preventing goal attainment, action taken by the protagonist to overcome these obstacles, and finally, the outcome of this action (Trabasso & Sperry, 1985).

The events of this sequence are causally connected, and form the structure or meaning of the story. In contrast, the surface features of the story are the details that play no causal role in the path of goal attainment (Holyoak & Thagard, 1989). Surface features, for example, can be the exact identity of the protagonist, or any particular detail that can be changed without changing the meaning of the story. There can be similarity between stories at either the level of surface features or structural features or both.

The set of correspondences that is constructed between the two domains can be formed in many different ways. Each domain may be thought of as being comprised of a set of elements. These elements can be mapped, that is a person can

construct a set of similarities between elements in the source and target domain. However if a person primarily forms the representation at this level the representation will be tied to the concrete, specific features of the domains. Problem solving using these sets of correspondences is often not successful as these specific surface features are usually not causally connected to goal attainment (Holyoak, 1984).

Representation of the source domain can also be constructed at a more abstract level. The attributes of the particular elements can be dropped, leaving a more abstract set of relations. This system of relations is the causal chain within the domain. If the subject can impose or transfer the set of relations in the source domain into the target problem, by recognizing elements within the target as matching the elements within the relations in the source domain, the subject can then use the relations in the source domain to understand how relations between elements in the target domain function. Gentner (1989) believes that mapping is preferentially and automatically performed using these systems of relations. Others, such as Holyoak and Thagard (1989) believe that goal related aspects can influence at which level representation and mapping occur. Overlap between these theories occur since causal relations are often tied directly to goal attainment (Novick, 1988).

In summary, successful analogies are usually constructed by mapping at the structural features of the stories, which are the abstract set of relations within the story. There has been much research on how the features of the source stories affect subsequent representation, mapping and use of the information in an analogical problem solving situation. If the source stories contain a problem, one possible representation of relations within the source story is a representation of the general solution procedure that the protagonist used to solve the problem. This type of abstract representation is also known as the solution principle. Gick and Holyoak (1983) found that providing two source stories, with instruction to compare these stories, greatly facilitated transfer. They argue this manipulation allows the person to form a schema of the solution principle, with the two given source stories given as examples of the schema. An example of such an abstract representation might be: "Both stories use the same concept to solve a problem, which was to use many small forces applied together to add up to one large force necessary to destroy the object" (Gick & Holyoak, 1983).

A similar result is seen in children's analogical problem solving. Chen and Daehler (1989) gave 7 year-old children two source stories that shared few surface features, but structurally were similar. The children were asked to compare the stories, and then to solve a problem.

The results, paralleling the adult's, revealed children who represented the stories at a relatively abstract level, by comparing the structure that was shared by both stories, showed much higher rates of transfer than did subjects who compared the stories in a more concrete fashion. Evidently, for both children and adults, there is some optimal level of representation which allows a person to perceive the underlying structural commonalities between the source stories, and between the source stories and the target problem (Trabasso et al, 1984).

Studies evaluating the role of level of representation in problem solving have utilized stories in which the structure has been complete. That is, the structure in these stories have contained all of the key components that would be necessary to form an analogy that would enable the person to solve the problem. Gick and Holyoak (1983) found that adults who had formed a complete abstract representation showed better problem solving performance than subjects who had an incomplete abstract representation. A complete representation contains all of the elements of the solution principle necessary to solve the new problem, while an incomplete representation would be missing some of these elements, for example not including the idea of the forces adding up to destroy the object. Similarly, Brown (1989) has found that children who remembered all aspects of the goal

structure showed higher transfer rates than did children who only remembered parts of the structure.

Causality of the source stories has also been manipulated to examine how the various aspects of the base structure influence performance in transfer situations. For example, Holyoak and Koh (1987) manipulated the structure of a base story by changing the constraints of the problem presented in the base story. In one condition the constraints in the base story were the same as the constraints in the problem that the subjects had to solve. In other cases the constraints of the base and the target were different. In both cases the actual solution principle was the same, but the rationale for why the protagonist had to perform it was different. Holyoak and Koh (1987) found that when there were similar constraints between the source stories and target problem, 78% of the subjects solved the problem as compared to 54% when there were different constraints. These numbers included both subjects who spontaneously solved the problem, and those who solved it after they were given a hint to try to use the base story to solve the target problem.

Hints are often given to those subjects who initially fail to solve the problem. Failure may not be a result of differences in structure, but of failing to access the base. Hints eliminate the need for subjects to spontaneously

access the base story because they are simply told that the source story is relevant.

Gentner and her colleagues have performed similar types of manipulations on the structure of the base information. Gentner and Toupin (1986) varied structure of the base story by either including or not including a moral, which acted as causal summary of the base information. Eight to ten year-old children benefitted in transfer performance when this summary was included. Gentner and Toupin (1986) claim including the causal summary produces an explicit systematic structure. A systematic structure enables the subjects to more easily transfer relational information because, according to Gentner (Gentner, 1989; Gentner & Toupin, 1986) analogical mapping is more likely to occur between higher order relations, or relations of relations, than between lower order relations or relations between objects.

Chen and Daehler (1992) also manipulated causality in stories given to children. Stories were composed of the following elements; intention to solve a problem, action taken to solve the problem, and a successful outcome. The children were either given complete stories with all the elements present or incomplete stories which eliminated either the intention to solve the problem, or the outcome of the action, or both of these components. By eliminating these features the action became an isolated component of the story, thus varying the degree to which the action was

embedded in the causal structure of the story. Chen and Daehler (1992) found both 5 and 7 year-old showed better problem solving performance when they were provided with stories that had a complete structure, as compared to stories that just had an isolated action. A similar study, with adults, showed that when adults received source stories containing only an isolated action, they performed no better than subjects who only received irrelevant base information (Chen, 1991).

All of the above manipulations examine the role of structure of the source stories in somewhat similar ways. The solution principle is presented explicitly. What has been varied are the causal antecedents of the solution principle so as to increase or decrease systematicity between the base and target. However, it may not always be necessary to give a specific solution action in order for the solution principle to be derived from the source stories. Just how explicit must this solution action be in order for the solution principle to be transferred from the source to the target in an analogical problem solving situation? Must it be described completely in the source stories, or can higher order relations such as the intention to solve a problem, a positive outcome and supporting evidence for the solution action provide a sufficient causal link to permit subjects to formulate for themselves the

solution action? The proposed experiment is designed to provide some information on this question.

Inferences in Reading

One could theorize that the solution principle needs to be explicitly present in the source information, because the solution action is the key component for establishing a representation of a principle that can be successfully transferred from the source stories to the target problem. Even though other aspects of structure such as intention or outcome are given if the solution action is not provided as such, a person may not be able to solve the problem. The solution principle is the relation that must be mapped or transferred from the source domain to the target problem.

However, part of the process of story representation can include the reader making inferences that add knowledge beyond what is explicitly given in the text (Warren, Nicholas & Trabasso, 1979). Therefore, perhaps it is not necessary to explicitly provide the solution action for transfer to occur. By varying the explicitness of presentation of the solution action in the source story and therefore the extent to which it is necessary to infer the solution action, we may learn more about the conditions under which analogical transfer occurs.

Theories of story representations often focus on the readers attempt to discover the causal links of that story (Black & Bower, 1980; Omanson, 1982; Schank, 1975). Many

theories stress the importance of causal connections between events in a story for the representation of events in a story. Causality in a story is always defined in the context of the situation, as what is causal in one situation may not be causal in another (Trabasso et al, 1984). Causality can be defined as " When event A causes event B, this means that A was necessary for B to take place. When event B occurs, event A was required because if A did not occur, then B would not have been possible" (Trabasso et al, 1984).

However, sometimes these causal links are not explicitly given in the text. Inferences, guided by linguistic and world knowledge, can establish connections between the events if these links are not stated in the text (Kemper, 1982). Inferences can fill in the missing events in story structures and they can connect elementary events in the structure with other events to produce higher levels of organization (Kemper, 1982; Warren et al, 1979).

Adults do seem to make inferences to establish coherence while reading. When adult readers are given pairs of sentences their reading times increased as the sentences decreased in the explicit causal linking (Keenan, Baillet & Brown, 1984; Myers, Shinjo & Duffy, 1987). Researchers infer from these results that the reader has reviewed the text in order to make an inference to maintain coherence. de Groot and Van der Pal (1989) found similar results when using short texts of ten to twelve sentences, instead of just

sentence pairs. Reading time increased for texts that were not causal, again indicating that readers made the necessary inferences to maintain coherence.

More disagreement is found on whether there are developmental differences in children's ability and tendency to make inferences. There is evidence that elementary school aged children make inferences, and some studies have found no developmental differences in the ability to make inferences between children in grades 2 and 6 (Danner & Matthews, 1980). Some researchers have found that children as young as three will make inferences about the causes of events (Das Gupta & Bryant, 1989).

Others have found that younger children are less likely to make some types of inferences than older children (Thompson & Myers, 1985). Ackerman (1988) speculates that young children may be less likely to generate inferences depending on the tasks and the nature of the stories given. For example, Johnson and Smith (1981) found that in very lengthy stories, 46% of children in third grade made appropriate inferences. When given the same information in sentence form, so as to reduce irrelevant information, 75% made the inferences. Other situations where the younger child may be less likely to make an inference is when there is less clue support for the inference (Ackerman, 1988). However, most researchers tend to agree on the fact that by grade 2-3, children can make some inferences. Given that a

person makes inferences for comprehension, how does this affect their representation of that material? Goldman and Varnhagen (1983) have found that when children in grades 2 and 5 were given stories that required inferences to be made for comprehension, the inferences were later added to the children's recall of those stories. Similarly, adults incorporate inferences for goals, plans and action in their memory representation of stories. When adults were given stories that suggested certain inferences, and then given a recognition task for elements found in the story, they showed a high false alarm rate to elements that would have been inferred (Seifert, Robertson & Black, 1985).

When a person makes inferences, this can allow them to gain a more thorough understanding of the text than if they did not make the inference. Inferences can link separate events in the story and the person can gain knowledge beyond what is provided. There is even evidence that in some cases having to make inferences to understand text can improve memory performance over not having to make inferences. Keenan, Baillet and Brown (1984) and Myers, Shinjo and Duffy (1987) presented adult subjects with pairs of sentences that varied in their degree of relatedness. Both sets of researchers found that sentences that were moderately related were recalled the best in a probe-recall task. Myers et al (1987) hypothesize that this result is obtained because of elaborative processing. Subjects encode both

explicitly presented concepts and concepts which they themselves have generated. With moderately related sentences, there is a high probability that most readers will generate inferences to connect the sentences, with the result that their representation will include this inference. At low levels of relatedness, subjects are less likely to generate inferences, and at high levels of relatedness, inferences are not required. Therefore in both of these cases the representation will be sparser than the representation of subjects exposed to moderately related sentences. The elaborations that become part of the representation of the text can provide additional routes to target information at the time of recall.

Overview of Experiments

As can be seen from the above research a person can make inferences about events in stories, and furthermore, that when a person makes an inference, it can affect the representation of that material. The present experiment examined whether the requirement to make an inference also affected performance in an analogical problem solving situation. More specifically, the extent to which the solution action was explicitly described was manipulated. Other aspects of structure, such as problem orientation and outcome, were held constant over all conditions.

In this experiment one group of subjects received source stories in which the action associated with the

solution principle was explicitly provided. Other subjects received stories in which the action was not given. In this later case, subjects must infer the action for themselves.

It was expected that subjects receiving the explicit version of the stories, which contain the complete solution principle, would show better performance than those subjects in the control group, who only received irrelevant information. Of more interest was whether there was a difference in problem solving performance in subjects in the implicit condition versus the control condition. Better problem solving performance from subjects receiving the implicit solution principle than from subjects in the control condition would suggest that the action does not have to be explicitly stated in a source story for that story to be used in analogical transfer. People would be able to use information that they have had to infer to solve a problem. Inferences about the solution principle that subjects generated would be incorporated into their representation of the source domain. These inferences would then be just as available for the subject to use in a mapping process to form the analogy as information that was explicitly given to the subject.

Previous research has shown that subjects can use some types of self-generated information in analogical problem solving. When adults have been asked to generate their own concrete examples of the abstract principle, they show about

equal facility in problem solving performance as when they are provided with the example by the experimenter (Chen, 1991). There is also preliminary evidence that when 7 year-old children have been given this same type of task, they can also use their self-generated examples in a transfer task (Chen, Daehler & Yanowitz, 1991).

Other researchers have also shown that adults can use self-generated information in analogical transfer. Gick and Holyoak (1980) gave subjects a source story with initial problem constraints and asked the subjects to generate solutions for this story. Then they were presented with Duncker's radiation problem and were asked to try to solve this problem. Gick and Holyoak (1980) found that of subjects who generated the convergence solution to the source story 41% then solved the radiation problem.

In the experiments conducted so far, subjects were given some analogical information to start off with, and/or were specifically asked by the experimenter to generate the source information. In the present experiment, subjects in some conditions were not given any specific directions to generate the action inference. The source stories contain support that may lead the subjects to make the inference of action, but the subjects must make the inference for themselves.

Subjects in other conditions were asked to make the inference by answering a question concerning the

protagonist's action in the story. This demand question forced subjects to verbalize what they thought the protagonist's action was in solving the problem. Performance of subjects receiving both stories that required generation of the action and questions that encouraged verbalization of this inference was expected to be better than performance of control subjects, nearly equal performance as when subjects receive the action explicitly. The demand manipulation was included to show that when subjects are forced to make the inference, they can then use this information in analogical transfer.

Some subjects who received the explicit versions of the stories were also asked demand questions. This was done as a check to see if subjects had represented this information and to determine the effects of asking these questions on performance. The demand questions may serve to focus attention on the solution principle. Such questions could encourage a subject to review this material and perhaps contribute to a change in representation. In addition, these questions could effect noticing process, by emphasizing to the subjects the importance of the base story. Therefore subjects who received the demand question could show better performance overall than subjects who did not receive these questions.

Comparison of performance between subjects receiving the explicit solution principle and the implicit solution

principle was also of interest. Subjects receiving the implicit solution principle could show a lower level of problem solving performance than subjects receiving the explicit solution principle. Subjects receiving the implicit stories could incorporate generated solution actions in their representation of the story less frequently than subjects who receive the explicit story, all of whom have a chance to incorporate the given action into their representation.

Alternatively, subjects could perform equally well in both the implicit and explicit conditions. Spontaneously inferred information, in this case the action in the solution principle, may be equivalent for problem solving compared to experimenter provided information. However, in the Gick and Holyoak (1980) experiment where subjects had to generate the entire solution principle, performance, although better than control, was worse than when the experimenter provided the answer. Gick and Holyoak (1980) speculated that perhaps the convergence solutions that the subjects were generating were either not complete or embedded in other solutions. In the present experiment, subjects only had to infer the solution action, and there was support in the story that should bias them to infer the "correct" action, as defined by the solution principle. Therefore, these subjects might do as well as subjects who receive the action as part of the story.

Both children and adults were used as subjects in these experiments. Since the materials and problems were very different for the children and the adults, no direct comparisons of performance were made. Many of the findings in analogical transfer have either not shown any age differences, or if there have been differences, these results can be explained by reference to the knowledge base rather than by differences in the process of analogical transfer (Brown, 1990; Brown, 1989; Brown & Kane, 1988). No specific prediction were made in regard to possible differences in the performance between the adults and children and the experiments were considered as replications. In summary, this experiment dealt with how explicit base information must be in order for it to be used in an analogical transfer task. Must all the information be presented to the subject, or can other cognitive processes, such as the ability to make inferences, influence the process of analogical transfer? This experiment may give us new knowledge of the conditions under which analogical transfer takes place, and of the role of the person's cognitive abilities in that transfer process.

CHAPTER 2

EXPERIMENT 1: THE EFFECTS OF GENERATING INFERENCES ABOUT A SOLUTION PRINCIPLE IN ANALOGICAL TRANSFER WITH ADULTS

Method

Subjects

180 college students from the University of Massachusetts participated in this study. Subjects received extra credit in psychology classes for participating. Subjects were limited to those students who reported that they had not taken the basic cognitive psychology course offered by the psychology department. 29 subjects were dropped from the study because they had heard of the Duncker radiation problem before participating, 1 subject refused to complete the study, and 2 subjects did not provide any recall of the source stories, thus 148 subjects are included in the analysis.

Design and materials

The experimental design was a 2 (Explicit solution principle, Implicit solution principle) by 2 (Demand, Non Demand) plus a control group. The explicit stories gave the complete solution principle, while the implicit stories did not give the action in the solution principle. The source stories involved the protagonist of the stories sending a force to a target, but an obstacle prevented simply sending the force en mass. The protagonist must therefore divide the large force into several smaller forces, to meet at a

general needed to send a large army to a fortress, but all the roads leading to the fortress were set with mines so that a large group of men traveling over a road would detonate the mines, but a small group would not. The general divided his army into several small groups, each taking a different road so they all met at the fortress without triggering any mines. The implicit stories eliminated the dispersion of the forces down different paths and their subsequent convergence at the target (see Appendix A).

The demand variations did not involve a change in the source stories themselves, but rather in how the subject was asked to think about the stories. After receiving each story, subjects in the Demand condition were asked to state how the protagonist solved the problem. This question forced the subject to explicitly state the action. If a subject received implicit stories, this forced him or her to generate the inference. For subjects who heard the explicit stories, this question acted as a check on memory of the action. No question was asked in the Non Demand condition, Instead, subjects were asked to briefly summarize the story, ensuring that all subjects spent approximately the same amount of time processing the stories.

The target problem was a standard form of Duncker's (1945) radiation problem (see Appendix A). This problem has been used in many experiments involving analogical transfer.

Procedure

The general format of the experiment was to first present stories to the subjects, and then to present the problem. No connection was made between the source stories and the target problem, and subjects were told that the study contained several different parts. All information was presented in booklet form, with the pages face down, so subjects could only see one page at a time, and the experimenter indicated when to turn the page. All responses were written down. Small groups of subjects participated at the same time.

Subjects were given 3 minutes to read the first source story. Then they were directed to turn over that page, and on the next page, write as much of the story as they could remember. Directions at the bottom of this page instructed subjects to either summarize the story (in the Non Demand conditions), or to state how the protagonist solved the problem (in the Demand conditions). Subjects were allowed up to 6 minutes for this task. This procedure was repeated for the second source story.

Subjects then compared the two source stories, and were given 4 minutes for this task. Following this task, the subjects were given the target problem. They were directed to provide up to five different answers to the problem, and were allowed up to 8 minutes to complete this task. After this point, subjects completed the rest of the study at

their own pace. Subjects were asked if the source stories helped in solving the problem, and rated the amount of help received. A hint was given that the stories could help them to solve the problem, and subjects were asked to provide the best answer possible to the radiation problems, based on that knowledge.

Results

Summary of Dependent Measures

Dependent measures examined in this study were based on problem solving performance, memory, and representation. The first type of measure dealt with the performance on the Duncker radiation problem. Problem solving performance was measured both pre and post hint. Subjects were scored as correct or incorrect on their answer to the problem. Two observers independently scored the problem solving performance. Observers agreed on 99% of their judgements on whether the subject had or had not solved the problem, and came to a consensus on any disagreements.

A second type of dependent measure involved subject's representation of the source stories. Subject's comparisons of the stories were categorized into three levels of representation; no comparison of solution principle elements, incomplete comparison of solution principle elements and complete comparison of solution principle elements. The author and another observer scored 24 randomly selected subjects, and agreed on 83% of their

categorizations on level of comparison. McNemar's test of correlated proportions (Hays, 1963) showed no differences between scorers' judgements of categories. The author then scored the remaining subjects.

Ability to generate the action inference was examined by response to the demand question of subjects who received the implicit source stories. Again, two observers scored all subjects responses, and had a 95% agreement on their judgment, and again there was no significant difference between scorers' judgements using correlated proportions. Any disagreements were resolved by consensus.

Another dependent measure was subject's memory for the source stories. Memory was scored by breaking down the story into the components of protagonist, problem facing the protagonist, obstacle preventing initial goal attainment, action taken to overcome obstacle, and goal attainment. Two observers scored all subjects, with a range of 95% to 100% agreement on presence of story components. Again, observers came to agreement on any discrepant scores. Element recall for each subject was assessed by averaging the recall of each element over the two source stories. Therefore the possible recall score for each element was 0.0, 0.5, or 1.0. Group recall was obtained by averaging each subject's average score.

Finally, subjects were asked to indicate if the source stories had been helpful to them when solving the problem

(yes/no). In addition, subjects responses on a 7 point scale ranging from 1 (not helpful at all) to 7 (extremely helpful) were analyzed as a measure of how helpful the source stories were.

Performance on the Duncker Problem

Table 1 contains the percentage of subjects solving the problem pre-hint, post-hint and the total problem solving performance. Examination of the pattern of pre-hint performance reveals that the percentage of subjects solving the problem pre-hint was low, ranging from 19% to 0% in the various conditions. An initial overall maximum likelihood chi squared yielded marginally significant differences between the five groups, $G^2(4) = 9.18, p < .1$. The maximum likelihood chi square procedure (Hays, 1963) is used for all following analyses involving categorical numbers. Pairwise comparisons revealed differences between the Control condition and; Explicit Demand, Explicit Non Demand, and Implicit Non Demand ($p < .05$) and between Control and Implicit Demand ($p < .1$). No significant differences were found between any of the experimental conditions.

Success on the problem was surprisingly low, even for subjects who received the explicit stories. The subjects in the explicit conditions read stories similar to those stories given in other experiments, conducted at the University of Massachusetts and elsewhere (Chen & Daehler, 1992, Gick & Holyoak, 1980, 1983). In previous studies

Table 1: Percentage of adult subjects producing the convergence solution

Condition	n	Before hint ¹	After hint	Total
Explicit Demand	26	15 ^a (4)	13 ^a (3)	27 ^a (7)
Explicit Non Demand	31	19 ^a (6)	16 ^a (4)	32 ^a (10)
Implicit Demand	29	7 ^{a,b} (2)	19 ^a (5)	24 ^a (7)
Implicit Non Demand	36	14 ^a (5)	6 ^{a,b} (2)	19 ^a (7)
Control	26	0 ^b (0)	0 ^b (0)	0 ^b (0)

¹ number solved are given in parentheses.

Note: values within columns not sharing identical superscripts differ significantly,

$p < .05$.

solution rates of 40- 60% were commonly reported in experimental conditions, but only 17% of subjects in similar groups in this study solved the problem. Possible reasons for this difference are discussed later on, but the relatively poor performance by subjects in the experimental groups in this study may have prevented differences between experimental groups from emerging.

Examination of performance of the subset subjects who only solved the problem post-hint (Table 1) revealed a fairly similar pattern of results as those reported for pre-hint solutions. Subjects in the Explicit Demand, Explicit Non Demand and Implicit Demand all solved significantly more problems than Control subjects after the hint was given ($p < .01$). Again, there were no differences between any of the experimental groups.

Total problem solving performance included subjects who solved the problem both before and after the hint. When the total problem solving performance was examined (Table 1) each experimental group outperformed the Control group performance ($p < .005$). However, there was still no difference between the experimental groups.

Subjects' solutions to the problem were further examined using a more liberal scoring criterion. In this case, any answer that mentioned use of multiple low intensity rays, regardless of how they were employed, was scored as correct. Although the percentage of correct

answers increased using this criterion, ranging from 35% to 70%, the pattern of results remains the same as for original scoring procedure. Therefore, only results using the original criterion are reported in the following analyses.

Data from the experimental groups were combined to examine the effects of subjects receiving the explicit or implicit solution principle, or of being asked how the protagonists solved the problem. No significant differences were found between groups receiving the explicit or implicit solution principle or between groups answering or not answering the demand questions, before receiving a hint, after receiving a hint or for total problem solving performance.

Other Analyses

52% of subjects who solved the problem produced a complete representation, while only 10% of subjects who did not solve the problem produced a complete representation (Table 2). Subjects who solved the problem had a higher level of representation than those who did not solve the problem ($G^2=16.91$, $p < .001$) However, no significant differences in level of representation between any of the experimental conditions was seen.

Production of the story elements in the recall task was examined (Table 3). As stated before, the data contributed by each subject for this measure is their average recall of the element, over the two source stories. No differences

Table 2: Percentage of subjects scoring at each of the three levels of story comparison

	Story Comparison		
	0	1	2
Adults			
Subjects who solved the problem	24	24	52
Subjects who did not solve problem	67	23	10
Youngest third of children			
Subjects who solved the problem	14	14	72
Subjects who did not solve problem	50	17	33

Table 3: Adult production of story elements (averaged over two source stories) in recall task

Condition	Story Elements					
	protagonist	problem	obstacle	action	solution	
Explicit Demand	1.0	1.0	1.0	1.0	1.0	1.0
Explicit Non Demand	1.0	1.0	1.0	0.9	1.0	1.0
Implicit Demand	1.0	1.0	0.9	0.1*	0.8*	0.8*
Implicit Non Demand	1.0	1.0	1.0	0.2*	0.9*	0.9*

Note: Starred values within columns differ significantly from non starred values, ($p < .05$).

were seen for memory of the protagonist, the problem facing the protagonist, or the obstacle preventing goal attainment among the four experimental groups. However, there was a large difference between subjects' reporting the action element. Very few subjects who did not receive the action in the source stories spontaneously added the action to their recall of the story. Pairwise comparisons between conditions, using the Bonferroni adjustment (Myers & Well, 1991), showed differences between subjects receiving the implicit structure as compared to the explicit structure, $p < .01$. There was also a difference in recall of whether the protagonists solved their problems. Tukey's studentized range method post hoc tests showed that subjects who received the implicit story structure had a poorer memory of the protagonist's success than did subjects who received the explicit story structure ($p < .05$).

Demand question answers were examined in a similar way as recall production. Each subject contributed a score, averaged over the two source stories ranging from 0 (no correct answer) to 1 (both answers correct). Subjects showed a high proportion of correct answers to the demand question. Subjects in the Explicit Demand condition showed an average correct answer rate of .9, while subjects in the Implicit Demand condition showed an average correct answer rate of .8. A comparison of these responses revealed no significant differences in correct answers between subjects who received

the explicit solution principle and subjects who received the implicit solution principle.

Finally, subjects' judgment of the usefulness of the source stories was examined (Table 4). Subjects in the experimental conditions recognized that the source stories did aid them in solving the problem. When asked if the stories helped them (yes/no), maximum likelihood chi squared procedure revealed that each experimental condition differed from the control condition ($p < .001$). Further examination of this measure revealed that most subjects who solved the problem reported that the source stories aided them in arriving at their solution. Surprisingly, many subjects in the experimental conditions who failed to solve the problem also said that the stories helped. However, few subjects in the Control condition claimed the stories aided them.

Subjects also rated the degree to which the stories helped them in solving the problem (Table 4). Again, many subjects in the experimental groups who failed to solve the problem gave ratings similar to those subjects who did solve the problem, indicating that subjects who failed to solve the problem thought the stories helped them in the problem solving task. However, subjects in the Control group produced a lower rating than subjects in each of the experimental groups ($p < .001$).

Table 4: Adult ratings of usefulness of source stories

Condition	% of subjects recognizing source stories as helpful	Usefulness rating
Explicit Demand	42 ^{a,b}	3.4 ^a
Explicit Non Demand	52 ^{a,b}	3.9 ^a
Implicit Demand	67 ^b	3.8 ^a
Implicit Non Demand	39 ^c	3.0 ^a
Control	4 ^d	1.8 ^b

Note: Values within columns not sharing identical superscripts differ significantly, ($p < .05$).

Discussion

Although there were differences between the experimental groups and the control group, the total number of subjects who solved the problem was lower than expected based on previous research. Several differences between procedures employed in this study and other studies might partially account for the low level of performance. In this study, subjects were instructed to "read the stories carefully, because they were going to be asked to recall as much of the stories as possible." After each story was presented, subjects engaged in this recall task. Other studies have not included this memory task (Gick & Holyoak, experiment 4, 1983) or have only asked for a brief summary of the stories (Gick & Holyoak, experiment 5, 1983). In addition, the Gick and Holyoak (1983) studies and others (Catrambone & Holyoak, 1989; Chen, 1991) first presented both stories and then asked for a brief recall. In this study the recall of each story was asked for immediately after the story was given.

These differences in procedure could have affected performance in two ways. First, a fatigue or motivational factor may have come into play. By the time subjects came to the problem solving task of this experiment, they had spent up to 22 minutes writing. In comparison in Chen (1991) and Catrambone and Holyoak (1989) subjects spent only about 10 minutes on the reading and recall tasks before receiving the

target problem. Therefore, because of the longer time in this experiment, subjects may have been less motivated to try to solve the problem. The experimenters noticed that many subjects did not seem to be actively trying to solve the problem for the full 8 minutes allotted for problem solving. Some subjects put down their pens and simply stared at the experimenter until work on the next section was allowed.

Second, the emphasis on memorization of the source information could have introduced a different orientation in the acquisition phase than that required for the problem solving phase. Similarity between acquisition processing and later problem solving tasks can increase problem solving performance (Adams et al, 1988; Lockhart, Lamon & Gick, 1988; Needham & Begg, 1991). The procedure of presenting one source story and then having subjects recall the story before presenting the second source story may have had the effect of producing memory-oriented representation, rather than a problem-solving orientation. In other studies, where both stories were presented one right after the other, subjects may have been encouraged to process the stories as a single unit.

Similarity in processing between acquisition of information and problem solving is assumed to increase accessibility of the source information. Many researchers (Brown, 1989; Gick & Holyoak, 1983; Ross, 1989) have shown

that accessing source information can be one of the main sources of difficulty for subjects engaged in an analogical problem solving task. In this study, after a hint was given to use the source information, which can help circumvent the problem of access, more subjects in each of the experimental groups were able to solve the problem. No subjects in the Control group were able to solve after hint, indicating that one of the reasons performance was so low was difficulty in accessing the relevant source information.

Since the percentage of correct answers was so low, incorrect answers were examined. The most prevalent incorrect answer given was to use a medium ray or some variation of the theme giving more than one ray, but not correctly specifying how the rays were to be used. These answers ignore the constraint that rays sufficiently powerful enough to destroy the tumor would also destroy healthy tissue. These kinds of answers may help to explain the surprising finding that among the experimental conditions, a fairly high percentage of subjects claimed the stories were helpful, even though they had not solved the problem.

Many subjects seemed to feel that they had solved the problem. One aspect of analogical transfer includes the ability to evaluate a potential analog and to adapt a solution from that analog. In this study, subjects did not seem to evaluate the adequacy of their answers. A high

proportion of subjects felt that the stories helped them in solving the problem and may have believed that they had indeed solved the problem. Subjects did not seem to realize that they were providing an incorrect answer. Although other studies have not reported this problem, Duncker (1945) and Gick and Holyoak (1980) showed that producing any one particular answer to the problem suppresses the ability of subjects to produce other equally plausible answers. People generally find the Duncker radiation problem difficult to solve if not given appropriate analogous information. If the discrepancy between the acquisition of the source information and the problem solving attempt blocked or lessened the ability to notice and retrieve the source information, many subjects may have been forced to rely on other resources. If subjects felt that they had generated the correct answer, other answers may not have been produced.

Despite the low level of performance, subjects did benefit from receiving the source information. For the total percentage solved, each of the experimental groups outperformed the control group. For subjects who received the explicit solution principle, this finding is confirmed by numerous other studies. Subjects who received an implicit solution principle were also able to use this principle in the analogical transfer task. Interestingly, there was no difference in performance between experimental groups.

Performance did not seem to be affected by whether the action was supplied by the experimenter or was self-generated. Subjects did not need to be explicitly presented the action of the solution principle, but were able to generate inferences which they could then use in analogical problem solving.

The fact that there did not seem to be a difference in the use of experimenter provided or self-generated knowledge is different from previous studies that required the subjects to generate a solution to similar types of problems. Gick and Holyoak (1980) found subjects who had to generate a solution to the source story had lower level of performance in solving Duncker's radiation problem than subjects who received complete source stories. Gick and Holyoak (1980) speculate that solutions subjects generated were less useful than the experimenter provided solutions. In the present study, subjects were provided support in the stories to generate the correct inference, so their inferences seemed to be as effective as experimenter provided information.

A complementary finding to the fact that there was no difference in solution rates between experimental groups is that there was no difference in level of solution principle representation between experimental conditions. Level of representation reflects the ability of subjects to engage in successful analogical transfer (Brown, 1989; Chen & Daehler,

1989; Gick & Holyoak, 1983). In this study the majority of subjects who solved the problem produced a complete representation of the solution principle. Although conclusions are limited by the overall poor performance, the finding that there was no difference in level of representation between experimental conditions provides support for the claim that subjects can represent and use self-generated and experimenter provided information with equal facility. Once the subjects had represented the source information, they were able to proceed with constructing a set of correspondences between the source stories and the target problem. Mapping did not seem to be affected by how the information was obtained in the representation.

CHAPTER 3

EXPERIMENT 2: THE EFFECTS OF GENERATING INFERENCES ABOUT A SOLUTION PRINCIPLE IN ANALOGICAL TRANSFER WITH CHILDREN

Method

Subjects

139 second and third grade students participated in this study. 47 students were from Mark's Meadow Elementary school, Amherst, Massachusetts. 92 students were individually recruited to participate at the Child Study Center in Springfield, Massachusetts. 2 subjects refused to participate, 1 subject was discovered to have a learning disability and 2 subjects were dropped because of equipment failure, so data from 134 subjects are included in the following analyses. The mean age was 94 months (8.5 years) and the range was 77 to 118 months.

Design and Materials

The experimental design was the same as in Experiment 1. Briefly, a 2 (Explicit structure of solution principle vs Implicit structure of solution principle) by 2 (Demand vs Non Demand) factorial design plus a Control group was used. The explicit stories contained the complete solution principle of connecting two short objects to make a long tool that could reach a goal object. For example, a cat wanted to reach a feather in a tree. In order to reach the feather, she had to combine a stick and a branch to make an

object long enough to reach the feather (see Appendix B). The implicit stories eliminated the combining action contained in the solution principle. The control stories contained only irrelevant information. The demand manipulation was similar to the one used for the adults. Subjects in Demand conditions were asked how the protagonists solved their problems. Subjects in the Non Demand condition were asked to give the main idea of the story.

The target problem was similar to one used by Chen and Daehler (1989, 1992, Chen, 1991). The problem required the subject to retrieve a ball from the bottom of a tall cylinder, without turning the cylinder upside down. The cylinder was located on a table along with a number of other common items including a tinkertoy stick and a spoon, and a number of irrelevant props including a toy key, a toy hammer, a S-shaped hook, toy scissors, a wooden block, a metal pan, toy stick of butter, a cup, and a box. The problem could only be solved by connecting the stick and the spoon together, which made a tool long enough to retrieve the ball.

Procedure

The general format of the task consisted of presenting two source stories to the children and then presenting the transfer problem. The entire experimental situation was videotaped.

The first source story was read and the child recalled as much of the story as he or she remembered. Experimenter's prompts were limited to general encouragement except when the child did not produce any recall within approximately 20 seconds. If no response was initiated by the child at this point, he or she was asked "what did (protagonist's name) do?". A child who produced any recall of the story after this point was given full credit for whatever was produced. After recall, in the Demand condition, the child was asked how the protagonist solved the problem. If he or she could not answer this general question, the questions became increasingly more specific, by asking how the protagonist used the two objects to retrieve the goal object. Subjects in the Non Demand condition were asked to tell what they thought the main idea or important point of the story was so as to equate the time spent on the story with the time spent in making inferences by children in the demand conditions. This same format was followed for the second story. After children had received both stories, they were asked to indicate the similarities between the two stories (e.g. "Was anything the same in those two stories? Was anything alike in the stories, how were things alike?").

The target problem was introduced as "now we are going to do something different". 200 seconds were allowed to solve the problem. If the child did not solve the problem after 200 seconds, a hint was given to the child to "think

about the stories. That could help you solve this problem." and another 100 seconds was allowed for problem solving. If the child still did not solve the problem, they were given another hint to "think about what the genie did to solve the problem and what the cat did to solve her problem", and another 60 seconds were allowed. Children in the Control group who did not solve the problem within 200 seconds were told one time that the stories could help them, but emphasis was put on "just keep trying". They were allowed another 160 seconds to try to solve following this information.

Results

Summary of Dependent Measures

Several types of dependent measures were examined. Problem solving measures included the percentage of subjects who correctly solved the problem pre-hint and post-hint, and time to solve the problem pre-hint and time to solve post-hint. An additional measure was the total percentage of subjects who solved the problem and time required to solve. Two researchers independently scored 14 subjects on these measures (8 at the beginning of scoring, and 6 about halfway through scoring). There was 100% agreement for solving the problem, and the Pearson product moment correlation was .99 for time to solve. One researcher then scored the remaining subjects.

Other measures involved subject's representation of and memory for the source stories. Level of representation was

based on the comparisons of the source stories and scored using the same scale developed for the adult's representation scores as described in Experiment 1 (no comparison of solution elements, incomplete comparison of solution elements, complete comparison of solution elements). Scorers agreed on 91% of the classification for 14 subjects and one assistant scored the remaining subjects. McNemar's test of correlated proportions showed no differences between category judgements.

Subject's memory for the source stories was also examined. Again, as in Experiment 1, source stories were broken up into story elements, including protagonist, problem facing the protagonist, obstacle preventing initial goal attainment, action taken, and goal attainment. Subject's recall was judged for the presence of each element. Agreements ranged from 82%- 96% for 14 subjects on the various elements, and again one assistant scored the remaining subjects.

Another measure examined the answers that subjects gave to the demand question. There was 100% agreement on answers to the demand question from 18 randomly selected subjects who received the demand question, and one observer scored the remaining subjects. Again MacNemar's test of correlated proportions showed no differences between category judgements between the two scorers.

Performance on the Problem Solving Task

Preliminary analyses showed no difference for gender, or between the two different sample populations on any of the aforementioned measures.

Table 5 shows the percentage of subjects who solved the problem pre-hint, post-hint and total problem solving performance measures. Considering first the performance of subjects pre-hint, the majority of subjects in all conditions solved the problem. As seen in Table 5, there were no significant pairwise differences between any of the experimental groups and the Control group for solving the problem pre-hint. There was also no difference between groups for time to solve the problem pre-hint, as seen Table 6. Time to solve was examined by either assigning a maximum value of 200 seconds for subjects who did not solve the problem (Chen and Daehler, 1992, 1989, Chen, 1991), thereby permitting all subjects to be included in the analysis, or by examining only the times of the subset of subjects who did solve the problem. No significant differences were found between groups for time to solve the problem pre-hint using either time measure.

A different pattern of results emerged when examining post hint performance (Table 5) for the subset ($n = 54$) of subjects who did not solve the problem before the first hint to use the stories was given. Only 6 subjects solved the

Table 5: Percentage of children who produced the combining solution

Condition	n	Before hint ¹	% solved After first hint ²	Total
Explicit Demand	25	64 (16)	33 ^{a,b} (3)	80 (20)
Explicit Non Demand	25	68 (17)	50 ^a (4)	84 (21)
Implicit Demand	27	56 (15)	50 ^a (6)	81 (22)
Implicit Non Demand	32	56 (18)	11 ^{a,b} (3)	75 (24)
Control	27	59 (16)	9 ^b (1)	67 (18)

¹ number solved are given in parentheses.

² based on the subset how had not solved prior to hint.

Note: Values within columns not sharing identical superscripts differ significantly, ($p < .05$).

Table 6: Children's time to produce combining solution

Condition	\bar{n}	Time to solve ¹ (seconds)		
		Before hint ²	After first hint ²	Total ²
Explicit Demand	25	108 (55)	78 (35)	150 (98)
Explicit Non Demand	25	122 (85)	72 (45)	154 (115)
Implicit Demand	27	131 (76)	83 (62)	173 (128)
Implicit Non Demand	32	141 (94)	94 (73)	195 (137)
Control	27	123 (70)	94 (30)	182 (94)

¹ time to solve includes maximum times of 200 seconds, 100 seconds and 360 seconds for non solvers for Before hint, After first hint, and Total, respectively.

² time in parentheses includes only subjects who actually solved the problem.

problem only after the second hint, so any separate analysis of post hint performance is limited to performance after the first hint. Control group post-hint 1 performance is taken as the percentage of subjects who solved the problem in up to 100 seconds after the hint was given. This ensures an equal time period for post-hint 1 for both experimental and control groups. The Control group differed significantly from the Explicit Non demand ($G^2(1) = 4.1$ $p < .05$), and the Implicit Demand ($G^2(1) = 4.9$, $p < .05$) groups for percentage of problem solving. Performance in the Explicit Demand and the Implicit Non demand conditions did not differ from the Control condition. Time to solve post hint 1, was not significantly different between any of the groups (Table 6). Again, time was examined both by including all of the subjects and assigning a maximum time to non solvers, or by including only those subjects who solved.

Since subjects were given two hints to encourage problem solving, total problem solving performance examines whether subjects solved the problem at all, either pre-hint or after either of the two hints. No differences were found between groups on total problem solving performance for any of the problem solving measures (Table 5 and Table 6).

Although there were few differences between the experimental and the control groups, analyses were performed to see if there were any indications of effects of experimental variables within the experimental groups. There

was no difference in the percentage of problems solved as a function of structure or of answering the demand questions, using the maximum likelihood chi squared method. Likewise, there were no differences on time to solve, both pre and post hint using the analysis of variance method on the 2(explicit action, implicit action) by 2 (demand, non demand) factorial design.

The overall high level of performance of subjects in the Control group was surprising. A comparison of the ages of subjects in this study with the ages of subjects that participated in studies using similar problems (Chen & Daehler 1989, 1992), revealed that subjects in this study were approximately a year older and the age range was substantially greater. Older children were deliberately selected for this study to ensure ability to make the inferences required by the implicit conditions. As a result the problem may have been too easy for most subjects. In this study, 59% of the control subjects were able to solve the problem before a hint was given. In comparison, only 20-30% of control subjects in the previously mentioned studies solved similar problems. Therefore, the data for the youngest third of the subjects included in this study ($n = 43$) were selected for further analysis. The mean age of these subjects, 86 months, more closely matched the ages of subjects in other studies.

The results for this subgroup of children, summarized in Table 7, also revealed few differences. Subjects in the Explicit Demand group showed a higher percentage of problem solved than all of the other experimental groups and the Control group, using the maximum likelihood chi squared procedure ($p_s < .05$) and solved the problem faster than any other group, using Tukey's post hoc comparison ($p_s < .05$). Time to solve, for this and the following analyses, included a maximum assigned time for subjects who did not solve. This procedure took into account those subjects who did not solve the problem to maximize the number of subjects in each condition.

Again, although few differences were revealed between the experimental groups and the control group, problem solving performance was examined to see if there was any differential effect of the experimental manipulations. Percentage of pre-hint problem solving was examined, as a function of structure and of receiving a demand question, by combining over groups. Subjects receiving a demand question solved more problems than subjects who did not answer any questions ($G^2(1) = 3.75, p < .05$). No significant difference as a function of receiving the implicit or explicit story structure was found. An analysis of variance was performed on the time to solve pre-hint using the 2 (Explicit solution principle, Implicit solution principle) by 2 (Demand, Non Demand) factorial design. This analysis revealed a

Table 7: Percentage of youngest third of children who produced the combining solution, and time to solve

Condition	n	% solved ¹		time to solve(sec) ²	
		Before hint	Total	Before hint	Total
Explicit Demand	7	100*(7)	100*(7)	57	57
Explicit Non Demand	9	67 (6)	89 (8)	121	125
Implicit Demand	8	50 (4)	75 (6)	139	195
Implicit Non Demand	10	50 (5)	80 (8)	170	224
Control	9	55 (5)	55 (5)	125	196

¹ number solved are given in parentheses.

² times include all subjects, with 200 seconds and 360 seconds given as maximum times to non solvers for Before hint and Total, respectively.

Note: Starred values within columns differ significantly from non starred values, ($p < .05$).

significant main effect favoring those subjects who received the explicit solution principle ($\bar{M} = 101$ seconds) versus those subjects who heard the implicit solution principle ($\bar{M} = 147$ seconds, $p < .05$). Subjects who answered a demand question also solved the problem faster ($\bar{M} = 94$ seconds) than subjects who stated the main point of the stories ($\bar{M} = 156$ seconds, $p < .05$). No significant interaction was seen.

No difference was found on total problem solving performance as a function of structure of the source stories or answering the demand questions. When the total time to solve, both for subjects who solved both pre and post hint is analyzed, a somewhat different pattern of results emerged, as compared to the pattern of time before hint. In this case, groups receiving the explicit solution principle structure did not differ from groups receiving the implicit structure. However, subjects who answered a demand question still solved significantly faster ($\bar{M} = 96$) versus those who did not answer this question ($\bar{M} = 211$, $p < .005$).

Other Analyses

An initial analysis comparing level of representation of the stories for subjects who solved the problem versus those who did not solve the problem revealed a significant difference between these groups ($G^2(2) = 5.94$, $p < .05$) 72% of the subjects who solved the problem produced a complete representation, while only 33% of the subjects who did not solve the problem produced a complete comparison (Table 2).

However, no difference was found in level of representation between subjects who received the explicit solution principle versus subjects who received the implicit solution principle. There was a difference in level of representation between subjects who answered the demand question and those who did not ($G^2(2) = 8.109, p < .05$). 81% of subjects who answered the demand question produced a complete representation, while only 39% of subjects in the Non Demand conditions produced a complete representation.

Finally, subjects' memory of the story elements was examined (Table 8). As with the adult's production, each subject contributed an score averaged over the two source stories. A series of comparisons, using the Bonferroni adjustment, revealed no differences between any of the groups for recall of the protagonist, the problem that the protagonist faced, the obstacle preventing goal achievement, or the fact that the goal was achieved. However, there was a difference in production of the action element. Production of the action element accurately reflected whether the subject had heard the action in the stories. Few subjects in the implicit conditions spontaneously added the action inference to their recall. Comparisons showed that subjects who received the explicit story structure produced the action more than subjects who received the implicit story structure, $p < .01$.

Table 8: Youngest third of children's production of story elements (averaged over two source stories) in recall task

Condition	Story Elements				
	protagonist	problem	obstacle	action	solution
Explicit Demand	0.6	0.9	0.6	1.0	0.9
Explicit Non Demand	0.8	0.9	0.9	1.0	1.0
Implicit Demand	0.8	1.0	0.7	0.3*	0.8
Implicit Non Demand	0.8	0.9	0.7	0.1*	0.7

Note: Starred values within columns differ significantly from non starred values, ($p < .05$).

The type of structure of the solution principle did not affect subjects' correctly answering the demand question. Again, each subject contributed an answer averaged over the two source stories. Subjects in the Explicit Demand condition produced an average score of 1, while subjects in the Implicit Demand produced an average score of .8.

Discussion

In general, the problem used in this study was solved by the majority of subjects. Even many of the younger subjects in the Control group had high levels of solving. The majority of subjects were obtained by recruiting parents to come to a child study center. This procedure may have had the effect of selecting a population of children that came from a family environment that placed emphasis on learning and discovery. Many parents indicated that their children loved puzzles or were at or near the top of their class academically.

Examination of the post hint 1 performance of the subset of subjects that did solve the problem before a hint was given revealed differences between conditions. A hint can help to overcome accessing difficulties, so some children evidently had difficulty in accessing the source stories. Children who heard the Explicit Non demand and Implicit Demand stories showed a higher level of problem solving than children in the Control group after a hint was given. Since these groups solved significantly more problems

than the Control group, which was given an equal amount of extra time, it was not just a matter of extra time needed by these subjects. Rather, subjects in these experimental conditions could now use the source information in a way that they could not do before a hint was given.

Even for the youngest third of the subjects, there were few advantages of being in an experimental condition compared to the control group, so any conclusions of effects of the experimental variables must be considered cautiously. However, structure of the stories did seem to affect their ability to use the stories. For example, the children who received the complete solution principle solved the target problem faster than those who had to infer the solution principle.

Encouragement to make the inference about the solution principle led to increased ability to use the information. Young children who received a demand question again performed faster and had a higher percentage of correct solutions than those who did not answer such a question. For children who heard incomplete stories, the demand question forced them to generate the solution principle. These young children could generate the solution action if directly asked, and indeed there was no difference in the frequency of correct answers for the demand conditions between these subjects and subjects who were reporting their memory of the action. Once they had generated the principle, problem

solving performance did not differ whether the principle was self-generated or experimenter provided. The demand questions may have helped focus attention on the solution principle. Answering the demand question also seemed to affect subject's representation of the story. The majority of subjects who answered the demand question then went on to produce a complete representation, which may help explain this group's overall high level of problem solving performance. Mapping of the solution principle relation from the source stories to the target problem could take place with this complete representation. Subjects could then use this relation to solve the problem. Again, it did not seem to make a difference whether this complete representation was formed from information that was given to the subjects or from information that was generated by the subjects.

Another procedure that encouraged the younger children to generate the action of the solution principle was a hint to use the story. When total time to solve the problem, (including children who solved post hint), was examined, no difference was seen in time to solve between children who heard the explicit solution principle versus those who heard the implicit solution principle. The hint may have encouraged the subject to generate the necessary inferences about the solution principle. When the child tried to map the source information to the target information, he or she may have generated the necessary inferences about the

solution principle that would complete the mapping. Again, whether information was experimenter provided or self generated seemed to have no effect on performance.

CHAPTER 4

GENERAL CONCLUSION

Although these experiments did not yield a strong pattern of results, some general conclusions can be gleaned from them. Both children and adults seem to be able to use self-generated information in analogical problem solving, although again floor and ceiling effects (for adults and children, respectively) prevent any unqualified conclusions. Source information did not have to be explicitly given for that information to be useful in problem solving. The ability to make inferences about the action of the solution principle can compensate for a lack of detail. When the subjects had generated the inference, they could incorporate it into their representation. Construction of the analogy did not seem to be dependent on whether subject's had explicitly received the solution principle or had generated the solution principle, once a complete representation had been produced.

Although it is difficult to directly compare the results for children and adults because of the differing types of problems and source information given, one can speculate on the different patterns of findings that were obtained for the two groups. The subset of younger children solved the problem faster if they were given the explicit structure as compared to the implicit structure, although there was no difference in percentage of problems solved.

This difference in time to solve disappeared once a hint was given. For adults, on the other hand, there was no difference in performance for receiving explicit versus implicit solution principles, and this pattern did not change after a hint was given.

Perhaps this developmental change is the result of improved ability or change in the likelihood of generating such inferences. Again, any such conclusions must be considered speculatively since two different measures, time to solve and percentage of solving are being compared. Young children may have difficulty in making such inferences, while older children and adults may make inferences more spontaneously.

Differences in ability to generate or use inferences may also be reflected in the way the source stories were represented. When asked to find similarities between the source stories, children who answered the demand question were able to produce a more complete representation of the solution principle than children who did not answer this question. Children who received the implicit solution principle had to be encouraged to generate the inference, which they could then add to their representation. However, for adults, answering the demand questions about the solution principle did not seem to have any effect on their level of representation.

More work needs to be done to explore the hypothesis that there is a difference between children and adults in generating and using inferences in an analogical transfer task, by using materials that can directly compare adult and child performance. A mathematical or scientific source domain could be used, which differed in the sophistication of the language, but included the same general principles to be transferred.

Additional work also needs to be done addressing if the difficulty of generating the inference affects performance. In this study, most subjects were able to generate the required inference when asked to by the demand condition. Asking subjects to generate a less obvious inference may affect their representation and use of that information. Subjects receiving this type of source information may do comparatively worse in an analogical problem solving task. However, there are indications from previous work on inferences in reading (Keenan et al, 1984; Myers et al, 1987) that in some cases generating inferences improves performance on memory tasks. A similar result could be seen in a transfer task. Subject's representation of this type of information may be different in a to allow for increased transfer. New ways of assessing representation may lead to finding differences in representation of self generated versus experimenter provided information. Although the present study did not show any advantages for self-generated

information, perhaps manipulations of the difficulty of generating such information may reveal some differential effects.

APPENDIX A

THE SOURCE STORIES AND TARGET PROBLEM USED IN EXPERIMENT 1

SOURCE STORY: REBEL GENERAL

A small country was ruled by a cruel dictator from a fortress situated in the middle of the country. A rebel general wanted to overthrow the dictator, so he needed to capture the fortress. There were many roads leading to the fortress, but the problem was that the dictator had planted mines on each of these roads. These mines were set so that a small group of men could pass over safely, but a large army would detonate the mines and destroy the neighboring villages. The rebel general needed all of his large army to capture the fortress, but he did not want to destroy the neighboring villages. The rebel general had an idea how he could use the fact that there were many roads that led to the fortress. [He would divide his army into small groups and send each group down a different road so that the entire army would arrive together at the fortress at the same time]* The rebel general tried his idea and he got his whole army to the fortress. He was able to capture the fortress, without destroying any of the neighboring villages

*the sentence in brackets is included in the explicit version, not included in the implicit version

SOURCE STORY: RED ADAIR

An oil well in Texas exploded and caught fire, burning an enormous quantity of oil each day. Famed fire fighter Red Adair was called in to put out the fire. He knew that the fire could be extinguished if a huge amount of fire retardant could be dumped all at once on the base of the well. He had hoses of all different sizes to work with. The problem was that a hose large enough to carry the large quantity of foam necessary to put out the fire was too big for the fire fighters to control. It would move around and knock down all the surrounding equipment. Each of the other hoses was too small to deliver the necessary amount of foam. Then Red had an idea how he could use the fact that he had many small hoses. [Each of his men would use a small hose to shoot foam at the base of the fire, so that a large enough quantity of foam would reach the fire all at once.*] Red tried his idea and enough foam fell on the base of the well to extinguish the blaze, without causing any other damage.

*sentence in brackets is included in the explicit version, not included in the implicit version.

TARGET PROBLEM: DUNCKER RADIATION PROBLEM

A doctor in a health center is faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient but unless the tumor is destroyed the patient will die. There is a machine that emits a kind of ray, similar to an X-ray that will destroy the tumor. If the ray is given at a high intensity this will destroy the tumor, but it will also destroy the healthy tissue around the tumor. A lower intensity ray will not destroy the healthy tissue, but it will not destroy the tumor. Using the rays, what type of procedure might be used to destroy the tumor and at the same time not destroy the healthy tissue?

APPENDIX B

THE SOURCE STORIES AND TARGET PROBLEM USED IN EXPERIMENT 2

SOURCE STORY: GENIE

Once there was a genie who lived in a bottle. He liked to do all kinds of magic tricks. One day the genie was on top of his bottle practicing magic. He needed to use his special box, but then he saw that it was in the bottom of deep well. The genie could not reach the box. The genie picked up a cane, but it was too short to reach the box. Then he found a pole, but it was also too short to reach the box. The genie had an idea how he could use the cane with the pole to reach the box [The genie tied the pole and the cane together to make one long pole*] The genie tried his idea and now he could reach his special box

*sentence in brackets is included in the explicit version, not included in the implicit version.

SOURCE STORY: CAT

Once there was a cat who saw a pretty feather. She wanted to get the feather to give to her kittens, but the feather was caught up high in a tree and she could not reach it. The cat looked around and saw a stick on the ground. She tried to use the stick to get the feather, but the stick was too short. Then she saw a branch, but it was also too short to reach the feather. The cat had an idea how to use the stick with the branch reach the feather. [The cat tied the stick and the branch together to make one long branch.]* She tried her idea and now she could reach the feather

*sentence in brackets is included in the explicit version, not included in the implicit version.

TARGET STORY PROBLEM:

Jennifer was a seven-year old girl. She had lots of friends. One day she was playing a game with some of her friends. They wanted to play another game, but one of her friends had dropped the ball they needed into a tall jar. Here is the jar, and here is the ball and here are all the things that they could use to get the ball out. Now can you help Jennifer and get the ball out? You can use any or all of these things here on the table to help you, but you can't turn the jar upside down. Now try to get the ball out.

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