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Effects of task context and domain knowledge on analogical transfer of science knowledge

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EFFECTS OF TASK CONTEXT AND DOMAIN KNOWLEDGE ON ANALOGICAL TRANSFER OF SCIENCE KNOWLEDGE

by

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Abstract

EFFECTS OF TASK CONTEXT AND DOMAIN KNOWLEDGE ON ANALOGICAL TRANSFER OF SCIENCE KNOWLEDGE

by

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An analogy is used when commonalities inferred between past experiences and a current event increase comprehension or help solve a problem. In introductory science courses, teachers often use analogies to bridge gaps between students' limited domain knowledge and the specific concept under study (positive transfer). Yet, for over a half century, analogical transfer studies show that approximately ninety percent of subjects tested do not transfer causal relationships in an analog to the problem they wish to solve.

This study suggests that context dependency and a learner's type of knowledge base are implicated in poor analogical transfer in experimental conditions. The contexts hypothesized to influence positive analogical transfer are those in which the analogs are 1. structurally associated with relationships in a target science task and are 2. phrased in a problem format. The form of prior knowledge, general or specific, was also hypothesized to predict positive analogical transfer in the science classroom.

The subjects, 266 freshmen in an urban high school, received three weeks of specific science instruction in their classrooms, by their science teachers. Prior to intervention, two knowledge assessments of their general and specific science knowledge were made. After random assignment to one of four experimental groups, the students read one of four analogs that differed in type (isomorphic in structure or in surface) and format (in problem or story form). They and a control group then attempted to solve a problem concerning the specific concept they had studied earlier. The problem was typical for science students.

All aspects of the study - instruction, knowledge assessments, and interventions - were carried out in the classroom. Results of a priori contrasts based on a randomized block design, and multiple regression analyses showed that specific contexts of analog type and format enhanced analogical transfer for the students in this study. Moreover, given knowledge of the students' group assignment and treatment, the form of the students' prior knowledge was a factor that increased the accuracy of the prediction of successful analogical transfer.

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Whenever the light at the end of the tunnel seemed to dim, he adjusted my perspective.
Thank you, my dearest friend.

My gratitude to Gloria. Her patience and generosity was a constant that never weakened, and I never took it for granted.
Thank you, my sister.

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I INTRODUCTION

It is common for people to draw analogies between their past experiences and the circumstances in a current situation in order to integrate their understanding or solve a problem. In science, teachers use analogies for both these purposes (Gentner, 1983). Analogy is the inference that certain similarities exist between past and present events. Most importantly, the inference implies further probable similarities between these events (Tversky, 1977). The use of analogies can assist science students in accessing what they already know in order to understand unseen natural phenomena. Reasoning by analogy can thus be considered a powerful cognitve heuristic that promotes knowledge acquisition. Thus science teachers use analogies in introductory science courses to help bridge the gap between students' formal science experiences and the complex and sometimes counterintuitive science phenomena introduced in class.

Yet empirical studies in various domains, including science, show that the use of analogy to increase comprehension or solve problems is surprisingly low. When groups tested in these studies used an analog provided by the experimenters prior to attempting to solve a problem task, less than twenty percent did so. Without prompting from the experimenters, few used the openly available analog to understand and solve a novel problem or adapt a problem solution to another appropriate context (Brown,Kane, & Long, 1987; Gick & Holyoak, 1980; Weisberg, deCamillo, & Phillips, 1978).

Researchers seeking to study the use of analogies to improve problem solving or knowledge use have generally taken two approaches: the manipulation of the task or enhancement of the knowledge base of the learner. Both approaches have been taken separately, and almost always in a 1:1 experimental setting.

The task manipulation approach to the study of improving analogical transfer generally involved altering the analogy and its context. In these contextual studies the analogy was situated so that it more closely replicated the target problem in function and form (Crisafi & Brown,1986; Perfetto, Bransford & Franks, 1983). Often performance improved only after expectations of spontaneous analogical transfer were abandoned and hints or prompts were given to subjects to use the available analogs (Gick & Holyoak, 1980). In none of these context manipulation studies were subjects' prior knowledge or the role played by domain knowledge examined.

The knowledge base approach involved the learner's prior knowledge or knowledge base and preparation. Expert-novice analogy performances have been compared in order to establish criteria for training (Larkin & Reif, 1979). Some investigations sought to induce schema formation in their subjects or provided intensive short-term training in the recognition and use of analogies (Alexander, Pate, Kulkowich & Wright, 1988; Bransford, Sherwood, Hasselbring, Kinzer & Williams, 1989; Gick & Holyoak, 1983). However, these knowledge base studies did not explore the context in which the analog is situated, and its effect on whether prior knowledge would be accessed or remain inert. Nor did these knowledge studies take place over extended periods of time, in their entirety, in the classroom.

Thus, two areas not yet paired and possibly implicated in the low level of spontaneous analogical transfer are prior domain knowledge and the context of the analogy task. That is, the problem context as well as the science competence of the learner may both be qualifiers of the use of analogical transfer. Preliminary work in each has been accomplished, but no study to date has used both as independent variables.

This study explores the combined effects of these two areas, task context and prior science knowledge, on spontaneous analogical transfer by adolescents. Specifically, the study examines the effects of two task contexts, the type and format of the analogy on positive analogical transfer in the classroom. The study also examines the effects of general domain competence in science and specific domain knowledge, the kinetic molecular theory, on positive analogical transfer. The subjects are students in an introductory ninth-year high school science course. The definitions of major terms used in the study are given in Table 1.

The next chapter reviews the research that has sought to improve analogical transfer by either addressing the task context or the students' knowledge base, and the most recent investigations that have led to the hypotheses examined in this study. Subsequent chapters describe hypotheses, methodology, and analysis of this study of the effects of both task context and science knowledge base on positive analogical transfer.

Table 1

Definition of Terms

Analogy The inference that certain resemblances between a past event and a current problem imply probable further similarity. (Gick & Holyoak, 1980)

Structural analogy An analogy that possesses the functional relationship to be mapped to the current problem or event. (Gentner, 1983)

Surface Analogy An analogy that possesses syntactic similarities in common with the target problem that are irrelevant for solution.(Gentner,1983)

Base A past event from which one draws the analogy.

Base analog A contextually manipulated base to which the experimental groups will be exposed prior to a target science problem.(as per Gick & Holyoak, 1980)

Target An event or information to be understood or the problem to be solved.(Gick & Holyoak, 1980)

Target problem The kinetic molecular problem to solve following exposure to a base analog. Answers to six target problem questions are the dependent variables.

Positive analogical transfer Using the structural relationships present in the base analog to comprehend a science concept or solve a problem (Gick,1987)

Negative analogical transfer Using irrelevant syntactic elements within the base analog that reduce solution below the level attained by a control group without an analog (Gick, 1987)

<u>Problem format</u> The base analog is presented in the form of a word problem to be solved.

<u>Story format</u> The base analog is presented in the narrative form of a story.

<u>Spontaneous solution</u> Utilizing information from a given base analog for solution purposes without receiving a prompt to do so. (Gentner, 1983)

II LITERATURE REVIEW

Overview

An analogy is considered a valuable teaching mechanism that can be used to integrate understanding for science students (Polya, 1957, Schoenfeld, 1985, Silver, 1985). Formal science, with its extensive vocabulary and its formidable hierarchy of knowledge, requires background knowledge the beginning science student lacks (Carey,1986). Thus a teacher's use of an analogy assumes that functional aspects within the base analog will make clear corresponding functional aspects in the science concept, the target problem.

This chapter will show that despite researchers' assumptions regarding this mechanism, analogical transfer remains demonstrably poor. Experimental evidence of low analogical transfer has been attributed to a variety of specific non-science instructional contexts such as the type or format of the analog. Poor analogical transfer has also been attributed to inadequate prior science knowledge and the resultant inability of a learner to perceive relevant patterns between the base analog and the targeted science concept.

A brief outline of experimental studies of analogies will be described in the first section of this chapter. Components underlying analogical reasoning, identified as the integral processing steps of encoding and mapping the analogy, will follow.

The second section of this chapter will examine research attempts to facilitate spontaneous use of relevant information by manipulating the context of the analog and task. An early experimenter's failure to obtain analogical transfer (Duncker, 1945) was the springboard for current research seeking to improve transfer by analogy (positive analogical transfer), and how to prevent irrelevant yet seemingly salient syntactical elements present in the context of the analogy from producing decrements in transfer (negative analogical transfer).

In the third section, research in how prior knowledge affects analogical transfer will be reviewed. There have been claims that assessments of analogical similarities change as a function of the development of expertise in a specific domain (Sternberg, 1977). Others consider general domain knowledge more predictive of whether or not dimensions in the base analog escape the attention of the science student (Janvier,1987).

Finally, this chapter will summarize findings that are relevant to the study of the effect of task context and prior knowledge on solution by analogy.

Analog Processing

Analogies are learning mechanisms crucial to knowledge acquisition (Brown, 1989; Chi & Bassock, 1989; Gick, 1987). They facilitate the retrieval and application of appropriate experiences to current problems and as such are teaching aids. Observers of introductory science classes can note that teachers often refer to analogies during the course of instruction.

Gentner (1983) defines an analogy as a correspondence between a prior and current event. The correspondences are expected to extend beyond similarities not explicitly stated in the analog. As such, analogical reasoning has been a focus of investigation for cognitive and educational psychologists for many years. Duncker (1945) is the referent point most cited in the current research in problem solving by analogy. He sought to examine how problem solutions are transferred by a series of experiments. The particular problem given to his subjects which interests us here is:

> Given a human being with an inoperable stomach tumor and rays which destroy organic tissue at sufficient intensity, by what procedure can one free him of the by these rays and at the same time avoid destroying healthy tissue which surrounds it?

Protocols of students' brain-storming sessions which followed showed that a few suggested, "...crossing several weak bundles of rays to the tumor, so that the intensity necessary for destruction is attained only here [at the tumor]" (1945, p.19). The other suggestions were deemed inadequate by Duncker as not observing the constraints of the problem. His subjects (university and high school students) were then individually required to solve the tumor problem, but, "...not one was stimulated to use the [correct] solution," even after they received a diagram which showed X-Rays entering from different directions (p.22).

In 1980, Gick & Holyoak ran a series of experiments involving the Duncker problem. Subjects were given an elaborated version of a story (a base analog) about a general who successfully stormed a fortress by deploying his limited forces from varying converging approaches rather than by sending his entire army as a single unit down an easily accessible, but heavily guarded road to the fortress. Following the base analog story, their subjects were given Duncker's tumor problem task (the target). On the average, ten percent spontaneously applied the analogy story to solve the problem. However, if given a prompt by the experimenters to use the fortress narrative to solve the tumor problem, over 60% made the successful transfer of solution. This indicated that their subjects understood pivotal correspondences between the base and the target but did not access what they knew without overt prompts.

From Duncker's time to this, the failure of people to spontaneously and successfully use an openly available analogy to transfer a problem solution they possess has been well documented (Perfetto, Bransford & Franks, 1983).

Current psychologists decomposed the study of analogical transfer into a series of subprocesses in an attempt to understand the reasons underlying non-spontaneous use of analogies in experimental settings. They have referred to concepts in information-processing theory to explain how people make representations and use analogies to make valuable inferences. That is, they have examined how analogies are noticed and encoded, and how they are processed, retrieved and applied.

The description of the following experiential learning sequences has been drawn from the work of several researchers. The sequences are not common to all researchers, but are included here to provide a composite of the steps that appear to be involved in problem solving by analogy. (1) The base analog is a source accessed from memory because the learner has noticed some relevance to the target problem (Thorndike 1913, Thorndyke, 1977). (2) Judgements of similarity or typicality are made between the base and the target, subject to the learner's specific knowledge base. This facility of judgement or coding may become automatized over time and experience (Kahneman & Tversky, 1973,1982). (3) The learner maps components in the base that are perceived to match components in the target based on the organization of the learner's prior knowledge (Gentner,1983). (4) The analogy is judged for soundness. The decision depends upon whether the accumulation of properties within the base analog can be easily transferred to the present event. Soundness requires the analogy to be potentially useful (Sternberg, 1977). (5) The learner represents the problem by abstracting or inferring causal relationships between the two systems, either by generating or testing hypotheses, recognizing constraints or applying a set of inference rules (Holyoak & Thagard,1989). (6) Problem solving components are inferenced and analogical transfer is attempted. The expectation that previouly mapped similarities will continue to play parallel roles generates solutions to the target problem (Gentner, 1983).

Each of these subprocesses has been examined independently because each has been considered to be affected by different psychological factors (Gentner, 1983). Of particular relevance to the present study are the aspects which refer to the learner's perception of task embedded features (the context) and those which refer to prior knowledge, which can connect or separate the components in the analogy from its intended use. These are two aspects that teachers can control or facilitate in classroom settings. While some researchers have manipulated the analogy and its context in experimental settings, and others have focused on their subjects' prior knowledge, the effects of both context and domain knowledge on the degree and direction of analogical transfer have not been examined. They have been selected here on the basis of their classroom applicability.

Context Effects Research

Analog Type: Surface vs Structural

Although real life learning takes place in contexts along a continuum between purely superficial or incidental contexts and deeply pertinent or pivotal contexts, some researchers find it convenient to use dichotomies of surface vs structural contexts (Gentner,1983; Gick 1987). These dichotomies provide the framework for comparing types of analogies.

Structural contexts have two active functions: they both direct action and provide feedback as a consequence of the action (Sherwood, Kinzer, Bransford & Franks, 1987). Over time relevant actions become bound to structural contextual cues that guide identification of a problem's critical features (Schoenfeld. 1985). Surface contexts are passive: they are incidental conditions present during learning which lack utility in solving or understanding the current event. Nevertheless, by their presence, they too may become associated with decision-making and problem solving (Kahneman & Tversky, 1972,1973).

Sensitivity to surface contexts was shown to affect judgement in two related studies. Kahneman and Tversky (1973) asked their subjects to judge what proportion of names on a list were male. The subjects assigned higher proportions to those lists in which the male names were famous. In actuality there were equal numbers of each sex. Tversky & Gati (1982) asked subjects to rate pairs of American cities for similarity. The pairs were rated as very similar when embedded in an international list of cities. When the list was exclusively American, the same target pairs were not judged as significantly similar. Kahneman and Tversky (1973, 1982) reasoned that learners are sensitive to surface similarity for good reason. In everyday living, appearances often correctly correlate with relevant factors in an event. In making judgements under uncertainty learners are wise to rely on surface cues, their only source of information. This sensitivity to context often pays off, reinforcing the link between the superficial cue and the decision taken.

In her earlier work on analogical transfer, Brown (1979) came to somewhat the same conclusion and suggested that these surface contexts may also be the cause of decremental transfer of some analogies (negative analogical transfer). Learners may prefer surface analogs as a guideline for effortless direct mapping. She explained that superficial features encoded during instruction and unallied to the fundamental concepts cannot be the basis for sustained learning. Her suggestion that reliance on surface factors during formal learning produces negative transfer has been well documented (Schoenfeld, 1987). Abstract structural analogs, on the other hand, require greater attention and processing because they lack the superficial similarity and ease of application of a convenient template.

Skorstad, Falkenheimer, & Gentner (1987) gave undergraduates of varying competence 32 short stories to read. Half were key narratives expected to serve as analog bases. A week later they were given two tasks, in which they were to judge pairs of stories for potential soundness or usefulness of match and analogy pairing. They read a new set of stories which were either structurally true analogies to the key stories, surface analogies or misleading false analogies. In the first task they rated the story pairs for soundness of match. All subjects had a significant preference for the true analogies. They explained that relational causal structures were important to them in determining the soundness of the analogy. However, in their second task, the same subjects tended not to retrieve and pair the true analog spontaneously from their previous week's readings, but instead, were more likely to access superficial mere-appearance matches.

In science and math domains, perceived similarity rather than structural isomorphism has been considered by some to be the best predictor of whether a subject will use the solution of a previously worked out problem to solve a current analogous one (deSessa,1987; Laurillard,1979). Specific domains like science have been found by some researchers to initiate a surface approach. Biggs (1982) compared the way science and liberal arts undergraduates approached their respective disciplines. The science students used a surface approach significantly more often than did the liberal arts undergraduates. It appears then that when surface knowledge lacks crucial connections between important scientific ideas, students' knowledge remains inert. This was found to be true for high school freshmen as well (Kirby & Biggs, 1981). Several explanatory hypotheses can be drawn from these studies. Perhaps the science students had no extensive schema on which to graft the new concepts. Or procedural knowledge may be valued by science students because it is pragmatically more effective (Laurillard. 1979). That is, science courses may emphasize "facts" which encourage memorization and reproduction of surface details at the expense of the structural concept. These hypotheses are as yet untested.

In a related study by Gentner (1988) it was shown that the salience of surface details is strong in non-science areas of learning as well, even when subjects are provided with explicit statements about the principle involved. Gentner (1988) trained undergraduates to use mapping in the analogical transfer of information. After the training period one-half of her sample received procedural models of an airplane altitude device, and the other half received, in addition, a causal model that explained the procedural steps of the operation. Within each half of the sample, half were given highly similar gauges during the study and the other half received gauges which varied in surface appearance, but which were identical in function to all the gauges in the study. The group which drew positive analogies most often were those in the group with the causal explanation and the highly similar devices. Those who drew incorrect analogies most often (negative analogical transfer) were the two groups, with or without causal explanation, in which the devices looked dissimilar.

Gentner (1988) assumed that her subjects were distracted by the surface appearance parallels between the training gauges (the base analog) and the target gauges in the study, and misconstrued the task. In order to improve positive analogical transfer, the same subjects were then explicitly told to ignore surface similarities and concentrate on structural, relational matches. This was followed by a brief causal rationale for the operation of the training device. The results of the second part of this study showed the subjects were still influenced by the salient appearance of the gauges and drew incorrect analogies (negative analogical transfer) again.

A possible explanation for the results described above lies in an earlier study of informed vs spontaneous analogical transfer (Perfetto, Bransford & Franks, 1983). When subjects attempt the analogical transfer task first, and then receive a hint to use the analogy, a stream of retrieval events has been encoded that cannot be diverted by the delayed hint or special instruction. Perfetto et al were able to support this hypothesis by giving a second group of subjects the analogy hint at the same time solution was attempted. This group retrieved the structural relations and solved the problem. Thus initial encoding of similar but irrelevant properties is sufficient to block retrieval of correct representative elements in the analogy when these specific instructions, hints, are given after the analogical transfer task has been attempted.

Several researchers agree that science students encode surface elements first but there is little accord as to why. Several reasons have been suggested. Working with cross-cultural populations solving physics mechanics problems by analogy, Fisher and Lipson (1983) believe that students cling to surface features to avoid extra mental effort. Salomon (1988) agrees. Students in his study developed a surface salience heuristic that guided their judgements in problem solving. By automatized mastery of surface cues and resultant procedures they reported they required less mental energy than that needed to search for structural relationships and with equal success in problem solving.

Laurillard (1979) and Solomon (1983) disagree. The best science students, they maintain, use analogies presented in class or self derived to increase deep understanding of science concepts because these analogies reveal causal and structural relationships. When those same students adopt surface level processing, they may have chosen an expedient strategy which requires less of him or her in a particular domain or school setting. Those same students can at other times, encode, retrieve and map structural relationships when it seems appropriate.

Another reason why surface cues are encoded before structural ones is proposed by Schoenfeld (1985). He doubts that students can switch awareness and application of the superficial and the structural effectively. Rather he suggests that formal education (in math and science in particular) involves inert knowledge that is taught, cued and tested with superficial matches between the example or analog and the target problem. For instance, homework problems and test questions closely match examples described in lecture class. Accordingly students have learned that attention to surface matches produces teacher-acceptable results. They have lost any expectation of having the analog or the problem make sense and no longer seek relationships.

In sum, in comparing structural and surface types of analogy, research results indicate that structural contexts direct critical identification of transferable relationships. Attention to surface context has been shown to be adversely associated with transfer.

Analog Format: Similar to vs Different from Target

Another contextual factor relevant to initial encoding concerns the format of the base analog and its similarity to the format of the target event. Duncker (1935) suggested that the format of the tumor problem described earlier included givens he characterized as "functionally fixed." These prevented his subjects from breaking out of a rigid mind-set in order to employ the solution mentioned in their brainstorming sessions or in the diagram he provided. He ruefully concluded that his problem might have been solved by his subjects had he developed the target problem in a less fixed format.

Posner, Strike, Hewson & Gertzog (1982) observed that when past and current instruction were similarly presented, students could detect a regularity of outcomes. Brown, Kane & Long (1987) trained children as young as four to develop a mindset that was not "functionally fixed". They gave the children base analog stories that were homologous to the target event, in format as well as in principles. Their subjects did not fail to use their prior knowledge to recognize problem isomorphs when past and present stories were introduced to the children in the form of problems. Brown,J., Collins & Deguid (1988) suggest that a problem-situated format presented during acquisition gains power as a covert prompt to elicit the correct functional features of the target problem. That is, if relationships in the base analog are initially encoded in an inquiry or problem solving manner, retrieval of both analog and solution may be enhanced during analogical transfer.

A series of studies have examined format and its affect on analogical transfer in problem solution. These are not analogy studies, but they have implications for the study of analogical transfer. Perfetto, Bransford and Franks in 1983 gave their subjects a series of simple insight problems (some might call them parlor puzzles), such as,

> A man who lived in a small town married twenty different women. All are still living and he never divorced a single one. Yet he broke no law. Can you explain?

Not only could the subjects not solve the puzzle, they did not raise their performance level above that of the control group even when the puzzle was preceded with declarative sentences that included the solution and the word "clergyman" as well. Viewed within the framework of analogy studies, the declarative sentences (the base) gave the subjects the background knowledge needed for solution but not the awareness that substitution of the word "clergyman" for "man" presented a new representation of the riddle (the target problem). When advised that the declarative sentences could help solve the riddle, the subjects accessed the solutions.

Seeking to improve analogical transfer using the same puzzles, Lockhart, Lamon, & Gick (1988) chose to alter the format of the base information. In a series of experiments their subject received one of two treatments. One group somewhat duplicated the Perfetto _et al_ (1983) experimental group except that the declarative acquisition condition was repeated twice. The second group received the information as a problem followed by a clue that could solve the puzzle. This latter group solved the puzzle significantly more often than did the repeated declarative acquisition group. Following the problem solving phase all subjects were given a free recall test of the base sentences that preceded the puzzle. No difference was found between groups, ruling out the possibility that the puzzle-acquisition encoding conditions increased memorability of the solution information.

Other researchers have examined how positive analogical transfer is enhanced when both the analog base and the target concept are introduced in parallel fashion in the format of a problem. Results suggest that when both base and target have the same acquisition format, solution by analogy increases significantly. For example, Adams, Kasserman, Yearwood, Perfetto, Bransford and Franks (1988) described how subjects who acquired knowledge in a problem solving way successfully used the information as a tool.

In early analogy studies the acquisition task usually took the form of a story, such as the fortress analog (Gick & Holyoak, 1980). As such, it was quite dissimilar to the later task of solving a problem. This may have affected the processing required of the subjects during analogical transfer. It conditonalized the information in the narrative story of the analog, leaving the subjects unprimed for the problem format of the analogical transfer task which followed, thereby reducing positive analogical transfer performance.

In the Adams et al (1988) study, two groups of undergraduates were given 10 statements to read, some of which had been used in the Lockhart, Lamon, & Gick (1988) study. However, this design eliminated repeated declarative sentences and base information formatted as a problem followed by a clue to solution. Instead, nearly syntactically isomorphic sentences were made into treatment conditions with the help of a comma and clause reversal. For instance, Group A's statements were factual, i.e., "Before a baseball game there is no score" or " A minister marries several people each week". Group B received the same information, but each sentence was composed of two clauses, i.e.,"All baseball games have no score, before they begin." or "It is possible to marry several people each week, if one is a minister". The authors suggest that Group B's acquisition sentence had a quizzical orientation in the first clause that introduced the problem, followed by the solution or explanation in the second clause.

Adams et al (1988) hypothesized that this format would direct the representation of the problem. That is, it would induce a problem-solving mind-set during acquisition that would in turn, lead to positive analogical transfer. The results supported their hypotheses. Group B was significantly more successful than Group A in spontaneously accessing a solution to the target problem which followed sometime later, i.e. "Nick the Greek can accurately predict the score of a baseball game before it starts. How does he do it?" or "In one town in Texas a man legally married several women without divorcing a single one. How is this possible?" Adams et al concluded that high similarity between the encoding process of the base analog and the processes invoked while solving a target problem will lead to positive analogical transfer.

Their study did not address rival reasons for the analogical transfer success. There was no control for the longer, playful, conditional if-then, more interesting sentences for group B. Nor was it clear what the operating agent in the two clause sentences was: were the base analog sentences similar in format to the target problem as they suggest? or did the comma and the reversed emphasis establish a momentary obstacle to skimming, a cognitive burr as it were that encouraged reader attention? Nor was their acquisition condition a problem. Like Lockhart, Lamon & Gick (1988) the acquisition sentences were declarative too. However that may be, the results of the study generally suggest that access to analogies and hence inert knowledge can be activated when the format of the base analog is manipulated to encourage processing that is similar to the way the target problem should be processed.

Although the reasons for the success of surface salience or processing format similarities on problem solving by analogy are not clear, perceptual similarity in both syntactic and acquisition format has been shown to have an effect on analogical transfer. While surface salience, the contextual variable discussed earlier has been shown to produce negative analogical transfer, problem format, the second context variable just described, has been shown to produce positive analogical transfer.

In all the context studies described above, learners were expected to go beyond the surface of the text in order to transfer knowledge by analogy. In examining the problem of enabling subjects to draw on information in situations where it is potentially relevant, the general or specific knowledge possessed by the learners was not examined. It is currently assumed that learners with high knowledge can better integrate components of a problem than students with low knowledge. This is because high knowledge subjects are assumed to possess schemas which guide their attention to certain contextual determinants and away from superficial data (Bisanz & Voss, 1981, Gick & Holyoak, 1983). The studies of surface similarity and of format, described earlier in this section, did not consider whether prior knowledge increased access by imposing organization on the base analog, the target problem and their contexts. The next section discusses those studies that remedied this omission and examined to what extent prior domain knowledge governs analogical transfer.

Studies of Prior Knowledge

Another area of study in analogies has examined the amount and types of knowledge acquired prior to the analogy task and their effect on positive analogical transfer (Gentner & Landers, 1985; Gick & Holyoak, 1983). These studies recognize close ties between transfer by analogy and schema formation. Most studies do not involve the science domain, nor do they establish ecological validity, but are included here to demonstrate pertinent areas of research.

Schema are cognitive structures containing knowledge within a particular domain. They guide attention, encoding and retrieval, and so direct the processing of information (Thorndyke & Hayes-Roth, 1979). Learners scan for relationships which already exist in their schema in order to map components of the base analog onto the target. Relational correspondences will then be extended to bridge gaps in their knowledge, and this generates solutions (Gentner & Toupin, 1986; Sternberg 1977).

It has long been suggested that a weak knowledge base with respect to the problem domain is a causal agent of poor analogical transfer. Duncker (1945) stated that a good mathematician possessed a coherent theory which enabled him or her to plumb the properties of an analog on an abstract level. Subjects who failed to realize the relevance of a previous problem did so due to the absence of prior knowledge and were therefore unable to extricate themselves from superficial perceptions.

Duncker's hypotheses have been supported by researchers of novice-expert paradigms, who recognize that analogies must, of necessity, imply conditions not explicitly stated in the problem. Only a strong knowledge base can assist the learner in recognizing which properties of the analog can satisfy those conditions (Chi & Bassock, 1989). Some researchers suggest that specific knowledge about the problem domain is essential for intelligent performance (Reed, Dempster & Ettinger, 1985). Others consider a broad general domain background more effective than a specific one (Brown, Collins & Duguid, 1988). Few empirical studies have compared the effect of high and low specific domain knowledge on analogical transfer. Fewer still characterize "high" and "low" or "good' and "poor" a priori.

Domain Specific Knowledge

Gick and Holyoak (1980) showed that few subjects solved

Duncker's tumor problem when it was preceded with the fortress analog. In an experimental setting they subsequently (1983) increased positive transfer by providing two analogs, with identical concepts but different syntactical form, prior to the target task. The increase in analogical transfer was due to intensive exposure to the same concept which, the authors explain, provided rich specific knowledge and induced schema that did not exist before. They hypothesized that aspects of events in the two analogs were encoded as connections. Multiple exposure to the principle involved established a specific knowledge base which supported positive analogical transfer.

Chi & Bassock (1989) observed individual science undergraduates from an introductory physics class solving physics problems after exposure to previously-solved analogous examples. Solution explanations were recorded during and after the task. Most students used the previously solved examples as their analogous base. Those students labelled "poor" by the team spent much time re-reading the examples. Their protocols revealed that this was done in an attempt to map the worked out solution _en toto_ . Their solution explanations were few and they detected comprehension failure rarely, and then only when they could not follow the math manipulations. The "good" students identified the examples as analogous to the target problem and relied on them only during the initial solution attempts, except to monitor their progress by examining specific sections. Their protocols revealed a rich specific knowledge base, because the learners were able to relate the analogous problem to the target by explaining how the analog was an instantiation of a science concept not explicitly stated.

In a related study, "poor" students were given intensive instruction in a specific mathematical procedure prior to exposure to problem solving by analogy. They showed improved analogical transfer (Kolokovsky, Hayes & Simon, 1985). They were exposed to many examples of a particular math strategy. Once it was ascertained that the learners were familiar with the fundamentals of the math principle, performance in analogical transfer improved.

The Chi & Bassock study (1989) however, did not explain how the "good" undergraduates gained that specific knowledge base. It also assumed that explicit verbalization is a sufficient converging measure of understanding of a worked out problem. Neither of the last two school-domain studies took place in the classroom. Moreover, the "good" and "poor" characterizations in both of the last studies were defined post hoc based on the learners' problem solving success during the experiment. This latter procedure does not accomodate other hypotheses, other than analogical transfer, for successful solution, and provided no generalizable criteria for predicting "good and poor."

Domain General Knowledge

Researchers of prior knowledge and analogical transfer do not agree on the type of prior knowledge needed for positive analogical transfer. Some researchers have argued that domain specific knowledge was too restrictive. Rather than facilitating transfer, specific knowledge could be characterized more as a source of automatic responses to very familiar problems than a true transfer of knowledge (Larkin & Reif, 1979; Schoenfeld, 1985). Lampert & Clark (1990) and Simon (1973) found experts were only able to manipulate structural principles in familiar situations, where stereotypical circumstances evoked routine responses. That is, experts had developed a repertory of generic responses to variations within a narrow framework in which they were extremely experienced. The experts' schema was automatically activated when a problem -type was recognized, which in turn terminated the search for solution.

Brown (1985) disagrees. She feels it is the experts who have the more flexible approaches to learning, whereas novices lack cognitive maturity and are deeply dependent upon specific knowledge and particular contexts in the learning environment.

Spencer & Weisberg (1986) examined this argument by replicating Gick & Holyoak's 1983 study, which used multiple analogs to induce specific knowledge schema. Spencer and Weisberg then varied one aspect of the replication. Their subjects were removed after the experimental 1:1 training condition with the experimenters, to the classroom to solve the distractor and target problems in a whole group setting with their teacher. No improvement in analogical transfer, such as that reported by Gick & Holyoak, was obtained. Spencer & Weisberg hypothesized that narrow expertise with a researcher in one experimental setting was insufficient to ensure analogical transfer of that expertise to non-training, specific task situations in classroom settings.

This had been observed earlier by Newell (1980). Newell felt specific schema encourage narrow strategies that are easy to teach but cast a "penumbra of generality ". That is, such narrow expertise is of limited use in analogical transfer if the new context shifts slightly from the original.

Several studies suggest that general domain knowledge may be more predictive of positive analogical transfer than domain specific knowledge. Knowledge rich in relationships and associative links may support enhanced accessibility of that knowledge in appropriate situations, as Brown suggests.

Broad knowledge in one or more domains increases a learner's ability to use formal knowledge structures in a variety of problems. Brown (1989) observed this with very young children whom she trained to recognize analogies and their value in further learning. She proposed that repeated exposure to analogies in disparate domains would free the structural principles from their setting and thereby increase generalizability. Children learn to make finer discriminations in their comparison processing (mapping) with age. Recognizing that developmental differences required careful calibration of levels of task difficulty, she piloted analogs and problems that were understandable and easy to apply. Those analogs chosen for her study (1989) were calibrated to meet the same solution rate as those found by Gick and Holyoak in 1980. Only 10-20% of the four year olds in a pilot study could solve the problems spontaneously. This is the same proportion of spontaneous positive analogical transfers Gick and Holyoak reported in their analogy studies with adults (1980,1983).

Brown gave five children (average age 4) a series of play situations in which a pivotal factor in the target problem, a piece of paper, was prominent in each situation, under various guises of utility. In the training examples prior to the target problem, the paper was alternately used as a carpet, a bridge or a telescope. The children demonstrated significant analogical transfer to the target problem which required a piece of paper to be used in a way (as a pea shooter) not previously encountered in the training examples for solution.

Prior to the same target problem, her control children were given extensive experience with drawing analogies, and identical play situations, but the piece of paper was presented in only one habitual function, for writing. Denied an expanded range of potential applications of a pivotal factor (a piece of paper), the controls were unable to use the analog to solve the problem. Brown suggested that broad knowledge, within the range of a young child's competence, reduces Duncker's "functional fixedness" and increases one's flexibility in noticing and applying solutions mapped from everyday and school analogies.

In comparing the effects of domain specific vs general domain knowledge on analogical transfer, Alexander, Pate, Kulkowich & Wright (1988) trained two groups of students (high school and college) in domain specific knowledge (immunology), analogical reasoning, and strategies in how to spot and use analogies. Prior to instruction, the students were identified as "high" or "low" general domain competent based on criterial science assessment tests devised for the study. "Highs" and "lows" were either 1/2 a standard deviation above or below the sample mean. A week prior to training all students were pretested for domain specific, analogy and strategies knowledge. Training then took place for three consecutive days. Post-tests were made the following week in two areas of instruction: immunological terminology and solving a target problem after reading the story that the experimenters provided as a base analog in immunology.

Instruction in analogical reasoning and strategies in how to recognize science analogies produced no significant effect on any student's transfer of knowledge by analogy. Domain specific training did have a significant effect on vocabulary posttests of the low science competent only. The factor which best predicted how well students solved a science problem in immunology by analogy was their pre-intervention general science competence assessment.

One can take issue with Alexander et al's decision to use vocabulary as an indicator of domain knowledge, or with the comparatively brief instructional period (3 days), but this study is significant to the research proposed in this paper on other grounds. It identified "highs" and "lows" a priori on the basis of general science competence to better assess the effects of specific training. It compared differing general competence levels in science and the effects of limited domain-specific instruction on solving an immunology problem via an analog base. It also carried out instruction in the dynamic context of a classroom rather than in a 1:1 experimental situation common to most other analog studies.

Summary

Five conclusions related to the present study can be drawn from the literature. First, although analogical transfer is considered a time-honored strategy for problem solving and knowledge acquisition, only 10-20% of the subjects exhibit spontaneous analogical transfer from base to target in typical studies. Second, contextual elements present in the base analog may either improve solution by analogy (positive analogical transfer) or reduce transfer below the performance of a control group given no analog at all (negative analogical transfer). Third, of the contextual factors examined, analogy type and analogy format appear to be significant factors in improved analogical transfer performance. A base analog in a problem format vs a base analog in a story format holds promise for positive analogical transfer. And, surface-similar base analogs irrelevant for solution are often sufficiently salient to produce negative analogical transfer (see Table 1).

Fourth, prior knowledge appears to help learners construct a representation of the target problem. The degree and direction of analogical transfer may be predicted by the prior knowledge possessed by students. This knowledge may be domain specific or domain general. Those who possess the latter form of knowledge are assumed to have developed extensive schema that are sensitive to diverse applications and relationships, the very sensitivity required in analogical transfer.

And fifth, few analog studies take place in the classroom, when they involve subject-matter learned in school as the focus of the analogical transfer task; and none have examined learners over extended periods of instruction.

The present study explored the use of analogical transfer by students in introductory high school science. The subjects were urban, adolescent science students in freshmen high school science classes. They received three weeks of instruction in a specific science concept (see Appendix A) in the classroom by exerienced science teachers prior to exposure to one of four experimental base analogs. A control group exposed to the same science instruction received no analog at all prior to solving the target problems.

The specific analogs were varied by type and format. The analogy type was either structurally appropriate or syntactically isomorphic to the target. The analogy format was either a traditional narrative story format or a problem solving format. The students were instructed first in a particular science concept within the state curriculum. They were then tested on their knowledge of the specific concept, as well as on their general science knowledge. Both of these knowledge assessments were used to determine the contribution of these forms of prior knowledge in predicting analogical transfer.

Science instruction relevant to the design and topic of the study, as well as assessments of prior knowledge were carried out in the classroom. The classroom was also the setting for the intervention namely, the analogical transfer task. The intervention permitted examination of the roles of two context variables, format and type of analogy, on the analogical transfer of science knowledge.

III HYPOTHESES

The design of the study is given in Table 2. There are four experimental groups and one no-treatment control. The base analog appears in one of four contexts shown as group 1, 2, 3, and 4 in Table 2. The context is analogous in either structure or surface to the target problem to be solved; and is given in either problem or story format. All Ss responded to the same post-intervention target problem measure. Analogical transfer of problem solutions in science was assessed by responses of each group to the target problem questions.

1 Main effect: Problem vs Story format

Subjects in the problem analogy format (Groups 1 and 3) will have a significantly higher mean score than subjects with a story format (Groups 2 and 4).

Spontaneous use of an analogy to solve a problem is enhanced when both analogy and test materials are processed in a problem format (Positive Analogical Transfer).

2. Main effect: Structural vs Surface Type

Subjects given a structural analogy (Groups 1 and 2) will have a significantly higher mean score than subjects given a surface analogy (Groups 3 and 4).

Table 2

Design of the Study: Distribution of Type and Format of Analogy

	Analog Type		
Analog Format	Structural	Surface	No Analog
Problem	Group 1	Group 3	-----
Story	Group 2	Group 4	-----
No Analog	-----	-----	Group 5

An analogy increases transfer of knowledge when it shares structural relationships in common with the target problem. (Positive Analogical Transfer).

3. Within group: Structural Type in Problem Format
   Subjects receiving an analogy of a structural type in a problem form (Group 1) will have a significantly higher mean score than the other experimental conditions of analogy type and format, or control (Groups 2, 3, 4, and 5).

   The combination of structural type and problem format of the base analog provides the greatest support for the transfer of knowledge (Positive Analogical Transfer).

4. Control: No analog vs surface analogs
   Control subjects will have a significantly higher mean score than students in the surface analogy conditions (Groups 3 and 4).

   Surface properties common to both the base analog and the target problem, but irrelevant for solution, will interfere with successful solution by analogy (Negative Analogical Transfer).

5. Domain Knowledge Effect: General and Specific Knowledge

Given knowledge of a student's treatment group, the accuracy of prediction of successful transfer of specific science knowledge by analogy will be increased by knowledge of the student's score on the general domain competence test (RCT).

This hypothesis examines whether domain knowledge, assuming the existence of broad schema, will be more highly associated with analogical transfer of science concepts and problem solutions taught in the classroom than will specific domain knowledge. That is, general rather than specific science knowledge may assist the the learner to a greater degree in recognizing analogous problem solving tasks in story formats or in avoiding seemingly analogous surface similarities for solution purposes.

IV METHODS

The study examined the effects of two task contexts and prior science knowledge on science problem solving by analogy for students taking a freshman high school science course. The task contexts refer to the form and type of analog presented. Prior knowledge was measured on two assessment tests. General knowledge of science was tested by a standardized New York State Education Department (NYSED) Regents Competency Test (RCT) in Science; specific science knowledge by a school-wide test on the kinetic molecular theory (KMT). Transfer of science knowledge by analogy was assessed by scores on a science problem task. Table 3 outlines the timing of the experiment.

Subjects

The students comprised all the freshmen science classes in an urban high school. Those excluded from the freshmen science pool from which this study's students were drawn were those who were not in NY State for each of grades 7, 8 and 9, or were absent from either the specific (KMT) or general (RCT) science knowledge assessments. Moreover, prior RCT failure students took part in mandated remediation programs and were not included in the subject pool.

Thus those that participated in this study were freshmen who experienced at least three weeks of specific science instruction and two weeks of review during the semester in which this study took place. In addition they were the only ninth graders who had completed three years of the uniform NY State science

Table 3 TIME LINE

	TIMING	STUDENT ACTIVITIES
1	Prior to experiment	Instruction in NY State science curriculum during grades 7 - 9.
2	Two months prior to intervention	Three weeks of instruction in specific science concept (kinetic molecular theory) in classroom followed by two weeks of review for final state RCT exam.
3	Three weeks prior to intervention	Final exam of semester which included domain specific assessment (KMT) conducted in the classroom.
4	Two weeks prior to intervention	Statewide general science assessment (RCT) administered in class.
5	One week prior intervention	Students who took both KMT and RCT assessments were ranked on their RCT score.
6	One week prior to intervention	Each student from consecutive ranked groups of twenty was randomly assigned (on paper) to 1 of 5 treatment groups in a randomized block design while remaining in a whole-class configuration.
7	Analogy intervention (double blind)	Subjects in treatment groups (N = 266) read, in class, an analog (groups 1-4) or no analog (control group 5) and then attempted to solve the target problem.

curriculum from grades 7 to 9 and sat for the state mandated domain general RCT test.

Procedure

During the last instructional half of the semester, all students in eleven freshmen science classes received three weeks of study in the kinetic molecular theory by their assigned science teachers, see Appendix A. The theory is part of the curriculum and the topic of the analogy problem intervention. Instruction was followed by two knowledge assessments separated by approximately one week and carried out by the same teachers in the classroom. The first, on domain specific knowledge (KMT), was tested with a 20 item exam on the kinetic molecular theory. It was a section of the semester final to ensure optimum attendance and uniform focus of instruction. Appendix B contains the twenty item test.

The following week students took the second knowledge assessment: a 70 item Regents Competency test (RCT) in science based on a three year state curriculum in science. After the classroom teachers graded both exams, students who took both tests (N = 300), were then ranked on their general science competency as reported by their scores on the RCT.

A randomized block design was formed to reduce experimental error in each of the treatment groups. The design increased the homogeneity of each of the treatment groups as regarding prior general science knowledge. The first-ranked twenty students were randomly assigned to a control group or one of the four intervention groups. Each succeeding block of twenty ranked subjects was similarly assigned to one of the five groups. Thus each student in each block of twenty was randomly placed in one of the experimental or control groups (Table 2). In this way, fifteen randomized blocks by five groups were obtained. This was intended to ensure uniformity of prior domain-general knowledge for each of the five groups.

Because the science classes were left unaltered and the students were not physically grouped in this double blind study, their names were later affixed to the intervention instrument for each of the group conditions to ensure accurate distribution based on their RCT rank.

Approximately a week after the RCT the students participated in the analogical transfer of knowledge intervention. This intervention was administered by their science teachers in the science classes. Students absent from either the KMT or the RCT tests remained in the science classes but did not take part in the intervention. Their names were on a self-paced drug opinion questionaire provided by their teachers. The time to complete this questionaire was equal in completion time to the intervention.

All students in the classroom (whether taking part in the intervention or not) were told that the work before them would provide the science department with information required for the coming year's freshman science courses. They were asked to do their best even though they had already taken the RCT and were told that their responses would in no way affect their course grade. None chose the option of not participating in the study. Pilot trials suggested that the analogy intervention would not exceed 20 minutes to complete; however there was no time limit for completion. All students finished the task within a half-hour.

Those students assigned to one of the four intervention groups read a base analog passage, see Appendices D-G. The base analog appears in one of four contexts: analogous in structure or surface to the target problem to be solved, and in either a problem or story format, see design in Table 2. The students were first asked to rate on a 5-point Likert scale how well they understood the passage and how difficult a passage it seemed. These questions were designed to direct the Ss attention to the analog and ensure that it was read and evaluated. They were given no hint or prompt to use the base as an aid in answering the science problems which followed.

The control group differed from each of the four experimental groups in one respect only. Controls were not given any base analog to read. They read instead a one page fact sheet on drugs.

The dependent measure instrument, identical for all the groups, including the control, was a 250 word passage about a particular aspect of a hypothetical high school science experiment (Appendix I). It concludes with a familiar school-based problem of how to interpret best what occurred from the reading, for a lab notebook writeup. All groups, including the control, then answered six multiple choice questions (four choices for each question) required for the lab writeup. The six questions were chosen from the RCT science syllabus. The base analog was designed to tap analogical transfer of kinetic molecular theory knowledge the students had studied two months prior, see Timeline in Table 3.

Design

The design of the study was based on five groupings within a randomized block design. This design was chosen to control for prior knowledge, a variable that has been hypothesized to influence analogical transfer. By identifying prior knowledge as a variable that may affect the outcome measure before assigning subjects to treatment groups, subsequent analyses are more sensitive to the effects of the interventions.

Subjects were first ranked on prior general science knowledge scores. The first twenty highest-scoring subjects comprised the first segment or block. Within each block subjects were randomly assigned to one of five treatment groups. Subjects in each subsequent ranked block of twenty were similarly randomly alloted to one of five treatments. Thus, on the basis of general science knowledge criteria, ranked subjects were blocked and then randomly assigned to one of the intervention groups.

The first four groups were constructed by forming a cross of two levels of analogy type with two levels of analogy format. If we consider just these groups the design can be viewed as a 2x2 factorial. The fifth group, the control, lacked both factors. Thus the overall design is not a true factorial one (shown earlier in Table 2).

The pre-intervention knowledge involved includes (1) general science competency as assessed in a statewide exam (RCT) and (2) domain specific knowledge as assessed in a school-wide uniform exam (KMT).

All aspects of the double-blind experiment were carried out by the regularly assigned science teachers in the science classroom. Thus within each science class there were students assigned to each of the five groups. At no time were science classes physically rearranged nor was identification of group assignment made known to teachers or students.

Group 1 received a structural base analog presented as a problem prior to attempting to solve the target problem (Appendix D). Group 2 read the same structural base analog but in the traditional form as a story (Appendix E). Group 3 received a surface base analog presented as a problem prior to the target problem (Appendix F) and Group 4 read the same surface base analog but in story form (Appendix G). Group 5, the control read no analog prior to the target problem. The dependent variable for all groups was the Ss responses to questions to the target problem which concerns transfer of knowledge of kinetic molecular theory.

Materials -Instruments

Specific knowledge assessment of kinetic molecular theory

A 20 item, multiple choice test constructed by the researcher (see Appendix B) was used to measure knowledge of the kinetic molecular theory (KMT). It was administered by the classroom teachers as part of the final exam to ensure maximum attendance. A reliability study made on 20 students not part of the target sample produced a reliability coefficient of .76, the standard deviation was 2.819 and the standard error of measurement was 1.36.

To indicate how the domain specific assessment relates to the analogy and target problem, a test map was made by four science teachers (see Appendix C). Test items were mapped on 6 categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. The items in the first half of the test mapped more heavily on the first 3 categories, while items in the last half mapped on the latter 3 categories.

All of the five experienced science teachers asked to rate this instrument, (four of whom constructed the test map) found the 20 item test a satisfactory test of kinetic molecular knowledge for science freshmen who have completed the RCT course. Eighty percent felt a score of 70% or better (14+ correct) was necessary to demonstrate knowledge of the theory (one teacher felt 65% was acceptable). All of the raters felt a majority of their students could demonstrate acquisition of the theory by obtaining a score of 70% or better. One of the rating teachers taught approximately thirty of the students participating in this study.

General knowledge assessment - the RCT/Science Test

This test was developed by the New York State Education Department (NYSED) and field tested for three years before it became a requirement for a high school diploma for all students of New York State graduating after 1990. It is administered to 9th graders in NY state who have taken the uniform 7 - 9 grade science curriculum on which the RCT/Science is based. The percent of NYS students who passed the RCT/Science in 1990 was 68% and in NYC it was 65%. The NY State Board of Regents Division of Science Testing and Evaluation supplied the reliability data. The Kuder-Richardson reliability was .85 for the RCT/Science (Appendix J).

Students exempted from the RCT/Science and its requirement for a diploma are those who did not attend a school in New York State for one or more years during the 7th -9th grades. Such exempted students were not part of the study.

According to NYSED guidelines, a score of 46+ in the RCT/Science indicates science competency and meets the diploma requirement. The top score possible is 70. The test measures concepts and problems included in the proposed study. Because it tests the students' ability to apply, analyze and predict, a score of 45- indicates, according to NY SED, that the student is not yet competent in science and must receive remediation in order to take the RCT/Science when next offered by the state. It is expected that the RCT/Science scores will increase with further appropriate instruction. Students in remediation were not part of this study.

The base analogy - the treatment

The base analog devised for the study is the source of information from which the student may spontaneously draw an analogy to solve the target problem. Spontaneous solutions are those in which the student has received no hint or advice to use the base analog for solution. The analog was set in two different contexts of type and format, each of which possesses two levels. That is, the analog type may be similar in structure or surface to the target problem to be solved. The format may be in either a story or problem form.

A structural analog possesses relationships that relate functionally to the solution required by the problem (see Appendix K). A surface analog possesses superficial syntactical similarities but lacks the elements needed to solve the problem (see Appendix L). The narrative story format is the traditional way an analog is presented prior to the transfer, whereas the problem format of the base analog parallels the problem format of the target problem.

Students randomly assigned to the control group did not receive this part of the instrument.

Transfer of Knowledge Assessment

The target problem common to all groups, including the controls, is a 250 word reading passage and series of six multiple choice questions about a familiar school-based experience in writing up a lab problem (Appendix I), K-R 20 reliability was .34 The questions were based on past RCT questions. Six experienced science teachers of High School Chemistry or Biology who taught the freshman science curriculum and have prepared freshmen classes for the RCT/Science in the past participated in the rating the relationships between the four analogs and the target problem study for the assessment instrument. Only one of the rater teachers taught students in this study.

All rated the structural type base as analogous to the target problem and the problem format as analogous to the target problem format. All six also rated the relationships within the structural base as analogous to the relationships integral to the kinetic molecular theory. Five of the six teachers (83%) rated the surface type base as superficially analogous to the target problem. And five out of six rated the solutions required to successfully transfer science knowledge to the target problem as indices of domain specific knowledge of the kinetic molecular theory (Appendix B).

Data Analysis

Each of the first four hypotheses was analyzed as a priori comparisons of performance means, using as an error term the mean square within cell, from the treatment by block design. A randomized block design was used and the experimenter randomly assigned ranked groups of twenty subjects to each of the four treatment or control groups. Each subsequent ranked group of twenty subjects comprised a block, resulting in fifteen blocks by five groups.

A series of four contrasts was constructed. For the first hypothesis concerning analog type, the means of the scores on the transfer dependent variable for groups 1 and 2 (structural types of analogs) were contrasted to the means of groups 3 and 4 (surface analogs). The second hypothesis concerned analog format so the means of groups 1 and 3 (problem format) were contrasted to the means of groups 2 and 4 (traditional story format). The third hypothesis contrasted group 1 (a structural type of analog in a problem format) means to those of all the others. These first three contrasts were designed to test positive transfer from analog to target problem.

The fourth hypothesis compared the control (no analog) means with those of groups 3 and 4 (surface - type analogs). This last contrast was designed to test for decremental transfer from analog to target problem (negative transfer).

Ho1 $(u1 + u3)/2 = (u2 + u4)/2$

Ho2 $(u1 + u2)/2 = (u3 + u4)/2$

Ho3 $u1 = (u2 + u3 + u4 + u5)/4$

Ho4 $u5 = (u3 + u4)/2$

The coefficients for the preplanned comparisons are:

		Treatment groups				Control
		1	2	3	4	5
	I	1	-1	1	-1	0
Hypotheses	II	1	1	-1	-1	0
Comparisons	III	4	-1	-1	-1	-1
	IV	0	0	-1	-1	2

The fifth and last hypothesis examined the question of whether the nature of pre-intervention science knowledge (general science competence assessed by the RCT, and domain specific knowledge assessed by the KMT) increased the prediction of transfer once a subject's treatment assignment was known. Multiple regression analysis was used to determine if prior knowledge (domain specific and/or domain general) increases prediction of positive transfer by analogy after knowing to which of the five groups the subjects were assigned. The significance of the B5 and B6 terms in the equation below were tested with a forward procedure.

$$Y = bo + b1x1 + b2x2 + b3x3 + b4x4 + b5spec + b6gen + e$$

Y = The score on the target problem question

x1 : Where x1, Ss are in the structure/problem group, zero for all others

x2 : Where x2, Ss are in the structure/story group, zero for all others

x3 : Where x3, Ss are in the surface/problem group, zero for all others

x4 : Where x4, Ss are in the surface/story group, zero for all others

b5spec : Score on specific domain assessment (KMT)

b6gen : Score on general domain knowledge assessment (RCT)

V RESULTS

The first portion of Table 4 presents the means and standard deviations for the measures of pre-intervention knowledge, both general and specific, for each of the five groups (N=266). The general science competence (RCT) and the specific science competence (KMT) means range from 53.20 to 53.94 and 13.48 to 14.05, respectively. As per the randomized block design, subjects were ranked on their RCT score. Each ranked subject, within each block of twenty, was randomly assigned to one of the four treatment and control groups. This produced a matrix of five groups by fifteen blocks. Thus the five groups did not differ pre-experimentally in their general science competence scores as indicated by mean scores that are relatively the same across all groups.

The second part of Table 4 presents measures of post-intervention knowledge (analogical transfer). The means of the dependent variable, from low to high, are 3.15, 3.39, 3.44, 3.56 and 4.21 for groups 4,2,5,3,1 respectively. Few of the students in any of the groups answered the target questions perfectly (17 out of 266), although there were twice as many perfect scores in group 1 as compared to the control.

Subjects who had taken both prior science knowledge assessments (the KMT and RCT competency tests) but were absent from the intervention constitute missing data. The loss of these subjects (n = 34) resulted in unequal cell sizes in the randomized 15 block by 5 group design (see Table 4).

Table 4

Means and Standard Deviations for General & Specific Science Knowledge Tests & Analogical Transfer Test

	Groups (N=266)				
Knowledge	1(Exp)	2(Exp)	3(Exp)	4(Exp)	5(C)
n	56	51	55	52	52
Pre-Intervention					
General Science (RCT)					
M	53.75	53.68	53.69	53.94	53.20
SD	7.40	7.83	7.64	7.36	7.52
Specific Science (KMT)					
M	13.73	13.60	13.54	13.48	14.05
SD	3.58	3.80	3.48	3.18	3.34
Post-Intervention					
Analogical Transfer					
M	4.21	3.39	3.56	3.15	3.44
SD	1.26	1.28	1.21	1.34	1.19

Group 1 = structural-type analog phrased as a problem

Group 2 = structural-type analog in traditional story format

Group 3 = surface-type analog phrased as a problem

Group 4 = surface-type analog in traditional story format

Group 5 = control (no analog)

The first hypothesis stated that those receiving a structural analog which shared relationships and solutions in common with the target science problem (groups 1 and 2) would obtain a higher mean transfer score than those students in groups 3 and 4 who read a superficially similar surface analog prior to the target problem. The effect was significant, $\underline{t}$ (191) = 2.834, $\underline{p}$ <.001. The denominator for the $\underline{t}$ was obtained from the mean squares within cell term. The denominator (1.10) was computed from the treatment (groups) by block randomized block design.

The second hypothesis tested whether those groups reading their base analog in a problem format (groups 1 and 3) would more likely show positive analogical transfer than groups 2 and 4, who read their base analog in a traditional story format. This effect was significant, $\underline{t}$ (191) = 3.940, $\underline{p}$ <.001. The third hypothesis stated that students in group 1 (who read their structurally analogous text in a problem format) would obtain a significantly higher mean score on the target questions than would all the other groups. This effect too was significant, $\underline{t}$ (191) = 4.793, $\underline{p}$ <.001.

The results of these first three contrasts testing hypotheses 1 - 3, suggest that for this population science analogs phrased as problems rather than story texts, and analogs which reflected the deep structural relationships of the target problem, increased the likelihood that science knowledge would be analogically transferred two months after instruction. Moreover, if these two aspects were both observed simultaneously, positive analogical transfer was supported.

A fourth hypothesis tested for negative transfer. It examined whether the mean score on the target questions achieved by the surface analog groups 3 and 4, would be lower than that of the control group which received no analog at all prior to answering the target questions. This hypothesis was not supported. Students who read the surface analog performed less well than the control group (see Table 4), but the effect was not significant: $\underline{t}$ (191) = .431.

The fifth and last hypothesis stated that because general science competence (RCT) reflects a cohesive and integrative foundation of knowledge, especially in science, it would be more significantly related to positive analogical transfer than would domain specific knowledge (KMT).

A multiple regression analysis was used to determine whether general (RCT) and/or specific (KMT) science knowledge added to the prediction of the dependent variable, given knowledge of group membership. A forward selection procedure was included to see whether pre-intervention knowledge variables (specific and/or general) would increase positive analogical transfer prediction given that group membership was included in the model.

When the significance of the B5spec (the KMT) and B6gen (the RCT) regression equation terms were tested, the RCT score was chosen as the best variable to enter. The regression shows that the specific science knowledge score (KMT) variable was not selected upon determination that no additional predictive information would be obtained by its inclusion in the regression.

The addition of the RCT raised the R square from .08 (just using group assignment) to .31. The gain was significant, $\underline{t}$ (260) = 9.56 $\underline{p}$ <.001. This overall R square of .31 was also significant, $\underline{F}$ = 24.16 $\underline{p}$ <.001. This suggests that the accuracy of predicting analogical transfer is increased when the RCT score of general science knowledge is added to knowledge of group assignment.

In sum, the data support hypotheses 1,2,3 and 5. Hypothesis 4 was not supported. The analysis results indicate that the context in which an analog was embedded and the kind of prior knowledge possessed by the science student may increase the likelihood that the student applied science principles to problems in which they would be relevant.

VI DISCUSSION

Positive Results

Prior studies have shown that a structurally relevant analog, although lacking syntactical elements in common with the target problem, can be recognized and applied as analogous (Brown 1979, Gick & Holyoak, 1983). It has also been documented that the salience of irrelevant surface features can reduce transfer (Gentner,1989) because the features are syntactically related, resemble transfer cues associated with homework and test problems, or are cognitively seductive to novice learners who lack linking schemata (Bassock & Holyoak, 1989, Sternberg 1990). Experimenters in other studies suggested that successful judgements of essential parallels between analog and target can be traced to the format in which the analog is presented prior to the target task (Adams, et al 1989, Duncker, 1945).

Recent related research of expert-novice learning, appropriate to the examination of analogical transfer, provide opposing support for either general or specific prior knowledge as a facilitator of transfer. Findings have not determined which form of past knowledge best transfer science concepts from familiar domains to isomorphic problems (Chi, Glaser & Farr,1989, Ennis, 1989, McPeck, 1990, Rumelhart,1980).

It was therefore predicted that students exposed to structural relationships analogous to a target problem (Groups 1 and 2) would use the analog, without prompting, even if it lacked syntactical similarities. Likewise it was hypothesized that presenting the format of the analog as a problem, rather than as usually examined, would orient the student's perception of the task and facilitate positive transfer (Groups 1 and 3). This was based on the assumption that both analogy acquisition and test materials would be processed in a similar problem-oriented manner. Descriptive statistics and a priori contrasts within a randomized block design supported each prediction, showing that these particular contextual elements significantly facilitated analogical transfer for the subjects in the study.

The data analysis on the third hypothesis compared Group 1 with all the others. The analysis showed a strong effect between the contextual elements tested. A relevant, structural analog phrased as a problem (a common learning situation for a high school student) which was presented before attempting to solve the target science problem increased the analogous points of similarity that may be transferred. The combination of the two contextual elements provided the strongest foundation for successful transfer. Group 1's performance compared to the others suggests that a dynamic relationship may have occured which either assisted in retrieval or rendered those in the group more acutely aware of usable parallels between the base analog and the target problem. It is noted that although there were twice as many perfect scores in Group 1 compared to the next highest group, the absolute number of successful students was low.

The fifth prediction stated that the kind of science knowledge a student possessed could also affect transfer (Brown et al 1988, Reed et al 1985). The data analysis indicate that a student's general science competency (RCT) score, but not the specific science assessment (KMT) score, increased prediction of positive transfer, given knowledge of the student's group assignment.

The RCT covered years of past science learning and included all the sciences (biology, chemistry, physics and the earth sciences). High scoring students presumably possess greater retrievable knowledge and more substantial schema than do low scoring students. They may thus be able to recognize when both the base analog and target problem contain comparable relationships critical to superordinate science knowledge (theories) and when to ignore superficial similarities. If so, the interaction between structures of knowledge and cognitive processes may be what assisted the students in applying their previously acquired knowledge more proficiently.

Negative Results

Students exposed to surface analog stories or problems (Groups 3 and 4) did not transfer the irrelevant information in attempting to solve the target problem (negative transfer) as presented in hypothesis four. It was predicted that students would be distracted by superficially isomorphic analogs which closely resembled the target question in words and setting, but lacked meaningful interrelationships, see Appendix L. Students in these surface treatments (Groups 3 and 4) did solve fewer target questions than did the control group of their peers who read no analog at all (negative analogical transfer), but the difference was not statistically significant.

This finding differs from findings in recent related research on negative transfer (Gentner 1989). Experiments have shown that superficially similar analogs possess distracting surface 'noise' that set learners on erroneous trains of thought from which they rarely recover during the course of solving the target problem.

Why did the students in the present study resist negative transfer? Specific parameters, i.e. an experimental environment identical to their learning environment over an entire semester as well as parallel acquisition conditions for learning and testing may be operating factors (Spencer & Weisberg, 1986). All aspects of the double blind study were carried out under the same conditions with the same group of teachers over two months. As such, the purposes assigned to the classroom by the students and the teachers were the same - to learn science concepts and apply them in solving science problems.

The topic of the target problem was specifically related to instruction to which they had been exposed for some time. It was based on a state syllabus within a defined domain that would later be tested on a statewide exam required for a high school diploma. Thus, unsurprisingly, students may have developed a science -problem mindset that prevented consideration of the surface "noise" as a possible source of solution.

Further study is required in improving the reliability of the analogical transfer instrument, given that the questions were based on previous RCT questions. The instrument can be lengthened and pre-tested to the level of solution determined by earlier researchers (Brown, 1987, Gick & Holyoak, 1980)

Several investigators have debated whether specific knowledge or general knowledge is a prerequisite of positive transfer. Proponents of the former argue that specific content knowledge is clearly defined and delimited by conditions of applicability, whereas general domain knowledge is so broad and diffuse as to place a high demand on cognitive processing that require expert schema (Chi & Bassock, 1989, Lampert & Clark, 1990, Simon, 1973).

Why did scores on specific science knowledge (KMT), the domain on which the analog and target problem were based, and which was closer in time to specific instruction, not have the advantage in predicting transfer? It may be that students' specialized science knowledge remained inert if it lacked integration or if it possessed "functional fixedness" or if was based on memorization of definitions of central terms rather than on organized units as would be expected of those scoring high on the general science knowledge assessment. Further research is suggested in exploring whether general or specific science knowledge can predict when students fail to either see or apply the relationships in the structural analog.

Summary

Students' ability to transfer specific science knowledge that had been taught them over the semester, differed when the format (problem or story) and the type (structural or surface) of the analog was manipulated. Successful transfer was supported when a structural analog was presented as a problem prior to solving the problem task.

The form of students' prior science knowledge (specific or general) also contributed to predicting positive analogical transfer by these subjects. Students' scores on a general science competence test, were based on three years of a New York State science syllabus. The scores were more predictive of success in solving the problem task, given knowledge of group assignment, than were the students' scores on a test of competency in a specific science domain upon which the transfer task was based.

Research Implications

The data in this study show increases in comprehension and transfer when task constraints were manipulated. That is, each group of students who did not differ pre-experimentally in their general science knowledge performed the analog task differentially. The groups' performances were based on how an analog was formatted and whether it possessed structural relationships to the transfer task. Although surface contexts between analog and target differed, the problem format guided identification of parallel tasks and perhaps parallel content.

Competence in general science knowledge was more predictive of positive transfer than was specific science knowledge, the very topic upon which the analog and transfer task were based. Perception of underlying patterns requires efficient integration and many discriminating examples (Lohman, 1990), two factors presumably possessed by high-scoring general domain knowledge high school freshmen.

This study differed in several other significant ways from recent related research on analogical transfer. All aspects of the study were conducted in the classroom, by the same teachers, during whole-class instruction over the normal course of the semester. Instruments were based on concepts in a science curriculum in which the classes had been instructed. Testing and intervention took place under the usual school testing conditions (i.e. final exams and statewide mandated qualifying exams) familiar to high school students in an urban city high school. This ensured that it was not necessary to simulate naturalistic learning conditions, since actual learning conditions were in effect throughout the experiment.

Practical Implications

This study lends some support to the findings of research on analogical transfer that contextual properties of an analogy can influence knowledge transfer. Teaching procedures, textbook examples, lab manuals, charts and diagrams, science videos and computer graphics can provide visual, literary, and manipulable analogies that observe the salient contextual factors tested in this study. Such efforts may faciliate knowledge acquisition by aiding retrieval or by stimulating schema and analytical abilities.

No analogy is perfect. The only representation just like the target problem in every respect is the target problem itself. Researchers know that analogies can influence the learners' notion of science principles either positively or negatively (Gentner, 1983, Haertel, 1989) depending on how much distortion is uncontrolled for in the elements to be mapped. This study has highlighted two situational variables that are under the conscious control of the teacher. Both are easily developed and/or examined in the lesson plan prior to instruction.

Well-wrought analogies can simulate the most complex science phenomena. Because they are one of the vehicles for association and interpretation they should be carefully designed to generate explanations and highlight salient relationships (Wittrock & Alessandrini, 1990). Enabling aspects of the variables of analog-type and analog-format should be incorporated in the design of an analogy presented during instruction.

Suggestions For Future Research

The applicability of this particular study to other populations is limited by the specifics of the variables involved : urban adolescents in a science classroom assessed on detailed statewide curricula and an analogy-transfer task. Because of the

RCT/Science curriculum and the specificity of the kinetic molecular theory, generalization of results to all Grade 9 students is unwarranted. Any conclusions concerning the effects of task context on the transfer of science knowledge is limited to two factors: the type and format of the base analog.

However, given the paucity of science analog studies carried out over time in the natural environment of whole-class learning, future research is needed to refine the treatment to increase generalization. If student performance is context dependent it would be desirable to examine students working on varied real science tasks in a real environment. For instance, researchers using science analogies almost always use examples in Physics or mathematics applied to Physics. The concepts involved are "clean" and lend themselves to operationalization in the experimental setting. Rarely is learning or instruction in the science class-room and under double-blind conditions so well defined and unadulterated.

Results of the present study support efforts to extend the investigation to other samples of science students and other science theories and concepts. In carrying out the procedure on different student populations or with different science concepts embedded in the analogy, it may be possible to identify other specific contexts and types of prior knowledge that support positive spontaneous analogical transfer.

Two directions for future research in analogical transfer are suggested, exploring transfer in the classroom condition and exploring transfer with different science concepts. Taking research out of a one on one experimental condition and using analogies in areas of science less well defined, but no less manipulable might more readily expose other influencing classroom contextual factors

Most teachers of introductory science courses in secondary and undergraduate levels are pragmatic, and will use what works in order to improve poor science preparation of American students. They often use analogies as teaching tools. Their students may devise them as a cognitive strategy as well. If specific, non-science contexts, such as a problem format, are found to better illuminate the mapping of base to target and tap science knowledge already possessed by the learner, these contexts should be observed by the science teacher when devising or presenting an analogy.

Knowing that students are responsive to all aspects of the teaching and learning environment, teachers who know how best to develop and present analogies have an immediate cost-effective strategy. Sensitizing teachers to this strategy requires modest teacher time and training.

Appendix A

Course Outline - Kinetic Molecular Theory
from NYSED Teacher Manual for Blocks A-J 1988

36. HOW MAY ONE FORM OF ENERGY BE CONVERTED INTO ANOTHER?
(Objects possess different forms of KE and PE and can be converted in either direction. Lab demo: KE by virtue of motion or molecular condition and PE by position and chemical arrangements)

37. WHAT IS HEAT ENERGY?
(Properties of heat explain what happens when a cold object comes in contact with a warm one - KE and PE differential)

38. WHAT ARE THE FIRST AND SECOND LAWS OF THERMODYNAMICS?
(E conversion. No conversion 100% efficient)

39. IMPLICATIONS OF THE LAWS OF THERMODYNAMICS
(E to matter, reverse. Random motion of molecules = heat. Heat is a less [ ] form of E and is therefore easier to convert other E forms into heat)

40. WHAT IS THE KINETIC MODEL FOR MATTER?
(Heat can be understood in terms of KE possessed by molecules or particles of matter which are in constant motion)

41. HOW DOES HEAT AFFECT EXPANSION OF MATERIALS?
(When objects are warmed, gain KE, the particles of which they are composed move faster and further apart)

42. LAB:TO OBSERVE WHAT HAPPENS TO GASES, LIQUIDS AND SOLIDS UPON HEATING

43. WHAT ARE THE PHASES OF MATTER?
(Molecular arrangements of substance that gains or loses KE when there is a phase change of gas to liquid, or a liquid to a solid and the reverse)

44. WHAT IS THE RELATIONSHIP BETWEEN PHASES OF MATTER AND THE PROPERTIES OF MATTER?

(Phases depend upon how close molecules are, how fast they move, i.e. the molecules in a solid are relatively slower, closer together and resist change of position than do molecules in a liquid of the same substance)

45. WHAT IS THE RELATIONSHIP BETWEEN HEAT AND PHASE CHANGE?
(When phase change occurs, E is either absorbed or liberated. Heat E can be converted into KE of motion or PE of particle position)

46. LAB: WHAT HAPPENS WHEN HEAT ENERGY IS ADDED OR REMOVED FROM WATER?

47. HOW MAY WE SHOW PHASE CHANGES ON A GRAPH?
(Graphing of freezing/melting points and boiling/condensation points of alcohol, sea water, distilled water)

48. HOW IS HEAT TRANSFERRED?
(Heat differs from temperature: the avg KE of molecules in an object. Heat is measured in cal, temp in Kelvin. As a result of temperature differential between matter, heat flows from areas of warm to cool temperatures)

49. WHAT ARE ENDOTHERMIC AND EXOTHERMIC REACTIONS?
(When a solid liquifies its particles have gained KE by absorbing heat E and when liquid freezes, its E is released)

50. WHAT ARE THE METHODS BY WHICH HEAT E CAN FLOW?
(Conduction, radiation, convection: demo bimetallic bar, greenhouse and convection apparatus with chimney)

51. LAB: HOW MAY WE INVESTIGATE HEAT TRANSFER?

52. FIELD TRIP TO CONSOLIDATED EDISON ENERGY CONSERVATION CENTER?

Appendix B

Domain Specific Assessment: Section of Student Final Exam

PART V Kinetic Molecular Theory

Directions: Please answer all of the following questions based upon the information given and your knowledge of science. Write the letter of the answer you think is best in the space provided. Take your time and recheck your answers. Leave no blanks.

____31. HEAT IS CONSIDERED TO BE A FORM OF...

a. regulation b. chemistry c. energy d. potential harm

____32. HEATING MAKES PARTICLES IN SOLIDS, LIQUIDS, AND GASES MOVE...

a. at the same speed b. in circles c. faster d. slower

____33. MATTER USUALLY EXPANDS WHEN HEATED BECAUSE ITS PARTICLES...

a. get larger b. break up c. get smaller d. move apart

____34. HEAT ENERGY ALWAYS MOVES FROM...

a. cool to warm places b. high to low places
c. warm to cool places d. low to high places

* USE THE DIAGRAM BELOW TO ANSWER THE NEXT 2 QUESTIONS (#35 & #36) *

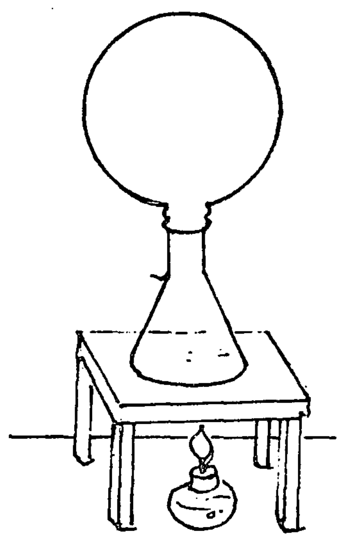
____35. WHICH OF THE ABOVE DIAGRAMS BEST REPRESENTS A SOLID?

____36. WHICH OF THE ABOVE DIAGRAMS REPRESENTS PARTICLES WITH THE GREATEST KINETIC ENERGY?

____37. AS THE TEMPERATURE OF MATTER <u>DECREASES</u> , THE SPEED OF THE MOLECULES ...

a. increases c. remains the same
b. is slowed d. is speeded up

* USE THE DIAGRAM TO THE RIGHT TO ANSWER THIS QUESTION: A BALLOON WAS ATTACHED TO A NARROW NECK OF OF A FLASK AS SHOWN. THE FLASK WAS THEN HEATED OVER A FLAME.



___ 38. WHY DID THE BALLOON INFLATE?

a. Molecules of air in the balloon moved further apart when heated.
b. Molecules in the air surrounding the balloon moved further apart.
c. Molecules in the glass flask permitted air to enter the balloon.
d. Warm air takes up as much space as the an inflated balloon does.

____39. WHICH PHASE OF MATTER HAS A DEFINITE SHAPE AND SIZE AND ITS MOLECULES HAVE LITTLE MOVEMENT AND SPEED?

a. solid b. liquid c. plasma d. gas

____40. WHEN THE TEMPERATURE OF A CAR DOOR RISES FROM 28oC to 49oC ITS SIZE WILL...

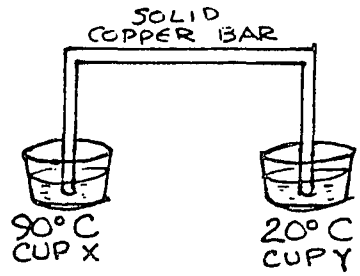
a. be unaffected b. depend upon the time of the year
c. increase d. be reduced by a few millimeters

____41. IF YOU ARE HAVING DIFFICULTY REMOVING A METAL CAP FROM A JAR,

IT MIGHT BE HELPFUL TO PLACE THE CAP UNDER HOT WATER. WHICH OF THE FOLLOWING STATEMENTS BEST SUPPORTS THIS ADVICE?

a. heating increases molecular energy causing the jar to contract.
b. the metal cap will expand because the molecules in it move apart.
c. heating decreases molecular energy and permits expansion.
d. hot water will loosen any dried material under the cap.

* THE NEXT QUESTION REFERS TO THE SET-UP SHOWN IN THE DIAGRAM TO THE RIGHT.



____42 .THE WATER TEMPERATURE IN BOTH CUPS WILL CHANGE OVER TIME BECAUSE...

a. Increased heat energy of water molecules will travel from cup X to cup Y
b. The heat energy in the water molecules will travel from cup Y to cup X.
c. The cooler temperature of cup Y will travel to cup X
d. The metal bar will remain cool to the touch throughout the experiment.

____43. IN WHICH PHASE ARE THE MOLECULES OF A SUBSTANCE CLOSEST TOGETHER?

a. a gas   b. plasma   c. a liquid   d. a solid

____44. WHEN THERE IS A PHASE CHANGE (when the state of matter is altered) ENERGY IS EITHER...OR...

a. increased, strengthened   b. released, given off
c. released, absorbed   d. reduced, doubled

____45. WHEN ICE MELTS, THE ENERGY OF THE MOLECULES IN THE ICE...

a. increases   c. crystallizes
b. is liquified   d. remains the same

____46. WHEN A LIQUID EVAPORATES (enters the gas phase),THE ENERGY OF THE MOLECULES...

a. decreases   c. is released
b. increases   d. remains the same

____47. ENERGY IS RELEASED WHEN A LIQUID BECOMES ...

a. a solid b. opaque c. a gas d. a cloudy mixture

____48. THE ONE MOST IMPORTANT FACTOR THAT SEEMS TO DECIDE THE STATE OR PHASE IN WHICH MATTER WILL BE IS...

a. the amount of substance present
b. the container the matter is in
c. the location on earth
d. the temperature of the substance

____49. IN WHICH OF THE FOLLOWING ARE THE MOLECULES FASTEST AND FURTHEST APART?

a. coconut pie
b. a coconut
c. a coconut shake
d. coconut perfume

____50. A STEAM BURN IS MORE HARMFUL THAN A BURN FROM BOILING WATER. THIS IS TRUE BECAUSE...

a. steam condenses on the skin at a temperature of 100oC.
b. steam absorbs energy as it condenses on the skin.
c. steam at 98oC has more molecular energy than 100oC water.
d. steam releases energy as it condenses on the skin.

Appendix C

TEST MAP FOR DOMAIN SPECIFIC EXAM (KMT)

TAXONOMY — KMT TEST QUESTIONS

LEVEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
KNOWLEDGE	X								X				X						X	
COMPREHENSION		X	X							X										
APPLICATION												X								
ANALYSIS							X													
SYNTHESIS				X	X	X					X			X						
EVALUATION								X							X	X	X	X		X

MAP SUMMARY

Test Q — Specifically involves:

1. Knowledge of heat as form of energy
2. Knowledge of effect of heat on speed and P
3. Comprehension of random motion,volume and pressure
4. Knowledge and synthesis of direction of heat flow
5. Comprehension and synthesis of diagram molecules in solid
6. Comprehension and synthesis of diagram of KE
7. Analysis of effect of lowered temp.on speed
8. Application and evaluation of heat and gas V
9. Knowledge of phases of matter
10. Comprehension of effect of inc. heat on V of solid
11. Evaluation, synthesis of inc. heat in common experience
12. Application, synthesis of conductivity
13. Knowledge of molecular arrangement in solid
14. Comprehension synthesis of phase change
15. Synthesis and evaluation of phase change
16. Synthesis and evaluation of heat in gas vs liquid
17. Synthesis and evaluation of heat in solid vs liquid
18. Synthesis and evaluation of effect of T on water
19. Knowledge of molecular structure as T decreases
20. Analysis and evaluation of common experience -exothermic

Appendix D

Structural Type Analog in a Problem Format

PART I SAMPLE

Directions: read this sample - its problem and solution. Then answer questions 1 and 2 below.

On a fine Saturday morning, a sleepy group of high school cheerleaders were lined up on the football field for practice. They were aligned in quiet neat rows. The marching band then began to practice on the other side of the field. The stirring music awakened the cheerleaders. Those at the ends of the rows were the first to sway to the music and step out of formation. Soon they scattered over the field. Some very active ones even leaped up into the stands bumping into each other and the seats at random. The music excited them and they lost all sense of order. Then the Dean rushed onto the field, demanding that everyone get back to business.

Problem If you were the Dean how would you restore formation quickly and with little fuss

Solution Ask a student to get the band to stop playing. Without the music most of the cheerleaders would quiet down, gather together and form rows again. Only a few of the very excited ones in the upper stands would not get back down to their original position on the field in time.

____ Q1 DID YOU UNDERSTAND THE PROBLEM AND ITS SOLUTION? (place a "yes" or "no" in the space provided)

____ Q2 COULD YOU RETELL WHAT YOU JUST READ TO SOMEONE WITHOUT READING DIRECTLY FROM THIS SHEET? (choose the letter from the choices below)

a. with great difficulty b. with some difficulty
c. possibly d.easy to do e.very easy to do

-go on to next page-

Appendix E

Structural Type Analog in a Story Format

PART I SAMPLE

Directions : read this sample story. Then answer questions 1 and 2 below.

On a fine Saturday morning, a sleepy group of high school cheerleaders were lined up on the football field for practice. They were aligned in quiet neat rows. The marching band then began to practice on the other side of the field. The stirring music awakened the cheerleaders Those at the ends of the rows were the first to sway to the music and step out of formation. Soon they scattered over the field. Some very active ones even leaped up into the stadium bumping into each other and the seats at random. The music excited them and they lost all sense of order

Then the Dean rushed onto the field, demanding that everyone get back to business. He tried to restore the cheerleaders' exact formation quickly and with little fuss.

He asked a student to get the band to stop playing. Without the music most of the cheerleaders quieted down, gathered together and formed rows again. Only a few of the very excited ones in the upper stands did not get back down to their original position on the field in time.

_______ Q1 DID YOU UNDERSTAND THE STORY YOU JUST READ? (place a "yes" or "not" in the space provided)

_______ Q2 COULD YOU RETELL WHAT YOU JUST READ TO SOMEONE WITHOUT READING DIRECTLY FROM THIS SHEET (choose the letter from the choices below)

a. with great difficulty b. with some difficulty
c. possibly d. easy to do e. very easy to do

-go on to next page-

Appendix F

Surface Type Analog in a Problem Format

PART I SAMPLE

Directions: Read this sample - its problem and solution. Then answer questions 1 and 2 below.

During an experiment in science class, it was necessary to cool a shatter-proof beaker of steaming, bubbling syrup. The beaker was placed on a block of ice set in a pan. The temperature of the contents of the beaker was taken every two minutes, and recorded by the students in a data table.

A student suggested it would cool faster if the block were crushed first and packed around the beaker. Crushing the block reminded some of the students of their work last term on the three forms of rock: igneous, metamorphic and sedimentary, and the heat and pressure necessary to alter the molecular structure of the minerals.

They packed the icechips around the beaker. By the time the syrup had cooled, there was still some ice and melt surrounding the beaker.

Problem If you were writing up this part of the experiment how would you explain what had occurred in the beaker?

Solution The team wrote that fast cooling was possible when most of the beaker was in contact with the ice. crushing the block and packing the chips around the hot beaker, the sugar had stopped bubbling and was ready for the weighing part of the experiment.

_____ Q1 DID YOU UNDERSTAND THE PROBLEM AND ITS SOLUTION? (place a "yes" or "no" in the space provided)

_____ Q2 COULD YOU RETELL WHAT YOU JUST READ TO SOMEONE WITHOUT READING DIRECTLY FROM THIS SHEET? (choose the letter from the choices below)

a. with great difficulty b. with some difficulty
c. possibly d. easy to do e. very easy to do

-go on to next page -

Appendix G

Surface Type Analog in a Story Format

PART I SAMPLE

Directions : Read this sample story. Then answer questions 1 and 2 below.

During an experiment in science class, its was necessary to cool a shatter-proof beaker of steaming, bubbling sugar. The beaker was placed on a block of ice set in a pan. The temperature of the contents of the beaker was taken every two minutes, and recorded by the students in a data table.

A student suggested it would cool faster if the block were first crushed and packed around the beaker.
Crushing the block reminded some of the students of their work last term on the three forms of rock : igneous, metamorphic and sedimentary, and the heat and pressure necessary to alter the molecular structure of the minerals.

They packed the icechips around the beaker. By the time the syrup had cooled, there was still some ice and melt surrounding the beaker.

In order to complete this part of the experiment, the lab team wrote up what had occurred in the beaker. The team wrote that fast cooling was possible when most of the beaker was in contact with ice. By crushing the block and packing the chips around the hot beaker, the sugar had stopped bubbling and was ready for the weighing part of the experiment.

_____ Q1 DID YOU UNDERSTAND THE STORY YOU JUST READ?
(place a "yes" or "no" in the space provided)

_____ Q2 COULD YOU RETELL WHAT YOU JUST READ TO SOMEONE WITHOUT READING DIRECTLY FROM THIS SHEET?
(choose the letter from the choices below
a. with great difficulty b. with some difficulty
c. possibly d. easy to do e. very easy to do

-go on to next page-

APPENDIX H

DIRECTIONS TO TEACHERS ADMINISTERING SCIENCE QUESTIONNAIRE

Dear

Please read the following directions to the class before administering the questionnaire:

1. This questionnaire and your answers will help the science department prepare for next year's freshmen science course.
2. There is no limit to the time you may have to answer.
3. Your answers will in no way affect your science grade in this class
4. Your answers will be most helpful if you do not rush through the questions.
5. You may use a pen or pencil.
6. If you do not wish to participate you will be given a science article to read.
7. There is plenty of time to read and answer the questions and to check over your answers
8. Those who wish to read a science article instead, please raise your hands and I'll place an article on your desk.
9. Thank you for your cooperation. You may begin now.

Appendix

Target Problem Questions

PART II Directions:
Read the following passage. Use it and your knowledge of science to answer all the questions that follow.

In a lab lesson at school, one step in an experiment required students to heat an open beaker containing a large block ice. The temperature of the contents of the beaker was taken every two minutes, and recorded by the students in a data table.

While heating, the ice block lost its edges and a small puddle of water formed in the beaker around the ice. As the block grew smaller, some of the water bubbled and turned to steam. The students immediately removed the beaker from the heat source. The bubbling stopped and the remaining contents of of the beaker were cooled rapidly in a freezer.

By the time the students were ready for the weighing procedure ice had reformed inside the beaker.
Before the next part of the experiment the science teacher required the students to write up their observations for full lab credit by answering the following questions:

__ Q 1 ACCORDING TO THE INFORMATION GIVEN, THE THREE PHASES INVOLVED WERE...

a. igneous, metamorphic and sedimentary
b. similar to the phases of the moon
c. solid, liquid and gas
d. molecules of different atomic numbers

__ Q 2 WHAT HAPPENED TO THE MOLECULES OF ICE AS THEY WERE HEATED? ACCORDING TO KINETICS THE MOLECULES...

a. were clearly visible through the glass beaker
b. had space in which to melt and reduce pressure
c. became misshapen
d. absorbed heat

__ Q 3 HOW WOULD YOU COMPARE THE NUMBER OF MOLECULES IN THE

BEAKER BEFORE AND AFTER HEATING? THERE WERE...

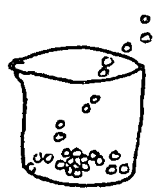
a. the same number of molecules before and after
b. fewer molecules in the beaker after heating
c. uneven amounts of molecules in the ice crystals
d. heavier molecules after heating

___ Q 4 WHAT HAPPENED TO THE MOLECULES AS THE ICE MELTED? THE MOLECULES...

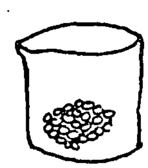
a. changed from solid molecules to liquid or gas molecules
b. gained energy, collided and moved apart
c. formed a steamy cloud over the beaker
d. cooled off like bubbling sugar crystals cool off in a beaker

___ Q 5 WHICH OF THE FOLLOWING DIAGRAMS SHOWS WHAT THE MOLECULES WERE DOING JUST AS THE BEAKER WAS REMOVED FROM THE HEAT?

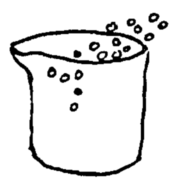
a



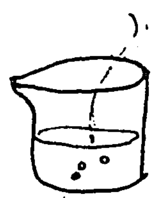
b



c.



d.



___ Q6 WHICH STATEMENT BEST SUMMARIZES YOUR UNDERSTANDING OF THIS PART OF THE EXPERIMENT?

a. blocks of crystallized ice are not permanent and can easily melt.
b. students must exercise care when handling hot beakers and thermometers.
c. if water molecules lose enough energy, freezing occurs and if they gain enough energy, evaporation occurs.
d. molecules of ice are made up of substances that are different from molecules of matter in vapor or water.

Appendix J

General Domain Competency test (RCT/Science)
Reliability Report

as per written correspondence with S.W. Miller, Division of Educational Testing, NYSED, Albany, 12234.

" This test was first administered in June 1988. It was designed to measure the core process skills and content understandings taken from 10 blocks of the [New York State] science syllabus 7 - 9. The June 1989 examination was field tested the previous year with a Statewide selected sample of 975 students. The Kuder-Richardson reliability was .85. Because the test is criterion referenced and is directly related to the State course of study, we do not obtain internal consistency coefficients for grade level/age... All questions are administered as pretests in a representative sample of freshmen science classes. After item analysis, questions are assembled into tests and reviewed by three additional committees. Because we develop three completely new tests each year, only KR estimates of reliability are part of these post-tests analyses...

Appendix K

Structural Analog and Target Problem Parallels

Analog	Target Problem	Question
cheerleaders	molecules	all
field	container	all
stands	outermost electron levels	1,3,4,5
music	heat energy	all
hear music	absorb energy	2,4
stop music	remove heat energy	6
in formation	solid (ice)	1
active cheerleaders	increased molecular movement	3,4
field formation lost	melting	1,2,6
restore formation	freezing	6
stirring music	increased heat	2,3
cheerleaders leave field	evaporation	1,2,4,5
very active cheerleaders still in stands	molecules escape from beaker	1,3,4,5

Note

The factors listed for the analog are considered structural in that they bear essential relationships to the kinetic molecular theory and the target problem. They can assist in correctly answering the questions listed.

Appendix L

Surface Analogs and Target Problem Parallels

Analog	Target Problem	Question
Experiment	Experiment	6,5
Science Class	Lab Lesson	6
Heating	Heating	2,3,5
Cooling	Cooling	4,6
Beaker	Beaker	2,3,5
Temperature taken	Temperature Taken	---
Recording Data	Recording Data	---
Two minute intervals	Two minute intervals	---
Ice	Ice	2,3,4
Preparation for Weighing	Preparation for Weighing	---
Crushing ice/rock	Crushing ice	---
Rock Phases	Rock phases	1
Lab write up	Lab write up	---
Bubbling Sugar	Bubbling	4,5

Note

The factors listed for the analog are isomorphic in syntax to the target problem or questions. They bear no relationships in common with the problem that are integral for solution.

REFERENCES

Adams, L., Kasserman, J., Yearwood, A., Perfetto, G., Bransford, J., & Franks, J. (1988). Memory access: effects of fact orientation vs problem orientation acquisition. Memory and Cognition, 16 , 167-175.

Alexander, P.A., Pate, V.L., Kulkowich, J.M., & Wright, A.D. (1988, April). Domain specific and strategic knowledge. Paper presented at the American Educational Research Association meeting, New Orleans, LA.

Bassock, M. & Holyoak, K. (1989). Interdomain transfer between isomorphic topics in algebra and physics. Journal of Experimental Psychology, 15 (1), 153-166.

Biggs, J.B. (1982). Student motivation and study strategies. Higher Educational Research and Development, 1 , 33-55.

Bisanz, G.L. & Voss, J.F. (1981). Sources of knowledge in reading comprehension. In A.M. Lesgold & C. A. Perfetti (Eds.), Interactive processes in reading. (pp.215-239). Hillsdale, NJ:Erlbaum.

Brown, A. (1979). Theories of memory and problems of development. In L.S. Cermak & F. Craik (Eds.). Levels of processing and human memory. Hillsdale, NJ: Erlbaum.

Brown, A. (1985). Teaching students to think as they read. (Reading Educational Report No. 58). University of Illinois: Center for the Study of Reading.

Brown, A. (1989). Analogical learning and transfer. In S. Vosniadou and A. Ortony (Eds.), Similarity and analogical reasoning. (pp. 17-34). Cambridge, MA: Cambridge University Press.

Brown, A. & Kane, M.J. (1988). Preschool children can learn to transfer. Cognitive Psychology, 20, 78-94.

Brown, A., Kane, M.J. & Long, C. (1987). Analogical transfer in young children: Analogies as tools for communication and exposition. Applied Cognitive Psychology, 11, 33-49.

Brown, J., Collins, A.,& Duguid, P. (1988). Cognitive apprenticeship situated cognition and social interaction. (Research Report No. 6886). B.B.N. Systems & Technologies Corporation. Boston: MA.

Bransford, J,D., Sherwood, R.D., Hasselbring, T.S., Kinzer, C.K. & Williams, T. (1989). Anchored instruction.

In D. Nix & R. Spiro (Eds.) Instructional Technology. (pp.11-19). Hillsdale, NJ :Erlbaum.

Carey, S. (1986). Cognitive science and science education. American Psychologist, 41, 1123-1130.

Chi, M., & Bassock, M.(1989). Learning from examples via self explanations. In L.B. Resnick (Ed.), Knowing and learning :Issues for a cognitive psychology of instruction. (pp. 109-123). Hillsdale,NJ : Erlbaum.

Chi, M., Glaser,R. & Farr, M. (1989). The nature of expertise. Hillsdale, NJ: Erlbaum.

Crisafi, M.A., & Brown, A.L.(1986). Analogical transfer in very young children. Child Development, 57, 953-968.

Davies, K. (1989, November). Of elephants and guinea pigs: On using analogies in teaching high school chemistry. Ninety-fourth Annual Conference of Science Teachers Association of New York. Ellenville :NY

diSessa, A. (1987). Phenomenology and the evolution of intuition. In C.Janvier (Ed.), Problems of representation in the teaching and learning of mathematics. (pp.83-95). Hillsdale, NJ : Erlbaum.

Duncker, K. (1945). On problem solving. Translated by Lynne S.Lees in 1945 from 1935 original. Psychological Monograph 58, No. 270 (Whole no.) 1 - 113.

Ennis, R. (1989). Critical thinking and subject specificity. Educational Researcher, 18 (3), 4-10.

Fisher, K.I. & Lipson,J.I. (1983). Information processing interpretation of errors in college science mathematics. Unpublished manuscript, University of California, Division of Biological Sciences and WICAT Systems, Inc., Orem, Utah.

Gentner, D. (1981). Generative analogies as mental models. In Proceedings of the Third Annual Conference of the Cognitive Science Society. U.of California, Berkeley: Institute of Human Learning. 99-100.

Gentner, D. (1983).Structure mapping: A theoretical framework for analogy. Cognitive Science, 7 (21), 155-170.

Gentner, D. (1989). Mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), Similarity and analogical . reasoning, (pp. 97-116). London :Cambridge University Press.

Gentner, D.,& Landers, R. (1985). Analogical reminding. Proceedings of the International Conference on Systems, Man & Cybernetics. Tucson, Arizona.

Gentner, D. & Toupin,C. (1986). Systematicity and surface similarity : Development of analogy. Cognitive Science, 10, 277-300.

Gick, M.L. (1987). Problem solving strategies. Educational Psychologist, 21, (1 & 2), 99-120.

Gick, M.L., & Holyoak, K.J. (1980). Analogical problem solving. Cognitive Psychology, 12, 306-355.

Gick, M.L., & Holyoak, K.J. (1983). Schema induction & analogical transfer. Cognitive Psychology, 15 (1), 1-38.

Gick, M.L., & Holyoak, K.J. (1987). The cognitive basis of knowledge transfer. In M. Bassock (Ed.), Transfer of Learning. (pp. 1-16). NY: Academic Press.

Haertel, H. (1987). A qualitative approach to electricity. (Tech. Report) Xerox Parc, Institute for Research on Learning, Palo Alto, CA.

Holyoak, K.J., & Thagard, P. (1989). Analogical mapping by constraint satisfaction. Cognitive Science, 13, 227-300.

Janvier, C. (1987). Representing and understanding. In C. Janvier (Ed.), Problems of representation. (pp.67-71). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Tversky, A. (1972).Subjective probability. Cognitive Psychology, 3, 430-454.

Kahneman, D., & Tversky, A.(1973). Availability: Heuristic for judging frequency and probability. Cognitive Psychology, 5, 207-237.

Kahneman, D., & Tversky, A. (1982). On the study of statistical intuition. In D. Kahneman, A. Tversky & P.Slovic (Eds.), Judgements under uncertainty: Heuristics and biases. (pp. 239-252). NY:Cambridge University Press

Kirby, J.R., & Biggs, J.B. (1981). Learning styles and information processing ability. Final Report, Australian Grants Committee. New Castle, Australia: University of New Castle.

Kolokovsky, K., Hayes, J.R., & Simon, H.A. (1985). Why are some problems hard? Cognitive Psychology, 17, 248-294.

Lampert, M., & Clark, C. (1990). Expert knowledge and expert thinking in teaching. Educational Researcher, 19 (4), 21-23

Larkin, J., & Reif, F. (1979). Understanding and teaching problem solving in physics. European Journal of Science Education. 1, 191-203.

Laurillard, D. (1979). Processes of Student Learning in Higher Education, 8, 395-409. Elsevier, Amsterdam, Netherlands.

Lockhart, R. S., Lamon, M., & Gick, M. (1988). Conceptual transfer in simple insight problems. Memory and Cognition, 16, 36-44.

Lohman, D. (1990). Human intelligence: an introduction to advances in theory and research. Review of Educational Research, 57 (4), 333-373.

McPeck, J. (1990). Critical thinking and subject specificity : Reply to Ennis. Educational Researcher, 19 (4), 10-12.

Newell, A. (1980). One final word. In D.T. Tuma & F. Reif (Eds.), Problem solving and education. (pp. 175-189). Hillsdale, NJ : Erlbaum.

Palmer, S.E. (1989). Levels of description in information processing theories of analogy. In S.Vosniadou & A. Ortony (Eds.), Similarity and analogical reasoning. (pp. 131-139). London: Cambridge University Press.

Perfetto, G.A., Bransford, J.D., & Franks, J.J. (1983). Constraints on access in a problem solving context. Memory and Cognition, 11, 24-31.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accomodation of a scientific concept: Toward a theory of conceptual change. Science Education, 66, 211-227.

Reed, S.K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. Journal of Experimental Psychology: Learning, Memory & Cognition, 11, 106-125.

Rumelhart, D.E. (1980). Analogical processes in learning. In J.R. Anderson (Ed.), Cognitive skills and their acquisition, (pp. 335-359). Hillsdale, NJ: Erlbaum

Salomon, G. (1988, April). Two roads to transfer: Two roads of transfer. Paper presented at annual meeting of the American Educational Research Association, New Orleans, LA.

Schoenfeld, A. H. (1985). Mathematical problem solving. Academic Press NY : Harcourt, Brace Janovich.

Schoenfeld, A.H. (1987). Cognitive science and mathematics. education . Hillsdale, NY: Erlbaum.

Sherwood, R., Kinzer, C., Bransford, J, D., & Franks, J.J. (1987). Some benefits of creating macro-contexts for science instruction. Journal of Research on Science Teaching, 24 (5), 417-435.

Simon, H. A. (1973). Structure of the ill-structured problem. Artificial Intelligence, 4, 181-201.

Skorstad, J., Falkenhainer, V., & Gentner, D. (1987). Analogical processing: A simulation and empirical collaboration. Proceedings of the American Association of Artificial Intelligence. Seattle, WA.

Solomon, J. (1983). Thinking in two worlds of knowledge. Paper presented at the International Seminar of Misconceptions in Science. Cornell University, Ithaca, NY.

Spencer, R.M. & Weisberg, R.W. (1986). Is analogy sufficient to facilitate transfer in problem solving? Memory and Cognition, 4, 442-449.

Spiro, R.J., Feltovich, P.J., Coulson, R.L., & Anderson, D.K. (1989). Multiple analogies for complex concepts. In S. Vosniadou & M. Ortony (Eds.). Similarity and analogical reasoning. (pp. 61-76). London:Cambridge University Press.

Sternberg, R. (1977). Intelligence, information processing and analogical reasoning. Hillsdale, NJ: Erlbaum.

Sternberg, R. (1981). Intelligence and non-entrenchment. Journal of Educational Psychology. 73, 1-16.

Thorndike, E.L. (1913). Educational Psychology, 2, New York: Teachers College: Columbia University.

Thorndyke, P.N. (1977). Cognitive structures in comprehension and memory of narrative discourse. Cognitive Psychology, 9, 77-110.

Thorndyke, P.N., & Hayes-Roth, B. (1979). Use of schemata in the acquisition and transfer of knowledge. _Cognitive Psychology,_ _11,_ 82-106.

Tversky, A. (1977). Features of similarity. _Psychological Review,_ _84,_ 327-352.

Tversky, A., & Gati, I. (1982). Similarity, separability, and the triangle inequality. _Psychological Review,_ _89,_ 123-154.

Weisberg, R., diCamillo, M., & Philips, D. (1978). Transferring old associations to new situations: A non-automatic process. _Journal of Verbal Learning and Verbal Behavior,_ _17,_ 219-228.

Winston, P.H. (1975). Learning structural descriptions from examples. In P.H. Winston (Ed.), _The psychology of computer vision._ New York : McGraw Hill.

Winston, P.H. (1980). _Learning and reasoning by analogy._ Communications of the ACM, (Research Rep 23 : 689-703).

Wittrock, M., & Alesandrini, K. (1990). Generation of summaries and analogies. _American Education Research Journal,_ _27_ (3), 489 - 502.