1-1-1995

Representation of domain structure and analogical reasoning with elementary school and college students.

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REPRESENTATION OF DOMAIN STRUCTURE AND ANALOGICAL REASONING WITH ELEMENTARY SCHOOL AND COLLEGE STUDENTS

A Dissertation Presented

by

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

DOCTOR OF PHILOSOPHY

September 1995

Psychology

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ACKNOWLEDGMENTS

I would like to thank Marvin Daehler, my advisor and chair of the committee, for his valuable guidance, for his constantly urging me to think critically about my work and for his careful editing of this manuscript. Carole Beal has helped me broaden my focus in my work, for which I am grateful. I would also like to thank Arnie Well for his advice in data analysis and for his support, and John Clement for his constructive comments at our meetings.

I could not have completed this work without the help of several undergraduate students, most notably Katherine Satterfield and Melissa Romanchuk. Both were willing to do whatever needed to be done, and I appreciate their enthusiasm. I would like to thank all of my friends, especially Cindy for being a wonderful office mate and friend, Stacey for all her encouragement, and Diana for all her support throughout the years since we first shared a desk together.

I would also like to thank my grandparents and the rest of my extended family for their support throughout this long process. I'm especially grateful to Adrienne and Richie, for all their encouragement, and to Jennifer, who can always make me laugh. Finally, I never could have finished without the love and support of my parents, who always believed I could accomplish all of my goals.

ABSTRACT

REPRESENTATION OF DOMAIN STRUCTURE AND ANALOGICAL REASONING

WITH ELEMENTARY SCHOOL AND COLLEGE STUDENTS

SEPTEMBER 1995

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Domain knowledge refers to the field of knowledge an individual has about a particular area of study. The structure of a domain are the relations governing the elements in the domain. The experiments in this dissertation dealt with representation of structure and differences between fourth, sixth, and college students.

Participants were provided with analogies comparing familiar source domains to unfamiliar science concepts in Experiment 1. Students received texts either with or without analogies. Several different tasks, such as answering fact and inferential questions and recognizing new examples of the scientific principles, were used to examine differences in understanding gained. All students who received texts showed higher levels of performance than students who completed the various tasks without receiving any texts. No developmental differences were found for the

benefit of analogies as students in all grades showed a higher level of performance on inferential questions after receiving analogical texts compared to receiving non analogical texts. However, performance on inferential questions was the only task to show such a benefit from receiving analogies.

Experiment 2A explored how the structure of domains influenced the ability to generate predictions about what would be true in a domain that was missing information. Students were given source stories describing an organism or object displaying an unusual trait. The source stories included an antecedent structure leading to a conclusion, with an additional arbitrary piece of information about the subjects of the source stories. Target stories contained either an antecedent structure similar to the one contained in the source story or a structure that was dissimilar. When both elementary school and college students received pairs of stories that contained similar structures, they were more likely to transfer the conclusion from the source story to the target. Students were not likely to transfer the arbitrary information. Additionally, students transferred the category membership of the object or organism in the source story to the target story, however, the matching or mismatching of the antecedent structure did not affect this transfer. Principles guiding analogy formation which can account for these patterns of results are discussed.

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CHAPTER 1

INTRODUCTION

Domain knowledge refers to the integrated field of knowledge an individual has about a particular area of study (Alexander, 1992; Alexander & Kulikowich, 1991). Domain knowledge is more than an accumulation of facts, since it also can include the organization and manipulation of information (Alexander, Pate, Kulikowich, Farrell & Wright, 1989). Researchers have studied how people understand many different domains, such as chess, baseball, physics, music, and dinosaurs. Although the definition of a domain is not well specified, one necessary component for many researchers is that domains have an organizing, underlying, structure (Alexander & Kulikowich, 1991; Gentner & Rattermann, 1991).

The structure of a domain is the set of relations governing elements in the domain. A change in a structural element may fundamentally alter the principles or relationships between elements in that domain. For example, consider the fact that planets orbit the sun. The structural features include the fact that smaller objects orbit a larger object and the associated physical laws causing the rotation. Changing the size of the planets would alter the precise orbiting relationship between the sun and planets.

How people come to comprehend the structure underlying a domain is an important, and unresolved, problem for understanding the principles involved in knowledge acquisition. The studies carried out in this dissertation focused on one way of organizing information which can influence how people ascertain the underlying structure of a domain. Specifically, the studies examined how using analogies affect comprehension of a domain and the particular characteristics of analogies that influence knowledge acquisition. In order to fully examine how analogies affect learners' understanding of a domain, developmental differences in the use of analogies were investigated as well.

Processes Involved in Analogical Transfer

Analogical transfer occurs when learners use previously acquired knowledge to understand an unfamiliar domain or to solve a new problem. Using analogies can be a very effective tool for promoting learning and conceptual change (Brown & Clement, 1989; Halford, 1993; Lawson, 1993; Vosniadou, 1989). Analogies allow individuals to gain new insight and make new discoveries by forming connections between different fields. Historical evidence has shown that many important discoveries, such as Harvey's discovery of the pumping action of the heart, were made using analogies (Gordon, 1979). Experts in a field also may use analogies to help them understand complex problems (Clement, 1989; Dunbar, 1995).

In order to fully understand a complex domain, the learner has to form a mental representation of the underlying structure. One mode of conceptualizing the representation is to say that a person forms a mental map or model of the structure. This mental model incorporates the relationships between objects in the domain. Furthermore, learners who have a fully developed model may be able to run simulations with the model to generate inferences about the results of changes in the system (Gentner & Gentner, 1983; Halford, 1993; Payne, 1991; Perkins & Unger, 1994). Learning utilizing analogies may promote the formation of a well developed mental model, particularly in forming a model of the structure of an unfamiliar domain.

Several different processes, such as accessing, representation, and mapping enter into analogical reasoning (Brown, 1989; Gentner, 1989; Gick & Holyoak 1983; Goswami, 1991). If an analogy has not been explicitly pointed out to the subject, then the problem of retrieving, or accessing, the source becomes important. For example, Gick and Holyoak (1980) found only 20% of subjects spontaneously used source information to solve a problem if not informed about the analogical relationship between domains.

An appropriate mental representation of the source, or prior information, and of the target, or unfamiliar domain, must also be formed. Learners use their representations of the domains to map important structural similarities between the source and target; similarities that are crucial for an analogy to be effective. Mapping of correspondences in the source and target can be between individual objects, but more importantly, relations between objects in the source can be mapped to similar relations in the target. For example, a common analogy is that the atom is similar to the solar system. One might map individual objects such as planets to electrons. However, the power of the analogy arises from a relational mapping between the corresponding concepts of "orbiting" in the solar system and in the atom.

Representation of an Unfamiliar Domain

Since forming a representation of domain structure is crucial for truly understanding the domain, what do learners perceive about an unfamiliar domain in an initial presentation? Novices in a field often find it difficult to form an integrated, coherent mental model of a domain (Chi, Feltovich, & Glaser, 1981; Larkin, 1983). Instead of forming a representation at the structural level, novices often develop a representation organized at a more shallow, surface level. Surface features are elements in a domain not related to the underlying principles that provide the causal structure of the domain.

The contrast between structural and surface features can be seen in the differences in how experts and novices understand physics problems. Problems can be sorted by the underlying physical principles (structural features) or by the type of objects mentioned in the problem (surface features). For example, one might contrast problems that used principles of acceleration with problems that used principles of velocity in their solutions (structural categorization). On the other hand, even though both problems might be solved by the same physical principle, one might contrast problems that contained pulleys with problems that mentioned inclined planes (surface categorization). Chi, Feltovich, and Glaser (1981) found that experts in physics categorized problems by the underlying physical principle, i.e., the structure of the problem, while novices sorted problems by the type of objects in the problem, i.e., the surface features.

This difficulty in representing and understanding structure is especially prevalent when people read expository text about an unfamiliar topic. Expository text is often characterized by unfamiliar context, heavy concept load, technical vocabulary, complex syntax and a hierarchical pattern of main ideas and details (Muth, 1987).

Adults who are unfamiliar with the topic of an expository text tend to focus on the individual items or details as a way of comprehending the topic, rather than understanding the overall structure of the concept (Cook & Mayer, 1988; Mayer, 1987; Spilich, Vesonder, Chiesi, & Voss, 1979; Wadill, McDaniel & Einstein, 1988). For example, Spilich et al (1979) found that adults who read texts describing an unfamiliar topic showed a different pattern of recall compared to experts in that field. Expert participants recalled information that was directly related to the structure of the domain, in contrast to novices who often recalled more peripheral information. Expert participants also organized their recall differently; recall was more hierarchical compared to novices who generally gave a list of relatively disconnected facts. Novices also appear to have different priorities when reading expository text. Dee-Lucas and Larkin (1988) found that novices allocated more of their reading attention to definitions of words rather than to the facts which described relations between objects in the domain.

Children's Representation of Domain Structure

Not surprisingly, children also appear to process expository text in a linear fashion, concentrating on processing individual sentences, rather than on abstracting the global meaning of the topic (Englert, Stewart & Hiebert, 1988; Kintsch, 1990; Scardamalia & Bereiter, 1984; Taylor & Samuels, 1983). This linear processing may be accentuated for younger children and less skilled readers (Scardamalia & Bereiter, 1984). Younger children often have had less exposure to expository texts and before third or fourth grade, reading materials in schools primarily use a narrative, rather than expository, structure (Williams, 1986).

Research examining children's understanding of structure has used both narrative and expository texts. For example, in order to test childrens' understanding of text structure, Brown and Smiley (1977) asked participants between the ages of 8 to 18 years to judge what were important units versus the more peripheral units in a narrative story. Younger children (8 to 10 years) were less able to verbally differentiate items in terms of their relative importance to the story. Van den Broek (1989) theorized that children between the ages of 8 to 11 are less likely than older children to generate connections between statements in text than older students, as indicated by their relative lack of understanding the importance of connecting causal relations between different episodes in a story.

Another indication that children have difficulty in understanding expository text comes from their relatively poor summarization skills. Summarization of a text is one way to measure readers' understanding of conceptual aspects of a domain (Armbruster, Anderson & Ostertag, 1987; Head, Readence & Buss, 1989; Kintsch, 1990). In order to provide a good summary readers must be able to abstract the global meaning of the concept discussed in the text. Kintsch (1990) found with increasing age (sixth grade to college) students provided more generalized information in their summaries, along with a corresponding decrease in the amount of detailed information. Elementary school children have difficulty in deciphering the main idea or important information in expository texts (Armbruster et al, 1987; Kintsch, 1990).

The Effect of Analogies on Representation of Domain Structure

Since learners have difficulty in understanding the principles of a domain, even when reading text specifically designed to teach them about these principles, how can analogies promote structural understanding? Analogies may aid in comprehension of a topic by encouraging learners to form a representation at the structural level. Individuals may spontaneously generate analogies to help them understand the structure of the problem they are facing (Clement, 1989; Dunbar, 1995). Directly providing analogies may aid learners in a similar manner, by allowing them to focus on the underlying structure of the target domain. The analogy highlights the important structural relations shared by the two domains.

If the analogy allows learners to better perceive and understand the structure of domain, then one can theorize that learners will be able to use this improved representation to generate inferences about the topic that are contingent on this structure. In effect, analogies may help learners form a mental model of the structure, which could then be manipulated to predict the results of changes in the domain. The representation of an unfamiliar target topic might be quite different when learners receive a text with an analogy compared to without an analogy (Donnelly & McDaniel, 1993; Iding, 1993; Moreno & Di Vesta, 1994). Analogies may also change the reading task from one of acquiring isolated propositions to one of acquiring relationships based on information available through the analogy (Moreno & Di Vesta, 1994).

Several different types of studies have been conducted to show the effect of providing analogies to learners. One type of study has been concerned with using analogies to overcome students' misconceptions about a domain. J. Clement and colleagues (Clement, 1993; Brown, 1993; Brown & Clement, 1989) found that using several different analogies, which gradually approached a misunderstood physical situation, served to change students' representations of principles underlying the phenomenon. For example, Brown and Clement (1989) reported that students who had not taken a physics course often have an incorrect understanding of the forces that act on a book resting on a table, i.e., students often deny the fact that the table exerts an upward force on the book just as the book exerts a downward force on the table. By starting with an initial, seemingly different, situation, where students did understand the correct principles, they were able to use several different bridging analogies to convince students that the initial situation and the final situation used the same principles.

Other studies have examined the effects of using a single analogy in text and its effect on representation. Cardinale (1993) presented college students with different texts about the heart and the circulatory system. Of special relevance for this review was the difference in learning between students who received a text which contained an analogy versus a control condition. The text described the circulatory system in great depth, and there were 12 different analogies available in the analogical text. After studying the texts for 45 minutes, students came back 2 days later to answer questions. Students who received the analogy text performed better on measures such as drawing the heart, labeling parts of the heart on a presented picture, and identification of various functions of the circulatory system.

Not all studies have reported an advantage of learning after using analogies. For example, Bean, Searles, and Cowan (1990) presented high school students paragraphs describing how enzymes fit into proteins. Some students received texts which contained the analogy that enzymes fit into proteins just as keys fit into locks, while others received no analogy. Both groups of students showed approximately equal levels of understanding of how an enzyme fits into a protein.

Other types of studies have required subjects to answer factual and inferential questions about the domains as a means of further examining the representation acquired with analogies (Donnelly & McDaniel, 1993; Halpern, Hanson & Riefer, 1990; Iding, 1993). Factual questions asked for information that was directly given in the analogy and non analogy texts. Inferential questions asked students about an example or situation that was not described in the texts, but which could have been inferred from the information presented. More specifically, these inferential questions asked participants to predict the result of changing some structural feature of the concept.

Halpern, Hansen and Riefer (1990) examined adults' learning of three science topics using far domain analogies, near domain analogies, or no analogy texts. Far domain analogies included a source analog that came from a domain which shared few apparent surface similarities with the science concept. Near domain analogies presented both source and science topics from similar domains. The no analogy text presented information only about the science concept. For example, one science concept taught how the lymph system operated. In the far domain condition the movement of lymph through the body was compared to the movement of water through the spaces in a sponge. In the near domain condition the lymph system was compared to the circulatory system. The no analogy text described how lymph moves in the body without reference to any other system.

Participants were asked fact questions (information directly presented in the text) such as "How does lymph move through the body?", and inferential questions (which required participants to use the information presented to infer the answer) such as "What might happen to the lymph flow if a person was paralyzed?". While this information was never directly stated, enough information was given about how lymph moves through the body to generate an answer to this question. Participants' free recall of the material and responses to the factual and inferential questions were better when texts included an analogy from a far domain compared to an analogy from a near domain or to no analogy. No differences in performance were seen between the near domain analogies and the control groups.

Halpern et al (1990) theorize that the far domain analogy encouraged subjects to concentrate on the shared structural features of the two domains. As a result, subjects acquired a greater understanding of the structure, which resulted in better learning. The finding that performance in the near domain analogy condition was similar to the no analogy condition was somewhat surprising. Halpern et al (1990) speculated that subjects who received a near domain analogy did not have to engage in much cognitive effort to understand the analogy, and so processed the texts on a more shallow level than subjects who received the far domain analogies. However, other factors might have contributed to diminished learning with the near domain analogies in this study. Participants' reports of relative greater comprehensibility of the far domain analogy, greater familiarity with the source of the far domain, and the potentially superior imagery associated with the far domain analogies all may have lessened the impact of the near domain analogies.

Iding (1993) presented a text designed to teach participants about the functioning of the eye. The analogical text compared the eye to a camera, while the non analogical text provided additional details on aspects of the eye's anatomy to equate the length of the two texts. After participants read either the analogical or non analogical text, they received various types of questions including fact and inference questions. Learners who received the text with an analogy performed better on the inferential questions than the subjects who received the text without an analogy. Both groups showed the same level of performance on the fact questions.

In a similar study, Donnelly and McDaniel (1993) taught adults 12 different scientific topics, again using either expository texts or analogical texts. For example, one of the topics described pulsars. In the expository condition, participants received a short paragraph explaining that pulsars are rotating stars, so their light appears intermittently to people on Earth. Learners in the analogical condition received the analogy that pulsars were similar to lighthouse beacons. Both pulsars and lighthouse beacons appear to be flashing because of rotation, and this relationship was made explicit through the use of the analogy.

Donnelly and McDaniel (1993) administered multiple choice tests comprised of both factual and inferential questions about the target domain. Overall, correct responses to the fact questions were higher than responses to the inferential questions. However, there was a significant interaction between condition and question type. Participants who received the text without analogies answered the basic fact questions better than the inferential questions. Participants who received the text with analogies showed the opposite pattern. They answered the inferential questions better than the basic fact questions.

This limited research on learning with analogies in expository text supports the theory that the representation of a complex science topic formed with an analogy allows students to more effectively comprehend the structure of newly learned material, as seen by their superior answering of the inferential questions. The analogical process appears to encourage learners to map objects and relations in the familiar source to objects and relations in the more unfamiliar target. This mapping may result in a better understanding of the structure and increased ability to predict the results of any changes in the target.

In some of the studies (Cardinale, 1993; Halpern et al, 1990) overall comprehension or answers to factual questions were better with an analogy than without one, while in others (Bean et al, 1990; Iding, 1993; Donnelly & McDaniel, 1993) there was no difference. Possible reasons for differences in the findings from various studies may include the fact that each used different science topics and different analogies and that the difficulty of tasks may not have been equal over the different studies. However, in no case was comprehension lower with an analogy than without one. More importantly, the result that participant's ability to answer inferential questions improved after receiving analogical texts (Donnelly & McDaniel, 1993; Halpern et al, 1990; Iding, 1993) suggests they understood the structure better than those who did not receive the analogical texts. Representation acquired with an expository text alone may not promote this same emphasis on structure, and as a result, subjects may have a more difficult time predicting what will happen if structure changes.

Children's Use of Analogies in Domain Representation

Experiment 1 was designed to address whether children, as well as adults, would show a comparable benefit in comprehending the structure of a domain after receiving analogical text. In order to benefit, children must be able to comprehend analogies in a manner similar to adults. Some researchers (Brown, 1989; Goswami, 1991; Vosniadou, 1989) claim that analogical processes function at an early age. Where developmental differences are found, they can be attributed to development in the knowledge base; what the analogy operates on rather than basic analogical processing.

If analogical processes are similar in children as in adults, one would expect children to show a corresponding pattern of learning with analogies as adults. In other words, analogies should help children to comprehend the structure of the target topic. In particular, learning with analogies might be expected to increase the number of inferences that children can make about a topic, as structural aspects of the target domain should be represented better when accompanied by an analogy than with no analogy. Thus, receiving text with an analogy should aid children in understanding and organizing an unfamiliar topic.

However, some researchers claim that children are unable to process analogies in the same way as adults (Bisanz, Bisanz, & LeFevere, 1984; Gentner, 1988; Gentner & Toupin, 1986; Halford, 1993). Halford (1993) claimed that only by fifth or sixth grade are children capable of encoding complex relations. If younger children have difficulty in encoding complex relations, they might not benefit from receiving analogical text. Moreover, Gentner (1988, Gentner & Toupin, 1986) claimed that children are more likely to interpret analogies based on common surface features rather than structural features. Holyoak, Junn and Billman (1984) found that younger children needed the support of surface similarity for transferring information more than older children. If younger children are more dependent on surface similarity, they might process an analogical and non analogical text in a similar fashion, that is with a focus on surface details rather than the relational structure that serves as the key component of using analogies effectively. Under these circumstances, younger children, compared to older children, could show less benefit in comprehending the structure of a domain after reading analogical, rather than compared to non analogical texts.

The research reviewed on children's reading comprehension of expository texts also suggests there might be a change in the way younger and older elementary school children process analogies in text. As already noted, younger elementary school children (under third or fourth grade) seem to have more difficulty in comprehending the structure of a text than older elementary school children (Kintsch, 1990; Scardamalia & Bereiter, 1984; van den Broek, 1989). If younger elementary school children have more difficulty in comprehending expository text, they may be less capable of using the analogy to organize their understanding of an unfamiliar domain.

Not a great deal of research has been conducted to determine if analogies aid middle and elementary school children in their understanding of a new domain. Mason (1994) found that fifth and sixth graders who understood and were able to articulate the analogical relations between how the post office delivers mail and how the blood delivers oxygen also demonstrated a deeper understanding of the structure and function of the circulatory system compared to students who could not explain the analogy. Simons (1984) demonstrated that students who heard analogies in lectures showed higher performance on an achievement test than those who did not receive the analogy. Unfortunately, Simons did not provide details about the type of information tested by this achievement test. Flick (1991) used an analogy of breaking down a sugar cube to explain how water changes state, from ice to liquid to vapor, as resulting from the action of particles, in a week long discussion group with third through fifth graders. He found that the student's understanding of state changes became more accurate after the session. Gobert and Clement (1994) found that providing a visual analogy increased the understanding of causal relations in the domain of geology.

While providing some indications that children benefit from receiving analogies for their understanding of a domain, the reviewed studies used analogies in lecture and class discussion, and many did not have a non analogy group as a comparison group. Using analogies in class provided additional support for the analogy compared to simply providing it in expository text; teachers could also explain features that were not clear in either the source or the target. Additionally, the children may interact with each other in a classroom setting, so peer learning and group dynamics could also have affected the results. All of these factors might contribute to the beneficial effect of analogies found in these studies.

Other studies with children have used text-based analogies to examine the effects of analogies without the support of teacher intervention. Simons (1984) found that 13 to 15 year-old students showed better recall of factual information 3 weeks after studying texts which contained analogies explaining the concepts. They also performed better on a transfer test which consisted of instances where the learned concepts and rules could be applied to new problem types not encountered before. Alexander and Kulikowich (1991) presented sixth graders with analogy or non analogy texts dealing with topics in biology/immunology. They found no difference in comprehension of the domains as a result of reading either text type.

The studies carried out with children dealt mainly with general recall and comprehension of the science topics. Only a few studies have examined children's inferential abilities after receiving analogical texts. Vosniadou and Schommer (1988) showed that five year-old children generally learned science topics, such as how the stomach works, better with analogical than non analogical text. Five year-old children did not show a difference in recall after receiving analogical or non analogical texts. Recall was examined further for evidence of spontaneous inferences and children were also asked inferential questions.

No differences were observed in either spontaneous inferences or answers to inferential questions between children given analogical text or non analogical text, for either the five or seven year-old children. However, the inferential questions were designed to test if children would inappropriately generalize information from the source domain to the target; not if they were able to predict the results of changes to the structure. For example, children were asked if "white blood cells felt bad when they killed the germs". In other words, the inference questions dealt solely with transfer of relations or characteristics from the source domain that would not be true in the target domain, and so were not comparable to inference questions that examine structural understanding.

Zook (1991, Zook & DiVesta, 1991) examined if older children (third and sixth graders) would also generate inappropriate inferences after receiving analogies. When students were explicitly informed of an overall relational structure between the source and target concepts, they did generate inappropriate inferences. For example, Zook and DiVesta (1991) presented children with texts that described how cows and farmers lived in a mutual dependence system and how ants and aphids also existed in a mutual dependence system. Both the third and sixth graders generated erroneous inferences about ants and aphids based on general knowledge about the cow-farmer system when the analogical relation was emphasized.

Summary

The studies reviewed in this chapter examining children's use of analogies have mainly focused on comprehension by asking factual questions about given information and by asking for recall of information. The studies that have looked at inferential ability (Vosniadou & Schommer, 1988; Zook, 1991; Zook & DiVesta, 1991) examined only if children overgeneralized the source information, i.e., generated inappropriate inferences. These studies have not examined if children can generate appropriate inferences about the structure of the target domain after receiving analogies. Therefore, Experiment 1 examined if children would show similar benefits from receiving analogies as adults for their comprehension of domain structure.

Even if children do show similar benefits as adults in domain comprehension after receiving analogies, there still may be differences in how children represent structure. The analogies used in Experiment 1 directly provide the analogical relationship between the source and the target, as did the educational studies reviewed in this chapter. However, when this direct mapping is not provided, children's representation of expository text may lead to differences in when analogies are formed between domains as compared to adults. One of the aims of Experiment 2 was to examine how changes in structure affect childrens' performance on a transfer task.

CHAPTER 2

EXPERIMENT 1: DIRECT ANALOGIES FACILITATE INFERENTIAL REASONING

Overview

Experiment 1 investigated whether analogies would aid elementary school children in perceiving the structure of an unfamiliar domain as results from Donnelly and McDaniel (1993), Halpern et al (1990) and Iding (1993) suggest they do for adults. To examine this issue, students were presented with a series of expository texts about different scientific topics from the domains of biology and physics. Some students received texts which contained analogies. The analogies specifically compared these science topics to more familiar concepts, such as how a vacuum cleaner operates. Other students received expository texts without analogies, which simply presented the information about the science concepts. Differences in comprehension of the target domain were assessed by examining performance on several different tasks.

Fourth and sixth graders participated in this study as well as an adult sample of college students. The reading comprehension literature reviewed in Chapter 1 suggested that a change might occur between the early and late elementary school years in how children understand expository texts. Later elementary school children are more likely to read a text for overall ideas, rather than focusing on more individual facts (Armbruster, Anderson, & Ostertag, 1987; Brown & Smiley, 1977; Head, Readence, & Buss, 1989; van den Broek, 1989). For instance, Ackerman (1988) has shown that children in the first and fourth grades were less likely than adults to infer the reason that a protagonist carried out an action in a narrative story. Johnson and Smith (1981) also showed that third graders made fewer inferences than fifth graders when the components necessary for the inference were located in separate paragraphs; younger children were less likely to integrate information from different sources. Younger children might have more difficulty in understanding the connections between the source and target that are specified in the analogies. Therefore, children in the fourth and sixth grades were included in this study to determine if there were developmental differences between these grades in abilities to comprehend analogies in expository text.

The ability to answer inferential questions about the target domain was the primary measure used to assess structural comprehension of the information presented in the texts. As indicated in Chapter 1, inferential questions require participants to generate information beyond what is specifically provided in the texts. The questions employed in this study required participants to make inferences about the different physical principles underlying the science concepts.

If children have difficulty in forming inferences about the science concepts, they might not be able to answer the inference questions regardless of whether they receive text which contains analogies or not. However, the analogies still might influence their understanding of the science domains. Therefore other tasks in addition to the inference questions were designed to help assess if analogies affect participants' understanding of the target structure.

One task examined participants' abilities to recognize new examples of the underlying science structure by matching these new examples to the appropriate science concepts. Two types of new examples were used; one utilized an abstract statement and the other a concrete statement. Abstract examples were included in this matching task because understanding an abstract version of the principle governing a domain reveals that comprehension is no longer tied to the specific context in which the knowledge was acquired. Research on problem solving with analogies has revealed that when participants have a more abstract understanding of a solution principle, they are more likely to use that principle to solve a problem than when they only understand the specific concrete form of the principle (Brown, 1989; Chen & Daehler, 1989, Gick & Holyoak, 1983).

Being able to recognize new concrete examples should also indicate a deeper understanding of the structure of the science domain. Participants who understood the principles of the science domain should be able to recognize them instantiated in a different context than the science context in which they were originally learned.

Formal, or classical, analogies were also used to measure participants' understanding of the structure. These analogies presented two objects that had been mentioned in the science domain. If the texts were successful in teaching the principles governing the relations between these objects, then students should be able to reconstruct this structural relation when given the objects. Students then had to apply this relationship to a new set of objects, in order to complete the analogy.

Finally, a picture selection task was also used to measure students' understanding of the structure. The pictures attempted to visually portray the structural relations between the objects in the science concepts, and participants had to chose which picture from a set of four best depicted this relation. If students understood the principles, they should be able to translate the principles into this spatial modality.

Method

Participants

Forty-two fourth graders (mean age = 9.8 years, range = 9.3 to 11.1 years), 33 sixth graders (mean age = 12.0, range = 11.5 to 13.3 years, and 54 college students participated in this study. Elementary school children were recruited from two schools in Western Massachusetts (Greenfield and Southampton school districts). University of Massachusetts students received extra course credit in psychology courses for participation. Due to experimenter error or equipment failure, responses for three elementary school students in the matching, formal analogies tasks, picture selection task were not included in the following analyses.

Materials and Design

Five short paragraphs about different science topics were used in this study. Texts were informally selected from a larger pool of 15 different topics. To select the final texts, the paragraphs were pilot tested with a small number of 8 to 9 year-old children. The author read various subsets of the 15 texts to the children and asked them to define various words included in the texts and to explain what the paragraph had taught them about the science topic. An undergraduate assistant observed their responses and noted general reactions, such as looks of puzzlement. Additionally, some parents who observed the procedure gave their reactions about the level of difficulty of various texts. Finally, three elementary school teachers (who were acquaintances of the author) read the texts for general comprehensibility. The final five texts selected for inclusion in this study were rated by teachers as comprehensible by third and fourth graders.

Each text (see Appendix A) was written in an analogical and non analogical format. The analogical texts compared a relatively unfamiliar science target domain to a more familiar source domain. For example, children were taught that "Mitochondria are things found inside cells in your body. Mitochondria send energy to your body, just like a power company sends energy to your house. You can use all the parts of your body, because the energy from the mitochondria makes them work, just like you can use everything in your house, because the energy from the power company makes them work". The analogical version of the texts explicitly compared the source and target domains. In other words, the various relations between elements in the source and target were specifically stated.

The non analogical texts presented the same information about the structure of the target as the analogical text. For example, "Mitochondria are things found inside cells in your body. Mitochondria are really extremely small. Mitochondria work by sending energy to the parts of your body. You can use all the parts of your body, because the energy from the mitochondria makes them work. The energy from the mitochondria is present in your body when you are a baby." Sentences such "the energy from the mitochondria is present in your body when you are a baby" were included in the non analogical texts to make the analogical and non analogical texts approximately equal in length so that participants spent about the same amount of time processing both versions. The filler sentences described either additional, non essential details, or were repetitions of other incidental information.

Students were randomly assigned to one of three different conditions for this study. Participants in the <u>analogical</u> condition received five texts which contained analogies; those in the <u>non analogical</u> condition received five texts which did not contain analogies. Participants assigned to the <u>control</u> condition did not receive any texts prior to being asked a series of questions about the science concepts. Since participants in the control condition had not been exposed to the texts, their performance on the questions provided a baseline measure of what subjects at each age level knew about the target topics, and how effective the analogical and non analogical texts were in teaching about the topics.

Several different types of tasks were employed in this study to gauge the effects of analogies on participants' understanding of the structure of the scientific concepts and other information provided in the texts. Students' free <u>recall</u> of the texts provided a measure of their memory for the structural principles taught about the science concepts. Table 2.1 presents the criteria used to score students' recall of each science domain.

Table 2.1

Scoring criteria for recall of structural principles

Science Concept	Structural principle
mitochondria	mitochondria sends energy
black hole	black hole suck up everything that comes near it
enzymes	enzymes have a shape that fits exactly into proteins (partial credit: enzymes fit into proteins)
ants and aphids for	aphids make food for ants and ants protect aphids (partial credit: given each unit in recall)
infection	infection heals when white blood cells stop germs (partial credit: white blood cells fight infection)

Participants were asked _fact questions_ which could be answered from information directly presented in text (for example, "Where are mitochondria found?"). The answer, inside cells, was explicitly stated in the text. Fact questions (see Table 2.2 for a list of the 2 fact questions used for each of the five texts in this experiment along with acceptable answers) were designed to measure basic recall and learning of the information directly presented in the paragraphs.

Inference questions asked subjects to provide information beyond what was directly given in the text. Inference questions could be answered by revising or modifying the structural information provided in the paragraph. For example, subjects were asked to predict "what would happen to your arms if a disease destroyed the mitochondria?". If participants understood the relation between energy and mitochondria, i.e., that mitochondria provide energy to the body, they should be able to predict that arms would have less energy, or become difficult to move. Table 2.2 lists the 10 inference questions (2 per text) used in this experiment and the responses that were considered correct in scoring this measure.

The _matching task_ presented five abstract statements summarizing each of the principles included in the texts and five new concrete examples of these abstract principles (one for each of the five science concepts introduced in the

Table 2.2

Scoring criteria for answers to fact and inferential questions

Mitochondria

Fact:

1. Where are mitochondria found?
   A: inside cells

2. What do mitochondria do?
   A: send power, energy, to your body

Inference:

1. What would happen to your arms if a disease destroyed the mitochondria?
   A: would not be able to move arms, arms would have no energy

2. What would happen if mitochondria started working harder?
   A: would have more energy, couldn't control body because too much energy

Black hole

Fact:

1. What gets sucked up by a black hole?
   A: light, comets, everything

2. Where is a black hole found?
   A: outer space

Inference:

1. What would happen if a black hole started to work backwards?
   A: everything in would get spit out

2. After things get sucked up, can you see them?
   A: no

Enzymes

Fact:

1. What do enzymes connect to?
   A: proteins

2. How many different things can each enzyme join to?
   A: one

Inference:
1. What would happen if the shape of the enzyme changed?
A: wouldn't fit into protein, wouldn't fit into opening, wouldn't be able to connect to the protein

2. What would you know about the shape of a set of enzymes if each enzyme fit into the same opening?
A: each enzyme is the same, all the enzymes are the same shape

<u>Ants and Aphids</u>

Fact:
1. What do aphids make for ants?
A: make sweet food

2. Where do ants keep aphids?
A: nest

Inference:
1. What would happen to the ants if they did not take good care of the aphids?
A: the ants would die, the ants wouldn't get any food

2. What would happen if the aphids ate alot more of the special plants?
A: aphids would make more food, the ants would get more food, the ants would get fat.

<u>Infection</u>

Fact:
1. How does the body fight an infection?
A: sends white blood cells, white blood cells attack the germs, attack the bad stuff

2. What happens then white blood cells stop the germs?
A: the infection is over, you get healed

Inference:
1. What would happen if the body had no white blood cells?
A: get sick all the time, get very sick, might die, infection doesn't heal

2. What could body do to help it win a fight against an infection?
A: send more white blood cells, make more white blood cells

texts) to the students. Participants were asked to indicate which of the five science topics each statement most closely matched, or if it matched none of them. For example, the abstract principle governing the information presented about mitochondria was that "Some objects send out forces that make other things function". An illustration of a new concrete example of this abstract structure was "The sun sends power to make plants grow". The relation of one component sending out energy to other objects is instantiated using a different context than the mitochondria. The 10 items used in this matching task are shown in Table 2.3.

The <u>formal analogies</u> included in this study were presented in the form of classical analogies (a:b::c:d). These formal analogies utilized two objects from each text that bore some structural relationship to one another. Participants had to draw upon the specific relation (for example, mitochondria sends energy to the body) taught in the text that linked these elements to complete the formal analogy involving a new set of elements. Students had to apply this structural relation to another pair of objects. In other words, to complete the analogy, they had to realize that a battery operates by sending energy to a flashlight, just as mitochondria sends energy to the body. The three distractor choices were an irrelevant word (school), and two associated terms. One of these alternatives belonged to the

Table 2.3

Abstract and concrete statements used in the matching task

Mitochondria:

abstract: some objects send out forces that make other things function
concrete: the sun sends power to make plants grow.

Black hole:

abstract: something can pull in other things
concrete: a pump will draw up water, and everything in the water

Enzymes:

abstract: some things work by having one piece fit exactly and only into another piece
concrete: one piece of a puzzle will only fit into its matching piece

Ants and Aphids:

abstract: some animals work together to help each other
concrete: a bird will pick fleas from an elephant's back and the elephant makes sure that no animal attacks the bird

Infection:

abstract: when something is in danger it can send out other things to stop the danger
concrete: when a lion tries to hurt a baby wolf, the chief wolf sends in the other wolves to drive the lion away.

same class of items as the c term, for example, both a motor and a battery can provide energy and the other was simply a related term associated with that domain, such as electricity. Judgements of association were made by the author and her dissertation advisor. Table 2.4 presents the formal analogies used in this task.

The picture selection task presented four different pictorial representations of each of the five science concepts described in the texts. Participants were instructed to choose the picture which was the best one to use to teach someone else about the science concepts. The correct alternative showed a spatial representation of the structure. Some of the pictures used arrows to depict objects in motion. The distractors included a static picture (the objects mentioned in each topic were independent of each other), and other incorrect structural representations. The picture selection task was included since if younger children had difficulty in articulating their knowledge, a picture task might be easier for them to demonstrate their understanding. Appendix B presents the pictures used in this task.

In order for an analogy to be effective, participants need to have knowledge about the source domain. Although pilot testing included questions about the source domains used in the analogies to ensure they would employ familiar source domains, participants in the control condition were

Table 2.4

Formal analogies

Science Domain	A:B	as	C:D
mitochondria	mitochondria:body	as	battery:flashlight (school, electricity, motor)
black hole	black hole:light	as	magnet:metal (attracts, drinking straw, crayons)
enzyme	enzyme:protein	as	chocolate bunny: candy mold bunny was made in (jelly beans, basket, lake)
aphid	aphids:ant	as	farmers:people who buy food in a grocery store (paper, ranchers, corn)
infection	white blood cells: germs	as	policeman:robbers (captain, fireman, kitten)

Note: distractor choices are in parenthesis under the correct relationship in c:d column also asked a series of questions to provide information about their knowledge of the source domains. The questions were designed to elicit analogous information to the information elicited from the fact and inference questions about the target domain. These questions are summarized in Appendix C.

Procedure

Fourth and sixth graders participated individually and followed a printed version of each text as it was read aloud. All questions were posed orally by one of two experiments (the author and a female undergraduate) and participants' answers were tape recorded for later transcription. Texts were read aloud to the fourth and sixth graders to ensure that students would not be unduly burdened by attempting to decipher the unfamiliar words in the science concepts.

Participants were instructed to follow the texts while they were being read aloud. Children were told "Today I am interested in seeing how I can help fourth (or sixth) graders learn science. We are going to read some paragraphs about different things. Then I'm going to ask you some questions about what we read. You can answer all of the questions from what we read so listen carefully".

Participants in the analogy condition received additional instructions to use the analogy to facilitate their understanding of the science topic. Children who received the analogy paragraphs were informed "The paragraphs are all written in a special way. The new things that you are going to learn about are similar to something that you probably already know. For example, suppose I wanted to teach you something about the stomach and how it works. I could tell you that the stomach is like a food blender. If you know that a food blender makes food all mushy, then you know something about what happens to food in the stomach. What happens to food in the stomach? Both the stomach and the blender change food into a mushy liquid. If I ask you a question about what the stomach does, you can think about what a blender does. You can use what you know about how a blender mushes up food to answer questions about what the stomach does. When we are reading the paragraphs, pay attention to those things that you already know about to help you think about how the new things you are learning about work".

After an initial reading the text was removed, and the child was asked to state what he or she could remember from the text. Regardless of his or her response, the text was made available and read a second time. Following this second reading the text was again removed and the fact and inference questions were asked. The order of question presentation was varied, so that approximately half the participants received the two fact questions first, followed by the two inference questions, while the others received the two inference questions first, followed by the fact questions. This procedure was repeated for each of the five science topics. Order of presentation of the texts was also counterbalanced.

Since the texts were designed for a fourth grade reading level, the procedure for adults was modified slightly in order to make the task more difficult. College students participated in small groups, which ranged from one to fifteen students, read all texts by themselves and wrote all responses. College students received instructions similar to those given to children, rewritten in adult-appropriate language. In addition, they were informed one purpose of the study was to compare how children and adults differed in reading comprehension so that the texts were written for fourth graders. They were also told that even though the paragraphs were written at a simple level, unfamiliar information might be presented, so they should read the texts carefully. College students were able to study all five texts for four minutes. The texts were then removed and students were asked to provide free recall of each text. After completing the recall task, college students were given all of the fact and inference questions for all five topics, which they completed at their own pace. The order of presentation of the questions followed the order in which the texts were printed. Approximately half the students received the two fact questions first, and then the two inference questions for each science concept, for each text while the others had the reverse order.

Participants in the control condition received additional questions about the source domain. The questions about the source domains were interspersed with the questions about the target domains, with the constraint that questions about any particular science domain was asked before the questions about the corresponding source domain. Questions about the source were mixed with the target questions in order to allow participants in the control condition to feel successful in the question portion of the study, as they were not expected to be able to answer many of the questions about the target domains.

After all the texts and questions were given, participants (both the elementary and college students) completed the remaining tasks. First the matching task was given. A large piece of oaktag with each of the titles of science topics and the word "none" written on it was placed in front of the children. They were asked to read aloud the titles of the science concepts and were given help if needed. Children were told they were going to hear some sentences that might be similar to one of the concepts and they were to match the sentence with that concept. They were also told that they could say that a sentence was like none of the concepts. Statements (both concrete and abstract) were mounted on index cards, and read to each student one at a time, while he or she followed along. The order was random, with the constraint that no abstract and concrete statement which described the same science concept was presented one after the other. Each student placed the card under the science title, or under the "none" option. This procedure was modified somewhat for the adults. They received all the sentences on one page, and had to indicate the science concept each sentence most closely matched. Adults were also given the option of choosing none of the science concepts.

After completing the matching task, participants received the formal analogies. Children were told "Here are three words (and were shown an index card with the analogy). You have to pick a fourth word that will finish the pattern. There is a certain trick to figuring out what the fourth word should be. First, think about how the first two words go together. Then pick a word that goes with the third word in the same way." The experimenter then repeated these instructions with the first analogy, using the appropriate terms in that analogy. Adults also received instructions to determine the relationship between the first two terms and then to chose a word that would generate a matching relationship between the third and fourth word. A single order of the analogies was randomly generated, and then every participant received the analogies in this order.

Finally, the picture task was given. Children and adults were told to pick the one picture within the set of four that was the best one to use to teach someone else the science concept. Again, a single order of the pictures was randomly generated, and all participants received the pictures in the same order.

Scores on the concrete matching task, abstract matching task, formal analogies, and picture selection task were summed over texts and could range from 0 (none correct) to 5 (all correct).

Results

Reliability and Preliminary Analyses

An undergraduate assistant and the author independently scored all participants' recall responses and their answers to the fact and inferential questions. Students received one point for each structural principle mentioned in their recall. As some of the principles were complex, partial credit was given. Participants received one point if they correctly answered each fact or inference question, and no partial credit was given. Percent agreement on recall for each story ranged from 86% to 100%, for each condition at each age level. Percent agreement on answers to each of the ten fact and ten inference questions was also high and ranged from 93% to 100%, for each condition at each age level, before discussion. Any disagreements were easily solved by discussion.

A preliminary analysis of variance showed no difference in performance on any of the dependent measures as a function of gender, order of text presentation, or order of question presentation. Therefore, these variables were not considered in further analyses of the data.

Performance on Questions Pertaining to the Source Domains

Responses to the questions about the source domains asked of the control group were examined to ensure that students at all ages tested were familiar with the source domains. An undergraduate assistant and the author independently scored all subjects' responses. Percent agreement for the individual questions ranged from 95% to 100%, for each age group. Participants were very familiar with the source domains; the average percentage of correct responses to the questions ranged from 74% - 89% (see Table 2.5 for responses at each grade level).

Although the scores were quite high, they were not perfect, even for the college students. One reason for the less than perfect scores was that the questions had other responses which were appropriate but were not analogous answers about the target domain. These answers were scored as incorrect. For example, consider the question "what does a key connect to?". The answer deemed to be correct was a lock. This answer is correct from the perspective of the analogy an "enzyme fits into a protein as a key fits into a

Table 2.5

Mean percentage of correct performance on additional questions asked about the source domains, as a function of age

Grade	Question type	
	Fact	Inference
4th	75%	77%
6th	80%	88%
college	74%	89%

lock". However, another acceptable answer from the viewpoint of just the questions is a "key chain". When considering all statements that could be true about the source domain, participants at all ages answered virtually 100% of the questions correctly, indicating that the source domains were familiar to them.

Performance on Recall

Table 2.6 contains the mean percentage of structural information reported in participants' recall. As can be seen, recall of structural information at each grade level was similar regardless of the type of text received and the amount of information recalled increased by grade level. A 2 (text type: analogy; non analogy) by 3 (grade; fourth, sixth, college) ANOVA was used to determine the effects of type of text on recall. A marginally significant effect for grade was seen ($F(2,79) = 2.5$, $p < .1$). The type of text students received did not affect their performance, and no significant interaction was seen between these two factors.

Performance on the Fact and Inference Questions

Table 2.7 contains the mean percentage of correct responses to the fact and inferential questions as a function of type of text and grade. As seen in this table, texts were effective in teaching participants about the science concepts. Furthermore, at each grade level, participants who received the analogical texts had a higher

Table 2.6

Mean performance (and standard deviations) on recall of structural principle as a function of grade and type of text

Grade level	Type of text	N	Recall
4th grade			
	analogy	15	57% (28.4)
	non analogy	14	58% (34.2)
6th grade			
	analogy	11	75% (15.1)
	non analogy	11	67% (22.4)
college			
	analogy	18	73% (27.5)
	non analogy	16	70% (30.3)

Table 2.7

Mean performance (and standard deviations) on fact and inference questions as a function of grade and type of text

Grade level	Text type	N	Question type	
			Fact	Inference
4th grade				
	analogy	15	65% (20.7)	67% (18.1)
	non analogy	14	64% (19.1)	44% (19.4)
	control	13	22% (15.4)	22% (13.4)
6th grade				
	analogy	11	85% (12.1)	84% (13.6)
	non analogy	11	84% (13.7)	70% (17.4)
	control	12	35% (18.8)	32% (16.6)
college				
	analogy	19	79% (17.1)	74% (21.1)
	non analogy	18	80% (10.7)	67% (22.1)
	control	17	42% (10.7)	36% (13.3)

level of performance on the inferential questions than students who received the non analogical texts.

To examine the effects of type of text on answering the questions about the science concepts, a 3 (text type; analogy, non analogy, none) x 3 (grade; fourth, sixth, college) x 2 (question type; fact, inference) mixed design ANOVA, with repeated measures on type of question, was performed. Grade level had a significant affect on performance ($F(2,120) = 16.6$, $p < .0001$). Text structure also had a significant influence on participants' performance on the questions ($F(2, 120) = 106.7$, $p < .0001$). A main effect was seen for question type as well. Participants showed superior performance on the fact questions (M= 63%) as compared to the inference questions (M = 55%, $F(1,120) = 22.1$, $p < .0001$). A significant interaction involving type of text and type of question was also observed ($F(2, 120) = 9.7$, $p < .001$). No other reliable interactions were found.

Pairwise comparisons, using the Bonferroni adjustment (for this and all other comparisons, unless noted otherwise) revealed that fourth graders answered fewer questions correctly (M= 61%) than sixth graders (M= 81%) or college students (M = 74%, p's < .05). There was no reliable difference between the sixth graders and the college students.

Participants who received the analogy texts showed a higher level of performance (M = 75%) compared to those who received the non analogy texts (M = 67%) or those who received no texts (p's < .05). Planned comparisons examining the effect of the interaction of type of text and type of question revealed that participants in the experimental groups produced significantly more correct responses than participants in the control condition to both the fact and inference questions (p's < .05). No reliable difference were between students who received the analogy texts (M = 76%) compared to students who received the no analogy texts (M = 76%) In contrast, type of text did affect students' responses to the inference questions. Students who received the analogy texts answered more inference questions correctly (M = 74%) than students who received the non analogy texts (M = 59%, p < .01). No reliable difference was found between answering fact and inference questions if students had received the analogy texts. However, students who received the non analogy texts performed significantly lower on the inference questions compared to the fact questions (p < .01).

Performance on the Matching Task

Table 2.8 shows the mean number of abstract and concrete statements matched correctly to the science concepts. The pattern of results shows that participants who received a text showed a higher level of correct choices

Table 2.8

Mean performance (and standard deviations) on matching concrete and abstract statements as a function of grade and type of text

Grade level	Text type	N	Statement type	
			Concrete	Abstract
4th grade				
	analogy	15	1.7 (1.9)	2.9 (1.6)
	non analogy	14	1.0 (0.9)	2.9 (0.9)
	control	12	0.8 (1.0)	2.5 (1.2)
6th grade				
	analogy	11	2.5 (1.4)	3.7 (1.1)
	non analogy	11	2.3 (1.3)	4.3 (0.7)
	control	10	1.5 (0.7)	2.7 (1.3)
college				
	analogy	19	3.5 (1.6)	4.1 (1.1)
	non analogy	17	3.4 (1.7)	4.5 (0.6)
	control	17	2.3 (1.5)	3.5 (1.8)

than participants in the control group. However, inspection of the pattern reveals only small differences in performance between the participants who received analogical texts and those who received non analogical texts. Students also showed more correct choices with the abstract statements than with the concrete statements.

A 3 (text type; analogy, non analogy, none) x 3 (grade; fourth, sixth, college) x 2 (statement; abstract, concrete) mixed design ANOVA, with statement type as the within subjects factor, was performed to examine the effect of type of text on the ability to match concrete and abstract statements with science topics. The analysis revealed a main effect for grade ($F(2, 117) = 10.9$, $p < .0001$) and for the type of text received ($F(2, 117) = 12.4$, $p < .0005$). Additionally, a significant effect for the type of statement indicated that participants produced a higher number of correct matches for the abstract statements ($M = 3.5$) than the concrete statements ($M = 2.2$, $F(1,117) = 93.5$, $p < .0001$). No significant interactions between any of these factors were obtained.

Pairwise comparisons revealed that fourth graders correctly matched fewer statements ($M = 2.0$) than sixth graders ($M = 2.9$, $p < .05$) or college students ($M= 3.6$, $p < .05$). Sixth graders also correctly matched fewer statements than college students ($p < .05$). Participants in the analogy condition and the non analogy condition (Ms =

3.1, 3.2, respectively) produced more correct matches than participants in the control condition (M = 2.3 p's < .05). No significant difference was found between the experimental groups.

Performance on the Formal Analogies

Table 2.9 provides the means for performance on the formal analogies task, as well as the picture selection task. Considering the formal analogies task first, performance at all grades follows the same pattern. Participants who received a text were better at completing the formal analogies than those who did not receive a text.

A 3 (text type; analogy, non analogy, none) by 3 (grade; fourth, sixth, college) between subjects ANOVA revealed a main effect for age ($F(2, 117) = 16.4$, $p < .0001$) and for type of text ($F(2,117) = 4.9$, $p < .01$). No significant interaction between these factors was obtained.

Further comparisons revealed that fourth graders' performance on completing the formal analogies (M = 2.6) was at a similar level as sixth graders (M = 2.5). College students were significantly more likely to correctly complete the formal analogies (M = 3.8, p < .05) than students in the fourth or sixth grades.

Participants who received the analogical texts or the non analogical texts showed more correct answers on the formal analogies (M's = 3.3 for both groups) than did

Table 2.9

Mean performance (and standard deviations) on formal analogies and picture selection as a function of grade and type of text

Grade level	Type of text	N	Formal analogies	Pictures
4th grade				
	analogy	15	3.1 (1.0)	3.7 (1.2)
	non analogy	14	2.5 (1.1)	3.4 (1.2)
	control	12	2.1 (1.3)	2.4 (1.3)
6th grade				
	analogy	11	2.5 (1.3)	3.9 (1.0)
	non analogy	11	2.9 (1.0)	4.2 (1.2)
	control	10	2.2 (0.9)	3.4 (1.2)
college				
	analogy	19	4.0 (1.3)	4.7 (0.5)
	non analogy	17	4.2 (1.0)	4.5 (0.7)
	control	17	3.0 (1.5)	3.6 (1.2)

participants in the control group (*M* = 2.5, *p*< .05). No significant differences in answering the formal analogies was found between the experimental groups.

Performance on the Picture Selection Task

A similar pattern of results was obtained for the picture selection task (see Table 2.9). Selecting the correct picture was benefitted by receiving paragraphs on the science concept, but there few difference were found as a function of the particular text type.

A 3 (text type; analogy, non analogy, none) by 3 (grade; fourth, sixth, college) between subjects ANOVA revealed a main effect for age ($F(2, 117) = 12.4$, $p < .0001$) and for type of text ($F(2, 117) = 12.5$, $p < .0001$). No reliable interaction was found between these factors.

As with the other tasks, further comparisons revealed that fourth graders selected fewer correct visual representations (*M* = 3.2) than college students (*M* = 4.6, $p < .05$). Sixth graders also chose fewer correct pictures (*M* = 3.8) than the college students ($p < .05$). No difference was found between the fourth and sixth graders.

Participants who had received the analogical texts or the non analogical texts selected the correct picture more frequently (*Ms* = 4.2 and 4.1, respectively) than participants in the control group (*M* = 3.2 *ps* < .05). No significant difference in performance was found between the experimental groups.

CHAPTER 3

DISCUSSION OF EXPERIMENT 1

The aim of Experiment 1 was to examine if analogies would facilitate elementary school children's understanding of an unfamiliar domain. The results indicated that analogies did aid in comprehension of target domains. Participants who received texts that used analogies to explain the science concepts were better able to answer inference questions which required them to reason about these domains compared to participants who did not receive such analogies. In contrast, when answering fact questions involving information that was directly provided in the text, no reliable differences in performance were seen as a result of receiving texts that contained analogies or texts that did not use analogies.

Analogies aided both elementary school and college students in their understanding of the structure of the science concepts. Furthermore, fourth graders were able to benefit from the analogies in a fashion similar to the sixth graders and the college students. Analogies aided participants' understanding of the target structure at all ages as evidenced by an increased ability to answer inferential questions when analogies were provided.

The research reviewed on children's reading comprehension suggested that comprehension of structure changes between the early and later grades in elementary school (Armbruster, Anderson & Ostertag, 1987; Englert, Stewart & Hiebert, 1988; Kintsch, 1990; Scardamalia & Bereiter, 1984; Taylor & Samuels, 1983; Van den Broek, 1989. Younger children seem to have more difficulty than older children in understanding the structure of a domain, identifying the main ideas in expository text, and generating connections between ideas. These facts suggested that a difference might emerge between the fourth and sixth grade in the ability to comprehend and benefit from analogies in expository text. However, no interaction with grade was obtained in any of the tasks.

The texts were fairly simple to ensure that fourth graders could comprehend the information. An additional factor which might have aided the fourth graders in comprehending the analogies were the detailed instructions to attend to and use the analogies. The instructions made the analogical organization of the text itself clear to students.

Expository texts may be organized in a variety of ways including presenting the information in a cause and effect manner, in a descriptive style, and in a compare-contrast framework (Kintsch, 1990; Williams, 1986). If readers (both adults and children) are made aware of text structure, their understanding of the topic of the text improves (Cook & Mayer, 1988; Lorch & Lorch; 1985; Samuels, 1989). For example, Cook and Mayer (1988) found that readers trained how to recognize text organization recalled more conceptual information about the topic than peripheral information. The opposite pattern held true for readers not trained to recognize text organization. The instructions given to the analogy group may have aided the fourth graders in understanding the analogy by helping them recognize the analogy in the text, and by providing a rationale for why it was important to pay attention to it. Future research could be designed to compare the effects of giving instructions which emphasize the use of the analogy for comprehension of the topic versus not giving such instructions to students who receive analogical texts. Younger students might show a greater need for the support of instructions than older children and adults, in order to show a benefit in inferential reasoning after receiving analogies. Such a finding would imply that without the instructions younger children might not use the analogical structure of the text to organize their representation of the concept, and so would process the analogical and non analogical texts in a more equivalent manner.

The lack of an interaction of text structure and grade on performance adds weight to claims of researchers who theorize that elementary school children can process analogical relations at an early age, and use similar mechanisms in their analogical reasoning as adults (Brown, 1989; Goswami, 1991; Vosniadou, 1989). Since the analogies used in Experiment 1 explicitly indicated the mapping between source and target, developmental differences still may emerge when students must form the analogical mapping for themselves. Nonetheless, Experiment 1 shows when the analogical relationship is provided in the text, analogies had similar affects on students's understanding of the science domains at all grade levels.

As expected, fourth graders did perform at a lower level on every measure compared to sixth graders and the college students. Since the elementary school students received the texts and questions individually and college students first received all the texts and then all questions, any interpretation of the developmental difference in performance must be qualified. Since the texts were designed to be comprehensible to 4th graders, they could be expected to be easier for sixth and college students to understand. Additionally, since the paragraphs used actual science concepts, older participants may have come into the study with more knowledge about the concepts than the younger children, leading to their overall higher level performance. For example, college students in the control condition showed higher levels of performance on each task than the fourth grade students in the control condition.

The finding that fourth graders can benefit from analogies in learning science concepts has some important educational implications. Analogies have not traditionally been used in elementary school texts, perhaps because educators as well as psychologist have been under the impression that children would not be able to comprehend them (Goswami, 1991; Glynn, Britton, Semrud-Clinkeman & Muth, 1989). Results from Experiment 1 indicated this is not the case. Analogies increased the amount of correct inferential reasoning children were able to engage in. One of the hallmarks of truly understanding a domain is the ability to use that information in a novel manner. (Perkins & Unger, 1994).

In addition to the inference and fact questions, which were modeled after work done in the adult literature (Donnelly & McDaniel, 1993; Iding, 1993), several other measures were used to gauge students' understanding of the science concepts presented in the texts. Each of these measures, that is, the ability to match concrete and abstract statements to the science concepts, recognizing relations in the formal analogies, and selecting the correct visual representation of the structure of the science concept, showed the same pattern of results. Receiving information about the concepts in texts aided performance, as students in both the analogy and non analogy conditions showed higher levels of performance than students in the control condition. Surprisingly, however, these measures revealed no effect of text structure on performance; no differences in performance were found between participants receiving texts containing analogies and participants receiving non analogical texts.

Why was the inferential reasoning task the only measure to benefit from analogical texts? One possible explanation is that the other measures were not sensitive enough to assess differences in comprehension. More speculatively, another explanation for this finding rests on the assumption that the various tasks required increasing levels of modification to the information provided in the texts, in order for students to be successful in that task, with the inference task requiring the most modification of information.

Modification of information refers to any changes that must be made to the structural information in order to apply that information to complete the different tasks. For example, the task requiring the least modification to the information provided in the texts was the fact questions. The fact questions could be answered by simply recalling information that was directly presented in the texts. The matching, formal analogies, and picture selection tasks required somewhat greater modification of the information than required to answer the fact questions. However, all used information that was directly presented in the texts. For instance, participants had to transform the verbal information into an analogous spatial-pictorial representation in the picture selection task. However, all the information needed to recognize the correct graphic depiction was provided in the text. As an illustration, the text on mitochondria specified that energy flowed from the mitochondria to the rest of the body. Students needed only to correctly interpret the direction of the arrows as representing energy in the direction that was stated in the text.

The matching tasks (both abstract and concrete statements) also required some modification of information that was directly provided in the texts. Nevertheless, both types of statements were examples of the exact structure that was presented in texts, and only required changing the specific context of science concepts in order for students to be successful on these tasks. For instance, the text on mitochondria directly stated that "mitochondria sends energy to make the parts of the body work". The abstract statement of this relation stated that some things send energy to make other things function; literally an abstract version of the purpose that mitochondria serve in the body.

The concrete statements substituted different objects for the source and target objects, but again, the structure referred to what had been directly presented in both the analogy and non analogy texts. For example, the concrete statement for mitochondria referred to the sun sending energy to make plants grow. Correctly classifying a concrete statement required participants to not only understand the general structural relations in the target, but also to be able implement this relation with a new set of objects.

Indeed, the performance on the abstract matching task was higher than performance on the concrete matching task. Perhaps participants found it more difficult to recognize the different context of the concrete statements than the relative lack of context, which defined the abstract statements. Still, receiving analogies did not aid in this task more than not receiving analogies. A stronger conclusion about the reason for the difference in performance between classifying the abstract and causal statements can not be made, as there was no independent measure of how well the abstract statements reflected the structure of the science concepts compared to the concrete statements. Further research is needed to quantify how well the statements were reflections of the structure, and to elucidate the precise reasons why concrete statements are harder to classify than abstract ones.

The formal analogy task also required participants to recall relations that had been presented in the text. The a and b terms of the formal analogy used objects (from the science domain) which had been given in the texts. Likewise, the relations between these objects were also given in the text. For example, the a and b terms from the formal analogy involving the mitochondria structure were "mitochondria :

body". Participants needed to remember the given relationship that mitochondria sends energy to the body. In order to complete the analogy, participants had to determine this relationship and then apply it to the c and d terms in the analogy.

Finally, the inference questions demanded the highest level of structural modification. In contrast to all of the other measures, only the inference questions compelled participants to deduce information beyond what was directly provided. The inference questions relied on participants extending the information that was provided in the text to answer the question. For example, the text on mitochondria never stated the results of mitochondria providing more energy than usual. However, if students understood normal mitochondria functioning they could generate an inference about the result of non normal functioning. Engaging in the mapping necessary to understand the analogies seemed to increase participants' flexibility in their understanding of domain structure. Analogies allowed participants to have a dynamic understanding of the domain. In contrast, the representation formed without an analogy may have been more static and tied to what is directly presented in the text. Representations acquired with both types of texts are adequate to answer questions regarding information directly provided, but only the representation acquired with an analogy allowed participants to move beyond the text.

CHAPTER 4

ANALOGY FORMATION THROUGH STRUCTURE MAPPING

Experiment 1 demonstrated that both children and adults benefitted from receiving analogies when engaging in inferential reasoning about changes in the target domain structure. These findings support the theory that analogies help subjects to understand the structure of the domains (Donnelly & McDaniel, 1993; Halpern et al, 1990; Iding, 1993; Vosniadou & Schommer, 1988). In Experiment 1, and in most of the research reviewed in Chapter 1 on analogical learning (Bean, Searles, & Cowan, 1990; Cardinale, 1993; Donnelly & McDaniel, 1994; Halpern et al, 1990; Iding, 1994; Vosniadou & Schommer, 1988), the material directly provided the analogical relationship to the participants. For example, students in Experiment 1 were told that " an enzyme fits into a protein like a key fits into a lock". The analogy furnished explicit guidelines for students to put objects such as "enzyme" into correspondence with "key". Additionally, the matching fitting relation was specified, that is enzymes fit into proteins just as keys fit into locks.

However, this explicit mapping need not be given to individuals for analogical transfer to occur. People can create an analogy for themselves by mapping the correspondences between the source and the target domains. In fact, research on problem solving with analogies has primarily relied on participants having to notice the similarities between the source and target domain for themselves. In the typical analogical problem solving task, researchers generally present participants with a source story and then with a separate target problem. Participants have to map correspondences between the source story and target problem in order to use the source information to solve the target problem (e.g., Brown, 1989; Goswami, 1991; Gentner, 1989).

By not specifying the analogical relationship, we can gain a better sense of how participants use information from one domain to understand another domain, not only for problem solving but in improving general comprehension as well. The particular relations and features in the source domain which are used in forming an analogy can affect how individuals understand the target domain. If, for example, in Experiment 1 participants had transferred the fact that keys can go in and out of locks, they may have also realized that enzyme binding is reversible. However, if they transferred the relation that a person must put a key into a lock, they may have also thought that an external agent was responsible for placing the enzyme into the protein.

Experiment 1 examined how direct analogies affected participants' understanding of the principles that governed an unfamiliar target domain. In contrast, Experiment 2A presented participants with separate source and target domains, without any experimenter provided mapping. In order to form an analogy between the domains, participants would have to access the source and map the corresponding relations between the source and target domains.

What features of the source and target domains influence whether people form analogies between two domains? Dedre Gentner and her colleagues (Clement & Gentner, 1991; Gentner, 1989; Gentner & Gentner, 1983; Gentner, Rattermann & Forbus, 1993; Gentner & Toupin, 1986) have theorized that the principle of structure mapping guides analogy formation. Analogies are formed when the structure of the source domain is placed into correspondence with the structure of the target domain. Information about the specific attributes of the domains, such as the semantic domain and the features of particular objects, is discarded. Gentner, Rattermann & Forbus (1993) have shown that adults judge analogies that contain overall matching relations as more sound than analogies which contain only matching object attributes. Markman and Gentner (1993) provided evidence that adults align the relational structure when performing similarity comparisons between two pictorial representations of structure, in preference to comparing the similarity of individual objects.

Clement and Gentner (1991) examined whether the principles of structure mapping constrained adults' transfer by using fairly complex source stories. They created science-fiction type stories for ease of changing the structural relations and to eliminate knowledge base differences; all answers would be based on information contained in the source domain and not on general knowledge. The source stories each contained two facts that potentially could be transferred to a target story. One of these facts was embedded in a relational structure that matched a relational structure in the target. The other fact was embedded in a relational structure that was not present in the target domain. Each of the two facts was equally acceptable for transfer to the target story, but differed in whether they were part of a shared causal system between the source and target domain.

Clement and Gentner (1991) used three different tasks to examine adults use of source structure in analogical transfer. In one task participants were asked to judge which fact in the source story created a better analogy to the target; a fact that was part of the shared causal structure between the source and target or a fact that was in a different casual structure. In two other tasks participants were asked to infer new information in the target story by using the source story. Again, if participants were guided by the relational structure common to source and target, they would be expected to show more transfer of the fact that was part of the shared causal structure than the fact that was not part of the shared causal system. This prediction was tested when participants had available both the source and target stories and when participants had to memorize the stories.

As a concrete example of a matching and non matching relational structure consider the following story about robots who use probes to collect data. One fact in the story was that robots sometimes stop using their probes. A reason for why robots stopped using the probes was that the internal computers overheated when they gathered too much data. Now consider another story about an animal that used a claw to collect minerals. In one version of this story, the animal overheated when it collected a large amount of minerals. In other words, a similar cause (overheating) was given as to why both the robot and the animal stopped using their respective gathering devices. The reason the gathering devices stopped working was embedded in the same relational structure in both the source (the robot story) and target (the animal story).

Another fact about robots, that probes could not function on a new planet, was also described in the source story. In a similar fashion, the target problem also reported that the animal could not use the claw on a new rock. However, this fact was embedded in a different structure in the source and the target; the reason why the gathering devices could not be used in new locations differed between the source and target. The robot was described as being unable to use the probe in a new location because the probes were fragile and could not survive the flight to a new planet. In contrast, the reason for why the animal could not use its claw on a new rock was that the claw became specialized for one type of rock and could not be adapted for use on another type of rock.

Participants were asked to rate which fact in the source created a better analogy to the target: a) the fact derived from matching causal antecedents in the target and source or b) the fact that did not share antecedents in the target and source stories. Participants chose the fact that had a matching causal antecedent and often justified their choice by mentioning the shared relational structure. When participants were asked to use the source story to generate predictions that might be true in a target story, they more readily transferred the information that was part of the shared relational structure. This finding was true both when the stories were available to the participant at test time and in a more difficult memory condition. Since either fact could be extended to the target story, the fact that participants preferentially transferred the fact that was part of a shared antecedent structure supports the theory that participants are more likely to represent and use the structure available in the source information rather than carry out transfer on the basis of isolated lower order relations such as simply transferring any fact in the source story that could be true in the target.

Other researchers have also examined how structure of the source domain influences transfer. Holyoak and Koh (1987) recorded transfer in a problem solving situation using Duncker's radiation problem. They presented participants with source stories that described how protagonists solved problems using a convergence solution principle. This same principle also could be used to solve a target radiation problem. In the matching structure condition, the reason why all three components of the convergence solution, that is, multiple, low-intensity, forces converging from different directions were necessary was the same in both the source and target; a fragile container would be damaged if high intensity rays struck it. In the non matching structure condition, the reason given in the source story why the forces must converge from different directions was that no machine was available to generate the high intensity ray. The target problem still described a fragile container (the human body) which would be damaged if high intensity rays struck it. In other words, the source and target stories provided different reasons for the necessity of convergence in the solution principle. Although the solution principle could still be transferred from source stories to solve the target problem, the reasons in each story that would lead to using the convergence principle differed. Holyoak and Koh (1987) found significantly more transfer when the causal antecedent of the convergence principle was similar in the source and target stories than when the antecedents were dissimilar.

In the studies carried out by both Clement and Gentner (1991) and Holyoak and Koh (1987), transfer was greatly increased when the information was embedded in the appropriate structure compared to when the same information was embedded within a non matching structure. The mere presence of information in the source did not promote the use of that information in an analogical reasoning task. Participants appeared to represent and use the entire structure of the source domain in forming the analogy, and in doing so transferred information more frequently than when it was part of a dissimilar structure.

<u>The Nature of the Information that is Transferred in Analogy</u>

Structure mapping theory (Clement & Gentner, 1991; Gentner, 1989; Gentner & Toupin, 1986) suggests that people should only (or preferentially) transfer information that is part of the shared structural system between source and target. Gentner and colleagues claim that common relations between the domains promote the formation of an analogy. Furthermore, only features and relations that are part of this matching relational structure are incorporated into the analogy. Attributes of objects and isolated relations, (relations that are not part of the overall matching system between the source and target domains) are typically disregarded and ignored in forming the analogy.

Gentner and Toupin (1986) used the Rutherford analogy of the solar system to the atom as example of what features in a source domain would not transfer to the target. In this example, since the relation that "the sun is hotter than the planets" is not part of the larger shared structure between the source and target domains, it is not readily transferred to the atom. Therefore, learners would not routinely claim that the nucleus is hotter than electrons.

The view that information in the source domain not part of the higher order relational structure shared by the source and target is not likely to be transferred is an underlying assumption of structure mapping. Attributes and isolated relations hold less weight in the analogy than information which is part of the overall matching structure. Transfer of information should primarily be an extension of the shared structural information. However, this idea has never been explicitly tested using a transfer paradigm.

One aim of Experiment 2A was to examine this assumption by including two types of information in the source domain which could potentially transfer to the target. One type of information was a fact which was connected to the overall causal structure in the story. A second piece of information was a more arbitrary, isolated fact, less connected to the overall structure of the source story. On the other hand, even though the arbitrary information is not directly connected to the causal structure, if participants are more likely to show transfer of structure related information when receiving a matching relational structure, they may also be more likely to transfer arbitrary information in this situation as well. If a matching structure guides analogy formation, then participants might attempt to transfer all possible information from the source domain.

Developmental Differences in the Use of Structure in Analogy Formation

A second issue explored in Experiment 2A was whether children would also benefit from a matching structure between source and target. As indicated in Chapter 1, some research reveals that younger children concentrate on processing the meaning of individual sentences in a text rather than abstracting the global meaning. As a result, children may form less complex or fully organized representation of the meaning of a text (Englert, Stewart & Hiebert, 1988; Scardamalia & Bereiter, 1984; Taylor & Samuels, 1983).

Previous research has shown that children are sensitive to some aspects of structure in analogies, although developmental differences are also hypothesized to exist. Gentner and Toupin (1986) reported that younger children (5 to 7 years) did not use the structure of a story in the same way as older children (8 to 10 years). Children acted out stories with toy characters. Transfer was measured when the children acted out the stories again with new characters. Structure was manipulated by adding a summary sentence, or moral, which emphasized the overall theme of the story. The moral provided a reason why the outcome of the story had occurred and emphasized the matching structure existing between the source and target, although participants were not explicitly informed about the relationship between story structure and moral.

The story plus moral aided the older children in transfer when surface features of the source and target were dissimilar. Transfer by younger children was not affected by the presence or absence of the moral. Gentner and Toupin (1986) concluded that emphasizing the structure promoted transfer for older participants when they could not simply map correspondences between surface features. Gentner and Toupin (1986) also concluded that younger children did not use the overall structure so that making the structure distinct did not aid transfer.

Gentner and Toupin's (1986) manipulation did not really alter the structure, rather the moral emphasized the structure of the story. Chen and Daehler (1992), however, directly manipulated the structure of source stories given to kindergarten and second graders. Narrative source stories were defined as having a structure comprised of:

intention to solve a goal, action or procedure initiated to solve the problem, and positive outcome of the action. Participants received source stories that had either a complete structure (intention, action, and outcome) or an incomplete structure (intention and action, outcome and action, or only an isolated action). Second graders, and to some extent kindergartners, showed better problem solving performance on the transfer task when source stories contained a complete structure compared to an isolated action. When intention or outcome was added to the source stories, transfer was marginally more effective then when either component was not present, with a larger effect for intention than outcome. Chen and Daehler (1992) concluded that transfer in second graders, and to some extent kindergartners, benefitted from the structure of the source stories.

In eliminating intention and outcome, Chen and Daehler (1992) changed the nature of the events described in the stories, thereby perhaps altering how stories were perceived by participants. Removing the intent from the stories changes the story from one involving a problem to one involving a play session. Researchers have shown that transfer is increased when participants process the source and target in a similar manner, for example when both source and target contain a problem solving orientation (Adams, Kasserman, Yearwood, Perfetto, Bransford & Franks, 1988;

Lockhart, Lamon & Gick, 1988). Recognition of corresponding goals and constraints in source and target can guide retrieval and mapping of the source domain (Reeves & Weisberg, 1994).

Chen and Daehler's (1992) results suggested that children are sensitive to some aspects of structure. Their manipulation did not reveal what aspect of structure children were using. Did they understand the correspondences between specific relations in the source and target when the structure matched between source and the target, or was it the general problem solving orientation of the source and target domains that aided in transfer?

Nippold (1994) found developmental changes in elementary school children's understanding of complex relational systems in formal analogies. When she presented 5th through 11th grade students with formal analogies that required them to use higher order relational similarity (i.e., similarity between pairs of relations) to correctly complete the analogy, accuracy steadily improved over grade. Nippold (1994) concluded that younger children might not be able to encode complex relations as well as older children, and so did not use the higher order relations in this task.

If younger children do not effectively represent the structure of a domain, perhaps they would be less likely to benefit from an overall matching causal structure between source and target. If this is the case, compared to older children and adults, younger children would not be expected to show differences in transfer when source and target domains have a matching structure rather than a non matching structure. Other types of similarity, for example similar contexts or the surface features of objects, might affect the children's analogical reasoning more than specific structural matching. Analogies affected children's and adults' understanding of the science domains in a similar fashion as shown in Experiment 1; adults did not receive any greater benefits than children in answering the inferential questions after receiving analogies. However, the analogical relationships were directly provided to participants in Experiment 1. In contrast, Experiment 2A required participants to map the relations between the source and domain for themselves. In this less supportive task developmental differences in understanding structure and its use in analogical reasoning might emerge.

CHAPTER 5

EXPERIMENT 2A: MATCHING ANTECEDENT STRUCTURE BENEFITS TRANSFER OF STRUCTURE RELATED INFORMATION

Overview

Experiment 2A examined how the structure of the source and target domains affected transfer by presenting participants with source and target stories that either contained matching causal antecedent structures or contained different antecedent structures. In addition to the antecedent structure, source stories contained a conclusion (information connected to the structure) and an arbitrary statement. Participants could transfer both conclusion and arbitrary statements to a target story, which contained neither of these pieces of information. Transfer was assessed by having participants generate information they thought would be true about the topics discussed in the target topic. Both an undirected phase, where participants simply generated facts, and a directed phase, where participants were asked questions about the target domains to encourage reflection on the conclusion and arbitrary information, were utilized in this study.

One goal of the study was to examine if there were any developmental differences associated with transfer. If children represent structure in a similar manner as adults then a matching structure between source and target should aid children and adults alike in their transfer of information that is causally connected to the structure. If younger children do not represent structure in the same way as adults, they may be equally likely (or unlikely) to form an analogy between domains that have either matching or non matching causal structure. As a result, they may show similar levels of transfer of the causally connected information. Experiment 2A also examined if only information that is causally connected to the overall structure of the source domain is transferred, or if the arbitrary information was transferred as well.

Method

Participants

Fifty-three fourth grade children (mean age = 9.7 years, range = 9.3 to 10.9 years), 62 sixth grade children (mean age = 11.8 years, range = 11.3 to 13.3 years) and 55 college students participated in this study. Five additional participants were not included the analyses due to experimenter error or equipment failure. Children were recruited from the West Springfield school district. College students received extra course credit for psychology classes in which they were enrolled.

Materials and Design

Source stories. Each of three source stories was designed as an encyclopedia entry. Source stories described qualities and attributes of an object or organism. Although the particular details concerning the topics of the paragraphs were anticipated to be unfamiliar to participants, they were expected to understand the central topic of each story; slugs and their efforts to defend against predators, robots engaged in mineral collection, and a particular manner in which fish hunted for food (see Appendix D for the complete texts).

All three source stories began with a general statement describing the topic which would be discussed in the paragraph. For example, the story about angler fish began "Angler fish live in the ocean. They have a special way of catching other fish to eat". The next few sentences consisted of an antecedent structure which allowed a certain fact, or conclusion, to occur. Each story contained one of two different versions of this structure. For example, one version (Version A) of the passage about the angler fish described angler fish as having "a long tentacle that grows out of their heads. On the end of the tentacle is something that looks like what other fish eat. The bait develops to look just like what other fish in that particular area eat. If angler fish go to a place where new kinds of fish live, the bait won't look like what the new fish eat. When this happens angler fish find a new method of catching fish" (see Table 5.1 for an outline of the different versions of the source stories). The antecedent structure of this version,

Table 5.1
Structure of source stories

Story	Topic	Antecedent structure	Conclusion	Arbitrary
Angler Fish	hunting method			
		A: mimics its prey's food	sometimes changes method of hunting	yellow scales
		B: swims at high speed	sometimes changes method of hunting	yellow scales
Slugs	predator defense			
		A: shoots noxious liquid over other slugs	even if one gets attacked, others are not hurt	little
		B: lives far apart from other slugs	even if one gets attacked, others are not hurt	little
Moon Rovers	mineral collection			
		A: stops collecting to relocate	retract probes when stop collecting	sees in all directions
		B: stops collecting to cool down	retract probes when stop collecting	sees in all directions

which describes the angler fish's method of hunting and that angler fish sometimes moves to an area where they can not engage in their normal method of hunting, leads to the conclusion that angler fish sometimes have to find a new method of catching fish.

A second version (Version B, see Table 5.1) described a different antecedent structure which again led to the conclusion that angler fish sometimes have to change their method of hunting. "Anglers have a long tentacle that grows out of their heads. There is a special chemical inside this tentacle. This chemical gives them a burst of energy. This lets them swim extremely fast and catch other fish. Sometimes the angler fish gets sick. If the angler fish gets sick, it can't make the special chemical that lets it swim fast anymore. When this happens, the angler fish finds a new method of catching fish".

The conclusion in the second version is that "angler fish sometimes have to find new methods of catching fish", just as in the first version. The difference between the two versions of the paragraphs is the reason governing <u>why</u> angler fish sometimes have to find a new method of catching their prey. In the first version, the reason presented is that angler fish move to an area where they can no longer produce a lure that mimics their prey's food. In the second version the reason given is that angler fish sometimes can not produce the special chemical that allows them to swim fast. Both stories, however, end with the same conclusion that angler fish sometimes have to change their method of hunting. The two different versions were constructed so that the antecedent structure could match or be different from the structure in the target story which was concerned with a similar topic.

Each source story ended with an additional fact about the topic. For example in the story about angler fish, both versions ended with the statement "angler fish have yellow scales". This arbitrary fact (see Table 5.1 for the arbitrary fact included in each story) was not related or dependent upon the causal structure of the story, but still made sense in the context of the story.

The other source stories described how slugs could defend themselves from birds, and how moon rovers collected rock samples from the moon. Each story included a set of statements which led to a particular conclusion, as well as an additional arbitrary statement describing a fact not related to or dependent on the causal structure of the story. Again, two version of each story were constructed so that each could provide a matching or non matching structure to a target story.

Target stories. The target stories used in this experiment described other fictional objects or organisms. (see Appendix E for the complete target stories). As was the case for the source stories, target stories began by describing a topic that was to be discussed in the paragraph. Although the object or organism presented as the subject of the topic was novel, the focus of the topics was familiar, as each of the three target topics matched one of the three source stories. Thus, analogous topics were created for source and target stories. For example, the first sentence in the story about Bems was "Bems have an unusual way of getting their food". Both the story about angler fish and the story about Bems were concerned with the unique way in which these organisms catch their food (see Table 5.2 for outlines of the different versions of the target stories).

The antecedent structure information that allowed the conclusion fact to occur in the source story was also present in the target story in a slightly modified form. This modification was necessary to prevent the conclusion from being obvious from the structure of the target story alone. As with the source stories, two different versions of the target stories were developed. The first version (Version A, see table 5.2) of the Bem story described the Bem as having the ability to mimic the prey of other creatures, therefore luring these creatures to the Bem. Furthermore, the Bem only had the ability to mimic the prey of other creatures with which it had been associated with since birth. This antecedent structure is analogous to the

Table 5.2

Structure of target stories

Story	Topic	Antecedent structure
Bems	hunting method	A: mimics its prey's food B: moves at high speed
Veisel plant plants	predator defense	A: shoots poison powder over other B: lives far away from other plants
Tams	mineral collection	A: stops collecting to move to relocate B: stops collecting to cool down

structure introduced in the source describing angler fish as mimicking what other fish ate. Thus, both the story about the angler fish and the story about the Bem described a similar mimetic ability, which could only be employed with animals the organism had been associated with since birth.

The second version of the Bem story, analogous to the second version of the angler fish story, described the Bem as having a sac attached to its body which gave it the ability to move extremely fast. The fact that the Bem and angler fish sometimes become ill was also stated in both stories. Therefore, both versions of these two stories contained the same antecedent structure describing the rapid motion of these creatures and a similar possible factor (becoming ill) which could interfere with this motion.

Design. The target stories differed from the source stories in that neither the conclusion or the arbitrary sentences were present in the target stories. Of primary interest in this experiment was whether participants would transfer both the conclusion and the arbitrary information from the source to the target stories and whether that transfer would take place more frequently when the antecedent structure matched or did not match the source story. In the matching structure condition, participants received three source and target stories that contained analogous antecedent structures. In the non matching structure condition, participants received three source and target stories that differed in their antecedent structures. Participants in a third group, the control condition, received only the target stories. Participants in the control condition supplied a baseline measure for whether the target stories by themselves influenced generation of the conclusion and arbitrary information.

Probe questions. In addition to the source and target stories, a series of probe questions were designed to encourage participants to describe and embellish their conceptualization of the novel organisms or objects introduced in each target story. The probe questions can be interpreted as types of hints to encourage participants to access and reflect more fully on the information in the source stories. For example, the probe question to encourage participants to focus on or elaborate a conclusion for the target story about Bems was "What happens when Bems can't capture any animals to eat?" Another probe question was designed to encourage participants to reflect on the arbitrary information in the source story, e.g., "What does the Bem's skin look like?" Table 5.3 contains the conclusion and arbitrary probe questions for each source story.

Procedure

As in Experiment 1, elementary school students participated individually and college students participated in small groups. Stories were read aloud to each elementary school child, and he or she could follow along from a

Table 5.3

Conclusion and arbitrary probe questions

Bems target story

Conclusion probe: What happens when Bems can't capture any animals to eat?

Arbitrary probe: What does the Bem's skin look like?

Veisel plant target story

Conclusion probe: If one Veisel plant gets attacked by bugs, what happens to the other Veisel plants?

Arbitrary probe: What do you think is the size of Veisel plants?

Tams target story

Conclusion probe: What does the Tam do with its special claw when it stops scraping up minerals?

Arbitrary probe: What is the Tams sense of vision like?

written version. All responses were made orally by elementary school children and were tape recorded for later analysis. College students proceeded at their own pace throughout the study, and read all stories and wrote their responses.

As a result of reading the stories aloud to elementary school children, the procedure varied slightly for children and college students. For each elementary school child the first source story was presented and after hearing it, the child was asked repeat it aloud. Regardless of the child's response, the story was read again. Then the source story was removed, and the child was read the corresponding target story, which again was available to the child in printed form, and was present for inspection during the transfer portion of the study. The child was given the following instructions after the target story was read: "Now let's pretend that you wrote this story. Your teacher said she wanted you to write some more sentences to add to the story. She wants you to add three more sentences about (name of target story subject). What are three more sentences you could add?" Pilot testing revealed that fourth graders had difficulty generating more than three new sentences about the target. Instead, they often paraphrased the information that was provided in the story. Therefore, participants in this study were specifically asked to generate three sentences. If hesitant about answering, the child was encouraged to say anything he/she thought was true about the topic.

As indicated earlier, probe questions were designed to encourage participants to further consider specific aspects of the domain information. After participants appeared to be finished with respect to generating sentences to add to the stories, he or she was asked the probe questions. Following the probe questions, the child was told that another story was going to be read, and the next source story was presented followed by the target story. The order of presentation of the three source-target pairs was counterbalanced.

The procedure for the adults followed the same general format as the procedure for the children. Adults were told that they would be reading a series of encyclopedia entries. They were also informed the texts were written so that fourth graders could understand them, but that new information would be presented so they should read the story carefully. After reading each source story, adults were asked to write a summary. When finished with the summary, they turned the source story over and read the target story. College students received the following instructions "Now imagine that you are the author of the following entry. Your editor tells you that this entry is too short and you need to provide more information. What are three facts about (subject of target story) you could add to this story to make it longer? (Please note: we are not asking you to come with questions that you would like answered about the topic, we want you to come up with three more sentences that you would add to the entry)". In the initial phases of writing these instructions, two undergraduate assistants indicated this note should be added in order to ensure students understood the required task of generating facts to add to the story rather than writing questions they wanted answered about the topic. After college students finished they received the probe questions. This procedure (spontaneous transfer followed by probe questions) was repeated with each pair of source-target stories with the order of the three sets of stories counterbalanced.

Dependent Measures

Sentence Generation of Conclusion and Arbitrary Information

When generating information to add to the target stories, participants could produce the conclusion of the source story, the arbitrary information provided in the source story, or other information. Each comment produced by participants was judged as similar to the conclusion, similar to the arbitrary information, or similar to neither. For example, a statement that "Bems sometimes have to change how they catch animals" was categorized as an extension of the conclusion of the source to the target. Initially, the arbitrary statement for the Bems was conceptualized as "Bems have yellow fur" and if participants produced this statement, it was considered an example of extending the arbitrary information from the source to the target story. After inspection of responses, however, it became apparent that participants could, and did, also transfer the arbitrary information that Bems have scales as the source story stated that angler fish have yellow scales. Therefore, both of these responses were considered indications of transfer of arbitrary information. The two other source stories had only one correct response for the arbitrary information. Participants did not have to use the exact wording of the source story, but did have to generate sentences that specifically conveyed the information in the conclusion or arbitrary sentences. Table 5.4 provides examples of responses illustrating the transfer of conclusion and arbitrary information for all target stories.

Total Production of Conclusion and Arbitrary Information

A second measure of the production of conclusion and arbitrary information was obtained by examining the total number of conclusion and arbitrary statements transferred either before or after the probe questions. Probe questions asked participants to answer specific questions about the target stories and were designed to more effectively elicit the conclusion and arbitrary information provided in the source stories. The same criteria used for scoring the sentence generation task was also used for scoring answers following the probe questions.

Table 5.4

Examples of acceptable conclusion and arbitrary transfer statements

Bems target story

Conclusion: Bems must change the way they catch animals, must change their hunting method, use a different hunting method

Arbitrary: yellow, or scaly

Veisel plant target story

Conclusion: other plants are not attacked by bugs, the other plants don't die.

Arbitrary: small, tiny

Tams target story

Conclusion: pulls the claw back inside its body, folds claw inside itself

Arbitrary: Tams can see in all directions, they can see all around

Note: Spontaneous transfer response and answers to probe questions are based on the same criteria.

Category Membership

A third dependent measure examined in this study was transfer of category membership for two of the target problems. Transfer of category membership was credited when participants, either prior to the probe or in response to the probe questions, described the subject of the target story as a member of the same category (machine or fish) as the subject of the source story. This measure was possible for only the two target stories involving Tams and Bems because category membership was not specified in either story. Veisels were described as plants and so responses bearing on category membership were not scored for this story. If, for example, a participant implied that the Tam was a machine he/she was considered to have transferred category membership. Statements such as "Tams are machines", "Tams were built by scientists" or "Tams are operated by human beings" all were acceptable responses to illustrate category transfer. Similarly, participants could indicate that Bems were a type of fish by directly stating that "Bems are fish" or that Bems were fish-like by "Bems live in the ocean" or "Bems need to live in salt water to survive".

Results

Participants' responses for generation of conclusion and arbitrary information, as well as indications of category membership transfer were independently scored by the author and an undergraduate assistant. Percent agreement ranged from 90- 100% on the these tasks, for each measure in each condition and grade level, and disagreements were easily resolved through discussion.

Table 5.5 displays the mean number of conclusion and arbitrary statements generated spontaneously as well as the total number of conclusion and arbitrary statements generated before or after the probe questions as a function of condition and grade. The most striking finding revealed by these measures was that transfer was extremely low. Scores could range from 0 (no responses for any of the three stories) to 3 (a response for each of the three stories). Many scores were 0, and for certain measures elementary school students produced no responses indicating transfer.

An analysis of variance was deemed inappropriate to perform on these data because of the non normal distribution and lack of variance in many cells. Therefore, the data was scored using a categorical criteria for each dependent measure. If a participant produced at least one sentence corresponding to the conclusion or arbitrary information during sentence generation for any of the three stories he/she was defined as a successful respondent for that particular measure. If a participant generated no transfer statements, he/she was counted as a non-respondent. A similar procedure was used for the total production measure of the conclusion and arbitrary information; if at any time during the three stories a participant generated a sentence

Table 5.5

Mean production (and standard deviations) of conclusion and arbitrary responses

		Spontaneous production		Total production	
Grade	Condition	Conclusion	Arbitrary	Conclusion	Arbitrary
4th	matching	0.21 (0.42)	0.21 (0.42)	0.63 (0.76)	0.58 (0.50)
	non matching	0.00 (0.00)	0.00 (0.00)	0.44 (0.61)	0.22 (0.33)
	control	0.00 (0.00)	0.00 (0.00)	0.12 (0.34)	0.25 (0.57)
6th	matching	0.19 (0.40)	0.00 (0.00)	0.86 (0.72)	0.38 (0.57)
	non matching	0.00 (0.00)	0.05 (0.21)	0.71 (0.64)	0.14 (0.14)
	control	0.00 (0.00)	0.13 (0.35)	0.27 (0.45)	0.14 (0.13)
college	matching	0.50 (0.50)	0.28 (0.57)	1.55 (0.86)	0.59 (1.18)
	non matching	0.20 (0.41)	0.00 (0.00)	0.80 (0.76)	0.30 (0.47)
	control	0.29 (0.47)	0.29 (0.69)	0.23 (0.43)	0.18 (0.35)

corresponding to the conclusion or arbitrary information, he/she was defined as a successful respondent for that measure. A successful respondent in the category membership transfer grouping was one who gave at least one indication of category transfer in the two target stories (Tams and Bems) that were used for this measure either before or after the probe questions.

Chi square analyses were performed on the number of successful and unsuccessful respondents for each dependent measure as a function of condition. An overall analysis ignoring age was carried out on each dependent measure and a further analysis of the pattern of performance at each age group was performed if this overall analysis revealed significant differences. Pairwise comparisons on condition differences, both for the analysis over age as well as the ones performed at each grade level, were performed only when the overall chi square analysis revealed significant differences, and comparisons were considered reliable if $p < .05$, following the recommendation for comparing three groups (matching, non matching, and control in this study) outlined by Levin, Serlin, and Seaman (1994). Fisher's exact chi square test is used to report significant pairwise comparisons whenever one of the expected cell values for the standard chi square test was less than five, which is the recommended procedure for analyses that result in more than 20% of the expected cell values under than five (Hildebrand, 1986).

Spontaneous Generation of Conclusion Information

Table 5.6 shows the patterns of performance for spontaneously generating the conclusion statement and the arbitrary statement as well as total production of these measures, as a function of condition and grade level. As can be seen in Table 5.6, students at all grade levels were more likely to generate the conclusion information if they had received source and target stories with matching antecedent structures compared to receiving stories with different antecedent structures. The analysis involving all participants' responses revealed significant differences between the matching, non matching, and control conditions ($X^2(2) = 25.2$, $p < .0001$). Participants who received stories with matching source and target structures were more likely to provide one or more conclusion statements than those who received the non matching structure ($X^2(1) = 10.1$, $p < .001$) and those in the control condition ($X^2(1) = 19.0$, $p < .0001$). Participants who received non matching stories were slightly more likely to generate a conclusion statement than participants in the control condition (Fisher's exact $p < .1$)

An examination of group performances at each grade level revealed significant differences for participants in

Table 5.6

Percentage (and number) of participants who provided a positive response for the conclusion and arbitrary measures

Production time	Information type	Grade	Matching	Non Matching	Control
Spontaneous	Conclusion	4th	21% (4)	0% (0)	0% (0)
		6th	19% (4)	0% (0)	0% (0)
		college	50% (9)	20% (4)	0% (0)
			29% (17)	7% (4)	0% (0)
	Arbitrary	4th	21% (4)	4% (1)	0% (0)
		6th	0% (0)	5% (1)	14% (3)
		college	22% (4)	0% (0)	18% (3)
			14% (8)	3% (2)	11% (6)
Total	Conclusion	4th	53% (10)	39% (7)	13% (2)
		6th	71% (15)	62% (13)	27% (6)
		college	94% (17)	65% (13)	6% (1)
			72% (42)	56% (33)	16% (9)
	Arbitrary	4th	58% (11)	33% (6)	19% (3)
		6th	38% (8)	14% (3)	32% (7)
		college	44% (8)	30% (6)	18% (3)
			47% (27)	25% (15)	24% (13)

the fourth grade ($X^2(2) = 7.7$, $p < .02$), sixth grade ($X^2(2) = 8.7$, $p = .01$), and college students ($X^2(2) = 12.3$, $p < .005$). Fourth graders who received stories with matching source and target structures were marginally more likely to generate at least one conclusion statement than children in the non-matching structure condition (Fisher's exact $p = .06$) and than children in the control condition (Fisher's exact $p = .07$). Perhaps more telling in this data is that no fourth grader provided a positive response in either the non matching condition or the control group, while four did so in the matching condition.

For the sixth graders, multiple comparisons revealed that students in the matching condition were more likely to generate at least one conclusion sentence than students in either the non matching condition (Fisher's exact $p < .05$) and than students in the control condition (Fisher's exact $p < .05$). As with the fourth graders, no sixth graders showed a positive performance in either the non matching or control conditions, however four did so in the matching condition.

College student who received the matching structure stories were also more likely to generate the conclusion sentence than students who had received the non matching stories ($X^2(1) = 3.8$, $p < .05$) or than students in the control condition ($X^2(1) = 11.4$, $p < .0001$). College students who received the non matching stories also performed marginally better than students in the control group (Fisher's exact $p < .1$).

Thus, the pattern of results is similar for all grade levels. Participants who received source and target stories with matching structures were more likely to generate at least one conclusion sentence than participants who received stories that contained non matching causal structures or who received no source stories. No difference was found for elementary school students between those who received the non matching stories or who received just the target stories. However, college students in the non matching structure condition showed a slightly higher percentage of generating at least one conclusion statement, a difference which was reflected in the slight difference found for this comparison in the overall analysis involving participants from all grades.

Spontaneous Generation of Arbitrary Information

The pattern of results for spontaneous generation of arbitrary information reveals that performance on this measure was affected less by condition (see Table 5.6). Overall, the likelihood of generating the arbitrary information was similar regardless of the structure of the source story or if participants received no source story.

However, the fact that six participants in the control condition generated at least one piece of arbitrary information was surprising. Responses to the individual stories were examined in order to try to explain this finding. Table 5.7 displays the percentage of respondents generating the arbitrary information for each story. As can be seen, a few students in the control condition were able to generate the arbitrary information for the Veisel and Bem stories. The arbitrary information for the Veisel story was "little". Some of the participants who gave the "little" response gave the rationale that if the plants were in danger from attack by bugs, they must little. Many plants are tiny, and so this response makes sense given only the target stories. The response for one of the students who generated the arbitrary information for the Bem story also provides some insight as to why three students were able to generate the arbitrary information for this story. This student indicated that the Bem must be a chameleon, and so had scaly skin (like a lizard), and the other students might have been reasoning along similar lines. In contrast, no student generated the response that "tams see in all directions". Although the arbitrary information was designed, from the perspective of the author, not to be related to the structure of the stories, participants might have taken advantage of their knowledge base in generating reasonable inferences, which happened to match the arbitrary information used in two of the source stories. Nevertheless, the overall chi square analysis revealed no significant differences in participants generating at

Table 5.7

Percentage (and number) of students who produced the arbitrary information for each source story as a function of condition

Source Story	Matching	Non Matching	Control
Veisel	3% (2)	2% (1)	9% (5)
Tams	3% (2)	2% (1)	0% (0)
Bems	9% (5)	0% (0)	6% (3)

least one arbitrary statement between the matching, non matching, and control conditions, therefore no further analyses are reported.

Total Production of Conclusion Statements

The total production measure refers to the generation of the conclusion or arbitrary information by participants at any point during the session. Table 5.6 (on pg. 100) also contains the overall pattern of the total production of at least one conclusion statement, as well as a breakdown by grade, for each condition. Participants who received the matching source stories still showed a higher proportion of producing a conclusion statement than those who received the non matching stories. However, 33 students who received the non matching stories did generate at least one instance of the conclusion statement, in contrast to the relative lack of spontaneous conclusion generation shown by students in this condition. The overall analysis revealed significant differences between the conditions ($X^2(2) = 37.3$, $p < .001$). Participants who received the matching structure stories were more likely to produce at least one conclusion statement than participants who received the non matching stories ($p = .06$) and significantly more likely than participants in the control condition ($p < .001$). However, participants in the non matching condition now were also more likely than participants in the control condition to produce at least one conclusion statement ($p < .0001$).

Significant differences in production of at least one conclusion statement were also found when considering the performance of students in the fourth grade ($X^2(2) = 6.2$, $p < .05$), sixth grade ($X^2(2) = 9.4$, $p < .01$) and college students ($X^2(2) = 7.4$, $p < .0001$). Multiple comparisons revealed no significant difference in performance of fourth grade students in the matching condition compared to students in the non matching condition. Students who received matching stories were significantly more likely to produce a conclusion statement compared to students in the control condition ($X^2(1) = 6.2$, $p < .05$). A marginally significant difference was also obtained between students in non matching condition and students in the control condition ($X^2(2) = 3.3$, $p < .1$).

Further comparisons of the sixth grade data revealed no difference in performance between students in the matching condition compared to the non matching condition. Students in the matching condition and the non matching condition both were more likely to produce at least one conclusion statement than students in the control group ($X^2(1) = 8.3$, $p < .005$, and $X^2(1) = 5.2$, $p < .05$, respectively).

Multiple comparisons between conditions for the college students' performance showed that more college students in the matching condition produced at least one conclusion statement compared to students in the non matching condition

(Fisher's exact $p < .05$). No significant difference was found in this measure for either the fourth or sixth grade children. Total conclusion production was also more likely to occur in the matching condition and the non matching condition compared to the control condition ($X^2(1) = 27.4$, $p < .001$, and $X^2(1) = 13.6$, $p < .005$, respectively).

In summary, the elementary school children showed a different pattern than college students in their transfer of a conclusion statement when considering the total production. For the elementary school children, no difference in performance was found between matching and non matching conditions in contrast to the greater likelihood of transfer seen for the matching condition in the spontaneous transfer. Both fourth and sixth grade students in the matching and non matching conditions were more likely to generate a conclusion statement than fourth and sixth graders in the control group. College students in the experimental groups also were more likely to produce a conclusion statement than college students in the control group. Additionally, a difference continued to exist in the total production of conclusion information for college students in the matching condition compared to students in the non matching condition.

<u>Total Production of the Arbitrary Information</u>

Table 5.6 (on pg 100) also contains the performance of students on the total production of the arbitrary

information. Students who received matching structure stories had a higher percentage of generating the arbitrary information than those who received the non matching structure stories or who just received the target story.

A significant difference between conditions was found when considering arbitrary responses produced before or after the probe questions ($X^2(2) = 8.6$, $\underline{p} < .01$). Students who received the matching structure stories were more likely to produce the arbitrary information than students who received non matching structure stories or students in the control condition ($X^2(1) = 5.7$, $\underline{p} < .05$, and $X^2(1) = 6.5$, $\underline{p} < .01$, respectively). No significant difference in likelihood of transfer was found between students in the non matching structure condition and students in the control condition.

For the fourth grade students, the overall test examining total production of the arbitrary information revealed significant differences between conditions ($X^2(2) = 5.9$, $\underline{p} < .05$). Students in the matching structure condition were more likely to produce at least one arbitrary statement any time during the session than students in the control condition ($X^2(2) = 5.5$, $\underline{p} < .05$). No other pairwise comparison was significant. Tests for the sixth grade students or college students revealed no significant differences on the overall analyses, so no further comparisons are reported.

Transfer of Category Membership

Table 5.8 shows participants' performance on the category transfer measure. Participants were scored as respondents if at any time during the session they indicated transfer of category membership from the source topic to the target on one of the two relevant stories. Students in all grades were likely to transfer category membership if they received either the matching antecedent stories or the non matching antecedent stories. The omnibus test revealed significant differences between conditions for all participants ($X^2(2) = 29.2$, $p < .0001$). No differences were found in category transfer between the two experimental groups. Participants in both the matching structure condition and in the non matching structure condition were significantly more likely to transfer category membership than participants in the control condition ($X^2(1) = 27.2$, $p < .0001$ and $X^2(1) = 25.1$, $p < .0001$, respectively).

The tests for transfer of category membership at each grade level revealed that fourth graders showed significant differences between groups ($X^2(2) = 7.1$, $p = .03$), as did sixth graders ($X^2(2) = 14.8$, $p < .001$) and college students ($X^2(2) =4.6$, $p < .01$). Multiple comparisons revealed a significantly higher percentage of fourth graders in the matching condition and the non matching condition generated at least one instance of category membership transfer compared to fourth graders in the control condition

Table 5.8

Percentage (and number) of participants who provided a category transfer response

Grade	Condition		
	Matching	Non Matching	Control
4th	37% (7)	28% (5)	0% (0)
6th	57% (12)	48% (10)	5% (1)
college	33% (6)	45% (9)	0% (0)
	43% (25)	41% (24)	2% (1)

(Fisher's exact $p < .01$, and Fisher's exact $p < .05$, respectively). No difference was seen between fourth grade students in the two experimental groups.

Other comparisons revealed that sixth graders in both the matching and non matching conditions were more likely to generate at least one instance of category membership than students in the control group ($X^2(1) = 14.19$, $p < .001$, and $X^2(1) = 10.5$, $p < .005$, respectively). No reliable differences were found in performance between sixth graders in the matching and non matching conditions.

As was the case for the fourth and sixth graders, subsequent comparisons for the college students revealed no difference in category transfer between students in the matching and non matching conditions. Students in both the matching condition and non matching condition were significantly more likely to provide at least one instance of category transfer compared to students' transfer in the control group (Fisher's exact $p < .01$, and Fisher's exact $p < .005$).

Students in all grades showed the same pattern with respect to transfer of category membership. Students in the matching and non matching structure conditions were more likely to transfer category membership compared to students in the control groups. No differences in transfer of category membership were found between participants in the two experimental conditions.

CHAPTER 6

EXPERIMENT 2B: STORIES WITH MATCHING ANTECEDENT STRUCTURES ARE JUDGED MORE SIMILAR THAN STORIES WITH DIFFERENT ANTECEDENT STRUCTURES

Most participants in Experiment 2A provided little indications of transfer on any of the three dependent measures examined in that study. One possible explanation for the low rate of transfer is that participants found it difficult to perceive the underlying similarity of the source and target structure, even in the matching condition. Perhaps only a few participants who received stories with matching structures represented them in such a way as to be able to notice the underlying structural similarity between the stories. If participants did not encode the structural similarity between the matching antecedents of the source and target stories they would be less likely to benefit from the potential analogical relation between the domains and a high transfer rate would not be expected.

A follow-up study was designed to ascertain if, in fact, participants could recognize the greater structural similarity between matching source and target stories compared to non matching source and target stories. One way to determine if students can identify the underlying structural similarity between matching source and target stories is to simply ask them which of two different target stories is most similar to a source story; one with a matching antecedent structure or one with a non matching structure. If participants do not preferentially chose the matching structure target stories when given this choice, they would not be expected to profit from the more complete analogy provided in the matching condition. Clement and Gentner (1991) asked adults to choose which of two facts, one embedded in a matching structure the other in a non matching structure, better contributed to the analogy between the source and target stories. They found that adults chose the fact which was part of the matching relational structure over the fact which was part of the non matching structure.

Simply asking participants to make such a choice, however, does not ensure that they would process the structural similarity between matching causal structures when a target story using a non matching structure is not included as a foil. Having both stories present may serve to emphasize the differences between the antecedent structures, which could aid students in choosing stories with matching antecedent structures. For example, Gick and Patterson (1992) found that adults were more likely to engage in analogical transfer when presented with two source stories that contained different structures compared to when they were given one source story. Gick and Patterson (1992) claimed the differences between the structures increased the salience of both structures, which in turn, aided participants in recognizing the source story that contained a solution principle applicable to the target problem.

In order to assess participants' judgements of structural similarity without the possible influence of comparing the structures affecting their decisions, participants were first given just one source and one target story to evaluate. Participants compared the stories and rated their similarity on a Likert scale. Some participants were given source and target stories that contained matching causal structures, while other were given stories that had non matching structures. If students processed the structure of the stories, those who received matching structure source and target stories should rate the two stories as more similar scale then those who received the non matching stories. Students' comparisons of the stories were also examined to determine exactly what similarities they incorporated into their evaluations of the source and target story.

Method

Participants

Nineteen fourth grade children (mean age = 9.3 years, range = 9.7 to 10.8 years), 13 sixth grade children (mean age = 11.9 years, range = 11.3 to 13.0 years) and 23 college students participated in this study. Students at each grade level came from the same school as those who participated in

Experiment 2A: the elementary school students attended the same West Springfield schools and the adult sample was comprised of University of Massachusetts students. No student participated in both Experiments 2A and 2B.

Materials and Design

The stories employed in Experiment 2A were again used in Experiment 2B. Briefly, source stories described a topic which included an antecedent-conclusion structure and a more arbitrary piece of information. The target stories described imaginary organisms or objects. The target stories included the antecedent information, but not the corresponding conclusion or arbitrary information that was present in the source.

In the matching structure condition, participants received source and target stories which contained matching causal structures. In the non matching structure condition, participants received source and target stories which had non matching causal structures. No control condition was utilized in this study.

Procedure

As in Experiment 2A, college students participated in small groups and elementary school students participated individually. College students read all stories and wrote their responses. Stories were read aloud to the elementary school children while they followed a printed version of the story, and all responses were made orally, and tape recorded for later analysis.

For all ages, the printed version of the source and target stories were presented on the same page. After each participant read the source and target stories, (or followed the printed version while being read each story), he or she was asked to compare the stories by responding to the question "Was there anything similar in these two stories?" He or she then evaluated the similarity of the two stories on a Likert scale.

Following the comparison and rating of the similarity of the source and target story, each participant was presented with two target stories, and asked to choose which of the two was most like the source story. One of the target stories was the same one he or she had received in the similarity rating task. The other target story was the version with the alternative structure. In other words, each participant was provided with two target stories, one that matched the source story in its antecedent structure and the other that did not match and the student was asked to choose which was most similar to the source story. This procedure was repeated with each of the other two topics in the stories used in Experiment 2A. Order of presentation of the three stories was counterbalanced.

Dependent Measures

Participants engaged in three different tasks designed to ascertain their judgments of the structural similarity of source and target stories. The story comparison task required participants to describe the similarities they observed between the source and target story. The responses were classified into one of four categories, depending on the degree to which the participants mentioned the structural similarity of the stories. This scale with examples of each level is presented in Table 6.1. If comparisons contained several comments which could fall into different categories of the scale, the highest possible score was given.

After participants generated their own comments on the similarity of the source and target stories, they rated the similarity of the stories on a Likert scale of 1 (extremely dissimilar) to 6 (extremely similar). A neutral point was not included, to encourage students to come to a decision regarding the similarity of the stories.

Finally, in the choice task, students selected which of two target stories was most similar to a source story. One of the target stories matched the structure to the source story; the other did not have a matching structure.

Results

The author scored the story comparisons twice, at intervals separated by 3 weeks. Percent agreement for the

Table 6.1

Four point scale for categorizing comparisons between source and target stories

Response	Category
No comparison or irrelevant to the topic of the stories (e.g., "both stories are about the same length")	1
Topic common to the source and target (e.g., "both have a special way of defense")	2
Explicit antecedent structure comparison (e.g., "both protect themselves by giving off a substance that repeals predators)	3
Explicit antecedent structure comparison with conclusion transfer (e.g., "both defend themselves by putting out something that tastes yucky to things that are attacking them so even if one gets attacked the others don't")	4

scoring at these intervals was 85% for comparisons produced by fourth graders and by sixth graders, and 86% for comparisons produced by college students.

Table 6.2 displays the mean scores on the story comparison scale. As seen in Table 6.2, comparisons produced by students who received the stories with matching structures were rated higher on the comparison scale than those produced from students who had compared stories with non matching antecedent structures. Additionally, the mean comparisons in each grade are similar, regardless of the structure of the source and target stories. A 2 (structure; matching, non matching) by 3 (grade; fourth, sixth, college) ANOVA was used to examine if the type of story pairs students received influenced their comparisons (and was used for all further analyses on the different dependent measures). Comparisons produced by students who received matching structure stories were rated higher on the comparison scale ($M = 2.6$) than comparisons produced by students who received non matching structure stories ($M = 1.8$, $F(1,50) = 44.2$, $p < .0001$). No main effect of grade was found, and there was no significant interaction between these effects.

Students who received the non matching structure stories could not produce a comparison that would receive a rating of three or four, unless they reconstructed the target story structure to match the source story structure.

Table 6.2

Mean performance (and standard deviations) on dependent measures for Experiment 2B, as a function of age and condition

Measure	Grade	Matching	Non Matching
story comparison (range 1-4)	4th	2.4 (0.6)	1.8 (0.5)
	6th	2.9 (0.6)	1.7 (0.5)
	college	2.6 (0.5)	1.9 (0.2)
similarity rating (range 1-6)	4th	4.2 (0.9)	3.4 (1.2)
	6th	4.7 (0.8)	3.3 (0.9)
	college	4.2 (0.5)	3.4 (0.8)
target choice (out of 3)	4th	2.3 (0.8)	2.2 (0.7)
	6th	2.9 (0.4)	2.2 (1.0)
	college	2.8 (0.1)	2.6 (0.5)

Three students, (one in each grade) did in fact transform the target structure so that it matched the source structure in their comparisons. Scores on the comparison scale were examined to see if students could recognize the similarity between the topics of the stories. 75% of the students produced three comparisons that received scores of 2 or greater, indicating they had recognized the similarity between the topics for each of the three source-target pairs. Recognition of topic similarity was also examined as a function of receiving matching or non matching stories. 88% of the elementary school students who received matching structure stories produced two or more comparisons mentioning topic similarity and 75% who received non matching structure stories provided two or more such comparisons. 100% of the college students in each group generated two or more comparisons acknowledging topic similarity.

Students' own ratings of story similarity can also be seen in Table 6.2. Participants who compared matching structure stories gave higher ratings ($\underline{M} = 3.4$) than subjects who compared the non matching stories ($\underline{M} = 2.5$, $\underline{F}(1,50) = 23.9$, $\underline{p} < .0001$). No main effect of grade was obtained and there was no significant interaction between grade and structure.

Students were also able to distinguish between the two target structures in terms of which was more similar to the source story. Sixty percent of participants correctly choose the matching target structure on all 3 trials, while 93% of the participants chose the target story that had the same structure as the source story on at least of two of the three different source-target topics. Participants' choices were summed so that scores could range from 3 (all matching choices correctly selected) to 0 (no matching choices correctly selected), and the average performance on this task is seen in Table 6.2. Performance on this task was very similar for students in each of the grades. No reliable differences were seen on the main effects of age or structure, and no interaction was found. Even though participants had more exposure to either the matching or non matching target story, there was no effect on selecting matching structure when given the choice between the two.

Conclusion

Responses on the dependent measures provided converging evidence that participants were able to recognize the underlying structure of the source and target domains. Participants who received matching stories generated comparative responses that were more effectively focused on the specific structure of the stories than those who received non matching stories who could only compare the topics of the stories.

Furthermore, students rated the matching structure stories as more similar on a Likert scale than non matching structure stories. Even after comparing the non matching target story to the source story, they were also able to correctly pick a matching target story as more similar to the source story. Both structural versions of the target stories began the same way, by describing a similar topic, and in either case this topic was analogous to the topic discussed in the source story. The only difference between these target stories was in the way the topic was instantiated. For example, both target stories about Bems described their unusual way of obtaining food. Each version described a different way that the Bems went about this task; in one version the Bem mimicked other animals and in the other it moved at high speeds. Participants were able to process these differences, and appeared to regard them as meaningful, since they chose the structure that matched the source structure as being more similar.

Another important finding from Experiment 2B was the lack of differences in performance as a result of age. Some research concerning children's comprehension of domain structure in expository texts implied that younger children might be less likely to represent the overall structure of these expository stories (Englert, Stewart & Hiebert, 1988; Kintsch, 1990; Scardamalia & Bereiter, 1984; Taylor & Samuels, 1983). However, this was not the case. Fourth graders were just as capable as adults in judging the finer similarities of matching antecedent structures.

CHAPTER 7

DISCUSSION OF EXPERIMENTS 2A AND 2B

Experiment 2A was designed to assess if there were developmental differences in how the specific antecedent structure of a domain affected children's and adults' transfer. Transfer of three types of information was examined; conclusion information that was connected to an antecedent structure, arbitrary information that was less connected to the antecedent structure, and category membership.

Before discussing the differences in transfer for the different types of information in Experiment 2A, one issue that must be addressed is the overall low transfer rate. Using a variety of tasks, Experiment 2B showed that participants judged pairs of stories containing matching antecedent structures as more similar than stories which contained different antecedent structures. Therefore, participants should have been able to recognize the potential analogous relations in the matching source and target stories in Experiment 2A.

In retrospect, however, the low transfer is not entirely surprising, as only one source story was given for each target story. Transfer rates dramatically increase when more than one source story is provided to participants (Catrambone & Holyoak, 1989; Gick & Holyoak, 1983). Receiving more than one source story may allow learners to form an abstract representation of the structure. However, Clement and Gentner (1991) provided only one source for each target story. In contrast to results of Experiment 2A, they found a high level of transfer of conclusion information when it was part of a shared antecedent structure.

Of course, Clement and Gentner (1991) used different stories and subject populations, so any reasons explaining the discrepancies across studies are speculative. However, one difference in procedure may shed some light on this issue. Clement and Gentner (1991) used complex source and target stories, each containing two episodes. Each episode in the source story contained conclusion information that could be transferred to the target story. One episode used an antecedent structure that matched a similar structure in the target, while the other episode used a non matching antecedent structure. Participants were instructed to use the source story to generate a prediction that might be true in the target. The explicit instructions to employ the source stories, and the fact that participants could compare the two different antecedent structures in making their choice, may have greatly elevated the amount of transfer Clement and Gentner (1991) observed. In comparison, Experiment 2A did not provide such an opportunity to compare and contrast the matching and non matching antecedent structures, which might have contributed to the low spontaneous transfer rate.

Experiment 2A examined the use of structure in transfer by using separate source stories. Even though the mean level of transfer was low, the likelihood of participants transferring conclusion information was greater when it was a component of an antecedent structure that matched between the source and the target, in the spontaneous generation task. This pattern of transfer held true at all grade levels. Fourth, sixth, and college students were all more likely to generate a conclusion statement when it was embedded in an antecedent structure that matched in the source and target compared to when they received stories using non matching antecedent structures, or when they received no source story.

Besides transferring conclusion information, students could also potentially transfer arbitrary information not related to the causal structure of the domains. In contrast to the pattern of spontaneous generation of conclusion information, students who received matching structure stories showed no advantage in generating the arbitrary information. In fact, the overall analysis revealed no differences between the matching, non matching and control conditions.

The combined results that students were more likely to transfer conclusion information that was part of a shared antecedent structure and that little transfer of arbitrary information occurred provides support for structure mapping theory (Clement & Gentner, 1991; Gentner, 1989; Gentner, & Rattermann, 1991; Gentner & Toupin, 1986). Analogies are formed, according to this theory, by establishing correspondences between relational systems. Arbitrary features and isolated relations are discarded, or given less weight, in the analogical process compared to the mapping of complex relational systems. Results from the spontaneous generation portion indicated that arbitrary facts were not transferred. Conclusion information was transferred only when a similar antecedent structure was shared between source and target domains.

However, the transfer of category membership indicates that structure mapping may not be able to account for all the transfer occurring in Experiment 2A. Participants in all grades were more likely to generate category membership for the object or organism in the target story if they had received a source story, in contrast to participants who had received only the target stories. No difference in category transfer was seen as a result of receiving matching or non matching antecedent structures.

The pattern for category transfer across conditions was different than the pattern of transfer for either the conclusion or the arbitrary information. Arbitrary information was not spontaneously transferred to the target, while category membership was transferred. Additionally, transfer of category membership did not differ as a result of antecedent structure matching, while transfer of conclusion information was benefitted by receiving matching antecedent structures.

One explanation for why transfer of category membership occurred, regardless of a matching or non matching antecedent structure, relies on the assumption that the topics or themes of each source-target pair of stories were alike. Each source and target story described the subject of the stories as displaying an unusual or unique trait. For example, the stories about angler fish and Bems both described an unusual way that these creatures obtained food. This topic similarity occurred both when the antecedent structure matched or did not match in the source and target stories. Story comparisons produced by participants in Experiment 2B showed that students could recognize this similarity, even when the remaining segments of the stories did not match. 75% of the elementary school students and 100% of the college students who received source and target stories with different antecedent structures produced comparisons that alluded to the similarity of the topics of each source-target pair in two or more comparisons.

Thematic correspondences may be a different type of similarity than matching of a specific antecedent-conclusion structure. The theme of a text can act as an organizing principle for the concepts developed in that text (Johnson & Seifert, 1992). For example, when examining the effects of structural similarity, Gentner and Toupin (1986) used the moral of a fable in order to emphasize the overall structure of a story. As an illustration, one fable described how a cat became upset that his friend, a walrus, played with another friend, a seagull. The cat became so angry that he jumped into a wagon, which started to roll down a hill. The seagull ended up saving the life of the cat. The moral of the story was that "being jealous gets you into trouble; it is better to have two friends instead of one". The moral provided an organizing structural framework to interpret the actions of each of the characters.

The theme of a story relies on the specific roles that agents occupy in order to provide meaning to the actions taken in the story and can be considered another component of source information that can contribute to transfer (Suzuki, 1994). The creature or organism in the expository source stories used in Experiment 2A could be regarded as the agent that initiated the topic of the story. In contrast, the antecedent structure contained in each story provided the specific details of how the general topic of the story was instantiated.

Hammond, Seifert, and Gray (1991) and Johnson and Seifert (1992) found that remindings of source stories can take place at different levels, based on different subsets of abstract features. The topics in the target story might have reminded students of the source stories, and so led participants to classify the stories as the same type (Suzuki, 1994). The creature or object that played a role in the topic of the source story might have been seen as analogous to the creature or object in the source story. Therefore, transfer of category membership ensued between source and target.

Since the texts were designed to teach about the creatures and their traits, the particular nature of the subjects of the source stories might have been an especially noticeable component of the topic of the texts to students. Vosniadou (1989) postulates that any similarities between representations of different domains which are salient to the individual may be used in an analogical reasoning task. The animate/inanimate distinction of class membership is a basic concept. Even preschoolers are fairly knowledgeable about the types of inferences one can make about members of different categories (Brown, 1989; Keil, 1986). Brown (1989) suggests that transfer is difficult to prevent when participants have a well-developed theory about a domain. Perhaps category membership is especially likely to be transferred in an analogical reasoning task. Other aspects of topic similarity might not be as readily transferred.

The pattern of category transfer may indicate that forming an analogy between two domains need not be an "all or none" process. Analogies might be formed as far as the source information allows, so that when some higher order aspect, such as the thematic context, matches between two stories, mapping and transfer of information specific to that level can occur. Such transfer is not dependent on the specific matching or non matching of antecedent structure, as indicated by the lack of difference between the matching and non matching conditions. However, simply because transfer of some higher order thematic information occurs does not imply that students will show indiscriminate transfer. For instance, the conclusion information presented in the source stories was constrained by the specific antecedent structure. Therefore, transfer of this specific information occurred only when the antecedent structures were analogous in the source and target texts. Similarly, transfer of arbitrary information was not readily obtained.

Another aim of the study was to examine developmental differences in use of structure. Some researchers, including Gentner (1989; Gentner & Toupin, 1986), Halford (1993), and Zook (1991) theorize that analogical reasoning in children may be more dependent on surface features. As indicated earlier, the reading comprehension literature also suggested that perhaps children would not represent the stories effectively at the structural level, but would process the information more as a collection of individual facts (Englert, Stewart & Hiebert, 1988; Kintsch, 1990; Scardamalia & Bereiter, 1984; Taylor & Samuels, 1983).

In both the matching and non matching conditions, the source and target stories described similar topics. Only the antecedent which lead to the conclusion differed between matching and non matching structure stories. If children were not sensitive to this particular structure, but viewed the stories as a collection of separate facts, then transfer (or absence of transfer) of these facts might have occurred regardless of structure. In fact, that was not the case. Elementary school children were sensitive to the matching structure of the source and target stories when transferring information that was directly tied to that structure. Students in all grades were more likely to spontaneously transfer the conclusion sentence when they received matching structure stories compared to the non matching stories or the control conditions. These results suggest that by fourth grade, structure representation and analogy formation may take place much as it does in adults.

Experiment 2B provided confirming evidence for the view that elementary school children are capable of processing the similarities between matching antecedent structure stories in a fashion similar to adults. Students in all grades rated source and target stories which had a corresponding antecedent structure as more similar than stories that did not share this structure. Similarly, no grade differences were found for participants' choice of which of two target stories was most similar to a source story.

Results for the total production measures of the conclusion information reveals additional information that participants will transfer conclusion information between non matching structure stories when given some prompt to do so. The total production measure takes into account responses generated before or after the probe questions. While the probe questions were not literally a direct hint to use the source story, they were designed to steer participants to consider specific aspects of the target story.

Given this additional opportunity to demonstrate transfer perhaps it is not surprising that the percentage of students who produced a conclusion statement increased, even in the non matching conditions. At all grades, participants who received the non matching stories were significantly more likely to produce the conclusion information than those who had only received the target stories. In contrast, before the probe questions were given, no difference was seen between the non matching condition and the control.

The initial impetus for spontaneously forming an analogy must come from some aspect of similarity between the two domains. When participants were asked to generate facts to add to the source story, similarity between the matching antecedents in the source and target stories may expedite access of that source story. Catrambone and Holyoak (1989) found a similar facilitating effect of matching structure. Therefore, spontaneous transfer of conclusion information occurred primarily between stories with matching antecedents.

However, the probe questions could act as a reminder of either a matching or non matching source story, as both types of source stories could provide an answer to the questions. Participants who did not access the non matching stories in the spontaneous sentence generation might well have done so after hearing the probe questions. Therefore, overall transfer for both the conclusion and arbitrary information increased in the non matching condition. With encouragement, students were able use a source story for transfer that did not match in the specific structural aspects of the target story.

The elementary school students showed such a large increase in transfer for the non matching stories that it diminished the differences in transfer between the matching and non matching groups. In contrast, college students were still more likely to transfer the conclusion information in the matching condition compared to the non matching condition. Differences in the experimental situation between the children and adults may provide a rationale for the discrepancy for why children, even though able to recognize a matching antecedent structure as being more similar, were equally likely to transfer the conclusion statement from the matching and non matching source stories. Children were tested individually with an experimenter who occupied a position of greater authority, due to age differences and the resemblance to a testing situation. After probe questions were asked, experimenters waited for an answer. This one-on-one interaction might have compelled elementary school students to try to answer the probe questions, and they used the information that had just been provided to them in the source story. Adults, on the other hand, participated in small groups, and so may have felt less pressure to answer the probe questions and more confident in rejecting information from the non matching source story.

This tendency to transfer regardless of antecedent structure did have some limits. A change was found in the total production of arbitrary information transfer as well as the conclusion transfer. Overall, participants who received the matching stories were more likely to transfer the arbitrary information than participants in the non matching and control. However, no differences were found for total arbitrary transfer between the non matching and control conditions. Transfer of arbitrary information may be so uncommon that perhaps only in the combined case of antecedent similarity between the source and target, and increased support to form an analogy, will it occur. Analogy formation may depend primarily on structural relations and analogical transfer occurs as an extension of that structure.

Chapter 8

GENERAL CONCLUSION AND FUTURE DIRECTIONS

The experiments in this dissertation were concerned with representation of the structure of a domain, and developmental differences in this representation. The two major experiments dealt with different facets of representation. Participants were provided with a direct analogy in Experiment 1 to determine how that affected their understanding of the structure of a target domain. Experiment 2A explored how the structure of domains influenced the ability to generate predictions about what would be true in a domain that was missing information.

Analogies did aid participants in their understanding of unfamiliar domains. Participants were more likely to generate correct inferences about science concepts if given the information in analogical form, as shown in Experiment 1. Similarly, providing a source domain that had an analogous antecedent structure to a target domain in Experiment 2A facilitated students' understanding of potential attributes that could be true in the target domain.

Analogies seem to have helped learners function in a manner corresponding to an expert's, as one characteristic of an expert's understanding of a field is their greater ability to generate inferences compared to novices (Gobbo & Chi, 1986; Shank & Abelson, 1977). Using the information provided in the source domains may have aided students' understanding of the structure of the target domains. Both Experiments 1 and 2A showed that receiving source information that was analogous to target information increased the likelihood of generating inferences about that target.

Generating inferences, however, is not always beneficial for understanding, as individuals may also generate erroneous inferences. Analogies may promote the formation of incorrect inferences, which can lead to misconceptions about the target domain that can be difficult to eradicate (Spiro, Feltovich, Coulson & Anderson, 1989). Learners might inappropriately transfer certain characteristics of the source domain to the target domain, which would limit the usefulness of using analogies in knowledge acquisition. For instance, students might inappropriately transfer information from the source domain that is not related the relational structure of the domains. Findings from Experiment 2A, however, revealed that, unless encouraged to do so by the probe questions, participants did not transfer the arbitrary information. In contrast, students were more likely to transfer conclusion information when they received source stories that had analogous antecedent structures. This combined pattern suggests that participants would not incorrectly transfer specific arbitrary information unrelated to the mapping structure used in the analogy, and so would not necessarily form this type of misunderstanding about a target domain.

Transfer of category membership provides some indications of when analogies might promote misconceptions about a domain, and the possible limits of analogies. Participants in Experiment 2A who received either matching structure stories or non matching structure stories were more likely to generate instances of category membership than participants who did not receive source stories. When the source domains were created, transfer of category membership was not a consideration. However, the topics of the stories matched in the source and target, and even if the particular antecedent structure did not match, participants transferred category membership. In the context of an analogical relationship, transfer of category membership could be considered an overgeneralization of information. Simply because the general topic of the domains are similar does not always imply that the topic should be transferred to the target domains.

As discussed in Chapter 7, category membership and the arbitrary information may involve different levels of source information, and certainly bears different links to the structure of the story appropriate for transfer. The arbitrary information is relatively separate from the antecedent-conclusion information. Category membership, on the other hand, is a component of matching thematic relations between the source and the target domains. This transferred information may be appropriate or it may be inappropriate in the target domain.

From the learner's perspective, transfer is inappropriate only if some knowledge is available about the target domain that would indicate its unsuitability. The use of analogies to assist transfer of knowledge can lead to both positive and negative outcomes, and educators may need to relate the limits of the analogy to prevent forming misconceptions. Setting limits might be especially important with regard to information that is connected to matching structural relations in the source and target to prevent the inappropriate transfer. Less care may be needed to prevent transfer of more isolated or arbitrary information in the source domain which is not directly related to any aspect of matching relations.

Spontaneous analogical transfer is often difficult for students to engage in. For instance, although students could recognize the greater similarity of source and targets stories that had matching antecedent structure compared to non matching antecedent structure, use of the matching antecedent source information was low. Difficulty in accessing prior knowledge is a common limitation in analogical reasoning (Bransford, Vye, Franks & Sherwood; 1989; Brown, 1989; Gick & Holyoak; 1983; Whitehead, A.N, 1929). Providing guidelines for mapping the relations in the analogy, as Experiment 1 did, may enhance any benefits that accrue when learning with analogies.

Analogies did improve the ability of elementary school and college students to generate inferences about science concepts. I proposed in the discussion of Experiment 1 that analogies gave participants' greater flexibility in their representation of the science concept. Participants may have been able to simulate the processes needed to answer the inference questions, and so generate the results. However, Experiment 1 did not address the mechanism by which this flexibility is achieved.

One manner in which analogies could benefit inferential reasoning is by allowing participants to resort to familiar source information to model the answer to the inference question. Participants might be using the specific elements and relations provided in the familiar source domain to reason about the unfamiliar target domain (Ross, 1987, 1989; Medin & Ross, 1989; Reeves & Weisburg, 1994). For example, consider the enzyme analogy. When asked the question about the consequences of changing the shape of the enzyme, participants may have drawn upon their knowledge of the results of changing the shape of a key and the subsequent failure of that key to fit into a particular lock to arrive at the appropriate inference concerning the enzyme-protein relationship. Participants could concretely substitute the objects in the enzyme domain for the objects in the key domain to obtain the correct answer.

Another possible mechanism by which receiving the analogy may have helped students generate inferences is by encouraging the formation of a more abstract structure governing both the source and target domain. An abstract representation, or schema, may be formed during mapping of the relationships in the analogy so that specific object attributes are minimized relative to the relational structure (Catrambone & Holyoak, 1989; Chen & Daehler, 1989; Gentner, 1989; Gick & Holyoak, 1983). This more abstract representation, in turn, may permit greater flexibility in reasoning about the target domain.

Students had a higher level of identifying abstract statements as examples of the science principles than the concrete statements from a different domain, perhaps indicating that students were able to form an abstract representation. However, since no benefit was found as a result of receiving the analogies, one can not conclude that the analogies provided an unique advantage in forming such a representation.

To examine if participants are directly transferring information from the source domain to answer the inferential questions or if the benefit is from forming an abstract relational structure, multiple source domains could be used. Presenting two or more source domains increases the formation of an abstract schema of the relations in the analogy (Catrambone & Holyoak, 1989; Gick & Holyoak, 1983). Performance on inference questions could be examined for participants who receive one source domain compared to participants who receive multiple source domains. If participants are reasoning directly from the source domain, then increasing the number of source domains should have little effect on performance, presuming participants are equally knowledgeable about the different domains. If forming an abstract schema aids in inferential reasoning, then performance should improve as the result of increasing the number of source domains. Additionally, students could be asked to generate an abstract statement of the relations taught in the target domains. If the analogies promote an abstract representation, students might be more likely to produce such a statement compared to students who did not receive the analogies.

Another line of research can be extended from the results found in Experiment 2A. The developmental difference in that study was seen in the likelihood of students' transferring the conclusion information when the total production of the conclusion information is considered. Elementary students did not show a difference between the matching and non matching conditions, while college students were more likely to transfer when they received the matching structure. As suggested in Chapter 7, a possible reason for this difference is that the attention of the elementary school students was more directed to source information during the probe questions than the attention of the college students.

A test of this hypothesis would be to examine if children believed the conclusion statement would be true about the topic in the target stories, especially when they were transferring from the non matching structure stories. If children in the non matching condition transferred conclusion sentences due to the experimental situation, they should be less likely to consider their transfer statements true compared to children who received the matching structure stories.

If differences were found between such ratings, this would suggest that, given increased access to source information, by fourth grade, transfer might consist primarily of structural information, but children might be more lenient as to the exact nature of that structure. One way to examine this issue would be to determine how children judge the soundness of an analogical relationship. Judging an analogical relationship is not equivalent to forming a relationship. Nonetheless, if children do not have the same criteria as adults for judging, that would suggest there might be differences in formation as well.

Finally, the issues explored in this dissertation also should be examined with still younger children. There were few indications that developmental changes occurred in the transfer process in the age ranges included in these studies. By the fourth grade, children and adults seemed to have similar capabilities in structural representation of a domain, and use of that representation affected transfer in similar ways. It was anticipated that perhaps developmental differences would occur between the fourth and sixth grade due to a relative inability to comprehend the relational structure of a domain. Results from this dissertation provide support to those researchers who claim that children can encode relations in a manner akin to adults.

However, the youngest children examined in these studies were approximately 9.5 years. Still younger children may not comprehend the relational structure of a domain as well as fourth graders. For instance, the analogies used in Experiment 1 could be employed with children in the second grade, by simplifying the language, and allowing children access to the texts. Younger children's use of antecedent structure in transfer could be examined by using more directed comparisons of source and target stories, using a narrative structure instead of an expository structure, or using pictorial representations of structure. Work with younger children would help complete the picture obtained in these studies of the developmental differences in understanding domain structure, and its affect on transfer.

APPENDIX A

SCIENCE TEXTS USED IN EXPERIMENT 1

Science texts:

1. MITOCHONDRIA:

Analogy: Mitochondria are things found inside cells in your body. Mitochondria sends energy to your body, just like a power company sends energy to your house. You can use all the parts of your body, because the energy from the mitochondria makes them work, just like you can use everything in your house, because the energy from the power company makes them work.

Non Analogy: Mitochondria are things found inside cells in your body. Mitochondria are really extremely small. Mitochondria work by sending energy to the parts of your body. You can use all the parts of your body, because the energy from the mitochondria makes them work. The energy from the mitochondria is present in your body when you are a baby.

2. BLACK HOLE

Analogy: A black hole is something found in outer space. A black hole sucks up everything that comes near it like comets and even light, just like a vacuum cleaner sucks up all the dirt that comes near it.

Non Analogy: A black hole is something that is found in outer space. There are many black holes in space. A black hole sucks up everything that comes near it, like comets and even light. Black holes are very powerful.

3. ENZYMES

Analogy: Enzymes are chemicals that join to proteins. The enzyme fits into an opening on the protein, just like a key fits into a lock. Each enzyme has a certain exact shape that makes it fit into only one opening in the protein, just like a key has a certain exact shape that fits into only one lock.

Non Analogy: Enzymes are chemicals that join to proteins. The enzyme fits into an opening on the protein. This helps the protein do its job. Each enzyme has a certain exact shape that makes it fit into only one opening in the protein. Enzymes are very important to help our bodies work.

4. ANTS AND APHIDS:

Analogy: Ants and aphids are bugs that help each other. Aphids can turn one type of plant they eat into a sweet food inside their bodies, like when cows eat grass they turn it into milk. Ants rub the aphids to get the sweet food, like farmers milk cows. Ants help the aphids by keeping them in a warm nest, like farmers help cows by keeping them in a safe barn.

Non Analogy: Ants and aphids are bugs that help each other. Aphids work very hard for the ants. Aphids can turn one type of plant they eat into a sweet food inside their bodies. Aphids really like the taste of these special plants. Ants rub the aphids to get the sweet food. Ants do their part to help the aphids by keeping them in a warm nest.

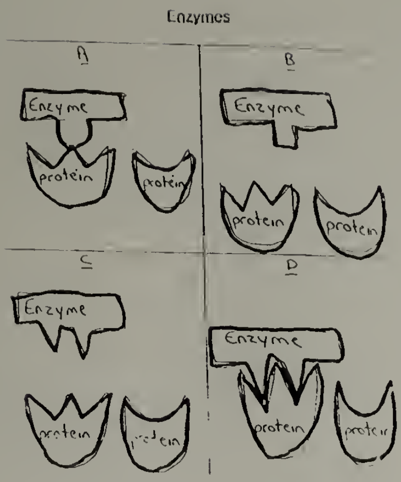
5. INFECTION

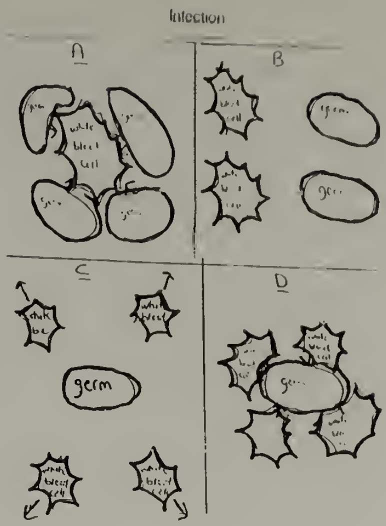
Analogy: Infections can make us sick. An infection is when harmful germs attack your body. When your body is attacked by harmful germs it sends white blood cells to fight the infection, just like a country sends soldiers to fight enemies. The infection heals when the white blood cells have stopped the harmful germs, just like a war ends when the country has won its battle with the enemy.

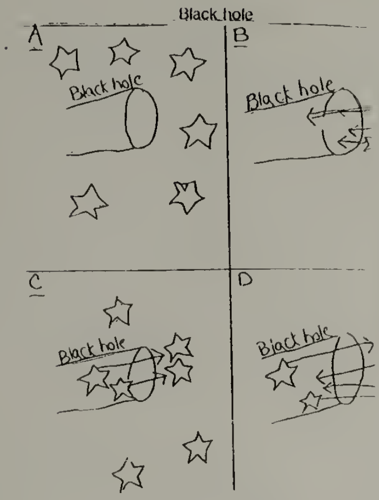
Non Analogy: Infections can make us sick. An infection is when harmful germs attack your body. Your body tries to stop the infection from growing. The body sends white blood cells to fight the infection. The white blood cells work very hard. The infection heals when the white blood cells have stopped the invading germs. Your body tries very hard to stop the infection from growing.

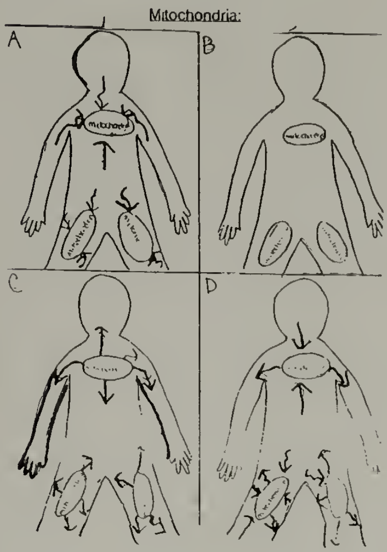
APPENDIX B

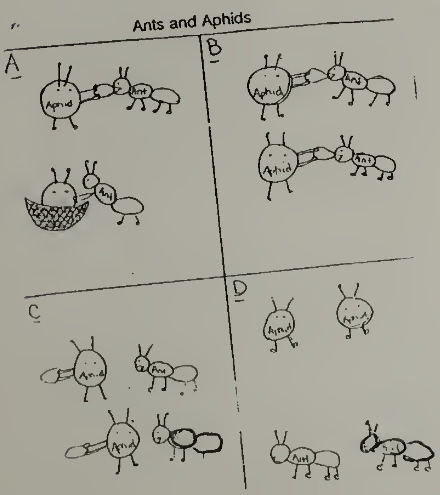
PICTURE SELECTION TASK











APPENDIX C

ADDITIONAL QUESTIONS (AND ANSWERS) ASKED OF PARTICIPANTS IN THE CONTROL CONDITION

Power company (source for mitochondria)

1. Where could you find a power company?
   A:in town, city

2. What do power companies do?
   A: send energy, power to house

3. What would happen to the appliances in your house if the power went out?
   A: appliances wouldn't work, have no power, energy in your house

4. What could happen if the power company started sending out even more power than usual to your house?
   A: have more energy in your house, have an overload

Vacuum (source for black hole)

1. What gets sucked up by a vacuum cleaner?
   A: dirt, dust

2. Where is a vacuum cleaner found?
   A: closet, store

3. What would happen if a vacuum cleaner worked backwards?
   A: everything inside would come out

4. Can you see things after they get sucked into a vacuum cleaner?
   A: no

Key and lock (source for enzyme)

1. What does a key connect to?
   A: lock

2. How many different kinds of locks can a key connect to?
   A: one

3. What would happen if the shape of a key was changed?
   A: key wouldn't fit into lock, couldn't open door

4. What would you know about the shape of a set of keys if the keys all fit into the same opening?
   A: all the keys have the same shape

Farmers and Cows (source for ants and aphids)

1. What do cows produce for farmers?
   A: milk

2. Where do farmers keep cows?
   A: barn, farm

3. What would happen to farmers if they did not take good care of the cows?
   A: farmers wouldn't get milk

4. What would happen if cows ate alot more grass than normal?
   A: cows would give more milk

War (source for infection)

1. How does a country fight a war?
   A: sends soldiers

2. What happens when soldiers stop the enemies?
   A: the war is over

3. What could happen if a country had no soldiers to fight a war?
   A: they would lose the battle, be destroyed, wouldn't win

4. What could a country do to help it win a war more easily?
   A: send or use more soldiers, send or use more weapons

APPENDIX D

SOURCE STORIES USED IN EXPERIMENTS 2A AND 2B

Angler Fish

Version A:

Angler fish live in the ocean. They have a special way of catching other fish to eat. Anglers have a long tentacle that grows out of their head. On the end of the tentacle is something that looks like what other fish eat. When the other fish come near to try to get the bait, the angler fish catches it. The bait develops to look just like what other fish in that particular area eat. If the angler fish goes to a place where new kinds of fish live, the bait won't look like what the new fish eat. When this happens the angler fish finds a new method of catching fish. Angler fish have yellow scales.

Version B:

Angler fish live in the ocean. They have a special way of catching other fish to eat. Anglers have a long tentacle that grows out of their head. There is a special chemical inside this tentacle. This chemical gives them a burst of energy. This lets them swim extremely fast and catch other fish. Sometimes the angler fish gets sick. If the angler fish gets sick, it can't make the special chemical that lets it swim fast anymore. When this happens, the angler fish finds a new method of catching fish. Angler fish have yellow scales.

Slugs

Version A:

Slugs crawl all over the place. Birds like to eat slugs. Fire slugs have a special way of stopping birds from eating them. Fire slugs can shoot out a liquid that tastes horrible to birds. This liquid gets on all the other slugs in the area. Birds don't attack the other slugs because they can smell the horrible liquid on the other slugs. Even if one slug is killed, the rest of the slugs are not attacked. Slugs are very little.

Version B:

Slugs crawl all over the place. Birds like to eat slugs. Fire slugs have a special way of stopping birds from eating them. Slugs live spread out all over the forest. This living arrangement is very important to slugs. When a bird attacks one slug, it won't find any more slugs near its nest. Even if one slug is killed, the rest of the slugs are not attacked. Slugs are very little.

Moon Rovers

Version A:

Moon rovers are machines that went to the moon in the rocket ships. Moon rovers were used to collect rock samples. They used scoops to get the rocks. The Moon rover collected all of the different types of rocks in one place. When the moon rover collected all the different rocks, it stopped collecting so it could roll to a new spot on the Moon. When it stopped collecting rocks, moon rovers pulled the scoops inside its body. Moon rovers could see in all directions.

Version B:

Moon rovers are machines that went to the moon in the rocket ships. Moon rovers were used to collect rock samples on the moon. They used scoops to get the rocks. If the Moon rover kept working all the time it would get extremely hot. When the moon rover overheated, it stopped collecting so it could cool down. When it stopped collecting rocks, moon rovers pulled the scoops inside the main body. Moon rovers could see in all directions.

APPENDIX E

TARGET STORIES USED IN EXPERIMENTS 2A AND 2B

Veisel plants (corresponds to source story Slugs)

Version A:

Veisel plants have a special way of protecting themselves from bugs. Veisel plants make a poison powder on the top of its leaves. When bugs eat this powder, it makes them sick. Wind can blow the powder from that plant all over.

Version B:

Veisel plants have a special way of protecting themselves from bugs. Veisel plants release tiny seed pods. These seed pods are blown away by the wind and grow up far away from the parent plant and from other pods.

Tams (corresponds to source story Moon Rovers)

Version A

Tams gather minerals. A Tam uses a special claw on its body to scrape up the minerals. A Tam will gather all the different minerals it can get in one spot.

Version B:

Tams gather minerals. A Tam uses a special claw on its body to scrape up the minerals. When the Tam scrapes the minerals for a long time, it gets hot.

Bems (corresponds to source story Angler Fish)

Version A:

Bems have an unusual way of getting their food. Bems pretend to be small animals. When other animals come near to try to get the small animal, the Bem can attack them. Bems can only pretend to be animals which they have studied since birth.

Version B:

Bems have an unusual way of getting their food. Bems have a large sac attached to their bodies. There is a substance inside this sac which gives the Bem the ability to run very rapidly in a sudden burst of energy. Sometimes Bems become ill.

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