PROBLEM-ORIENTED TRAINING
PROMOTES SPONTANEOUS ANALOGICAL TRANSFER

By

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Abstract

Analogical transfer is using information from one problem to help solve a subsequent problem to which it is equally as applicable. This transfer is called "spontaneous" if it occurs without any hint being given to the solver that the information from the earlier problem (the training analogue) will help solve the current problem (the target problem). The research literature shows that although subjects can use information from a training problem to help solve a target problem when explicitly instructed to use the information, they do not often do it spontaneously. In this thesis, thirteen experiments work together to demonstrate that problem-oriented processing of the training information leads to significant levels of spontaneous analogical transfer. Experiments 1, 2a, and 2b show that when subjects attempt to solve training problems, fail in their attempt, and then are provided with the appropriate solution and explanation, transfer of the training problem's principle to the target is likely, resulting in high solution rates on target problems. Whether or not the scenario of the training problem is the same as that of the target problem makes little difference so long as the principles are the same. In Experiments 3 through 8, and 11 and 12, it is shown that if subjects try to solve a training problem before hearing its solution, or try to explain a training problem's solution before hearing the correct explanation, spontaneous analogical transfer is much more likely than if subjects study the training problem for memory before hearing its solution or explanation. The advantage of

problem-oriented training over memory-oriented training prevails despite the fact that the solution and explanation attempts nearly always fail, and the advantage is just as robust if the target problem is tested approximately 16 minutes after training rather than immediately thereafter. In Experiments 9 and 10, the extent of the benefit when the explanation does not follow the attempt to explain is examined. In Experiment 9, when the experimenter-provided explanation is replaced with verbatim repetition of the story, the benefit decreases a little. In Experiment 10, when the subjects are asked to recall the training story rather than listen to the experimenter-provided explanation, the benefit is eliminated. Problem-oriented training is superior to memory-oriented training when subjects are tested on problem transfer, but when the test is a memory test, memory-oriented training is superior to problem-oriented training.

I conclude that problem solvers can spontaneously transfer information from analogous problems if they try to solve or explain the earlier problems and receive the appropriate solution or explanation feedback. The reason for the effect is that problem-oriented processes performed at study are the appropriate processes to use at test.

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"... in the discovery of knowledge, there is great entertainment - as conversely, in all good entertainment, there is always some grain of wisdom, humanity, or enlightenment to be gained."

Walt Disney

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Chapter 1

INTRODUCTORY REMARKS

This thesis is concerned with spontaneous analogical transfer in problem-solving tasks. Spontaneous analogical transfer is using information from an earlier problem to help solve an analogous current problem to which that information is equally as applicable, without being told to use the earlier information. I will begin the discussion of spontaneous analogical transfer in Chapter 2. The conditions under which problem solvers use this past information will be elucidated. Before that, however, I present this brief introductory chapter for two reasons - first, to show how and why cognitive psychologists investigate problem solving in general, and second, to show that the role of one's past experience in problem-solving performance has been a controversial issue.

Cognitive Psychologists and Problem Solving: Why and How?

Every day people encounter problems that they need to solve. Whether it be replacing a flat tire, identifying a chemical unknown, calculating a probability, selecting the right time of year to travel, or figuring out how to bring peace to the Middle East, problems of all magnitudes dominate one's life. Consequently, cognitive psychologists

are interested in the ways that people approach problems, what takes place when people try to solve a problem, and how the solution finally materializes. Also of interest are variables that affect problem-solving ability; why is it that some people can solve a problem quickly, yet other people need much more time to solve the same problem? What are the problem-solving strategies that can be taught to make someone a good problem solver, and under what circumstances do these strategies come into play? These and other related issues have dominated most of the research on problem solving in cognitive psychology (Ashcraft, 1989).

Understanding how individuals solve problems is obviously a worthwhile enterprise. The intelligent component of one's behaviour is typically assessed in terms of one's problem-solving ability; therefore, in order to best comprehend human intelligence, psychologists must delve into the process of problem solving. Also, the better the process of problem solving is understood, the better able cognitive psychologists will be to train people to solve problems quickly, efficiently, and intelligently. This training would lead to important improvements in education system, psychotherapy, job performance, and so on (Wessels, 1982).

Chi and Glaser (1985) define a problem as a situation in which a person is trying to reach some goal and must devise a plan of attack for reaching that goal. There are four steps that occur during a problem-solving episode. First, the solver must identify the problem, by determining the starting point, or <u>initial state</u>, and the end point, or <u>goal state</u> of the problem. Second, a strategy must be devised; the

strategy selected ultimately depends on the difficulty of the problem, the likelihood that the given strategy will succeed, and the characteristics of the problem solver. Third, once the strategy has been chosen, it must be applied to the problem. The final step involves evaluating one's progress towards reaching the goal state; will the strategy result in the solution? The solver must decide whether the strategy should be continued or abandoned. The four steps of defining a problem, planning a strategy, executing a strategy, and evaluating progress can interact extensively as problem solving occurs (Best, 1986; Newell & Simon, 1972; Wessels, 1982).

Adults employ a variety of strategies which, on a broad level, can be divided into <u>algorithms</u> and <u>heuristics</u>. An algorithm is a solution procedure that always solves a problem, even if it takes a long time and even if the solver does not know why it works. For example, the formula [Area = πr^2] is the algorithm to solve for the area of a circle; using this formula guarantees the correct answer. In contrast, a heuristic is a solution method that may be used to solve a problem quickly, but it is not guaranteed to work (Kahneman & Tversky, 1973; Wessels, 1982).

The experiments which investigate problem solving are varied. Typically, subjects are given a problem that they are required to solve. The problems chosen are usually domain-free problems (problems that have a clear solution, but no special training is needed to solve them). Furthermore, the problems are challenging but they can be solved. Although the problems used are not particularly profound (see Appendix A for examples), there are some potentially far-reaching conclusions to be

drawn. Performance during the solving attempt is closely monitored, and subjects may be asked to evaluate their performance during the attempt. Occasionally, subjects may be asked to verbalize whatever they think of as they work on the problem, even if they believe it to be irrelevant. Sometimes subjects may be trained on the principles of the problem before they try to solve it; the experimenter might be interested in how closely subjects follow earlier examples, if at all, to help them solve new problems (Best, 1986; Weisberg, 1986).

Although the world of problem-solving experiments is very diverse indeed, the experiments are united by the common goal of understanding human problem-solving behaviour to help us all become better able to solve the problems that we encounter. Furthermore, a common thread which seems to run through many of the experiments is the role of the subject's past experience. The role of past experience in problem-solving performance has been debated for a long time. I now describe a few theories of problem solving, focussing on the parts concerning past experience.

Theories of Problem Solving: The Role of Past Experience

The Gestalt psychologists believed that solving a problem entailed going beyond one's past experience to work out each new problem as an independent event. A person can solve a problem with no specific knowledge or experience simply by considering what the real difficulty in the problem is, and how to overcome it. In other words, the solver does not have to refer to a previous episode to solve a new problem. No special knowledge is needed to produce a solution; all that is necessary is that the solver consider the problem in the right way. So, in short,

the Gestaltists focussed on solvers producing novel solutions to problems, solutions which do not seem to rely on any specific experience from the past (Weisberg, 1986).

The Gestaltists argued that past experience can frequently be misleading; solvers can become fixated on this misleading information and be led astray. Gardner (1978) popularized insight problems - a problem where the solution suddenly appears with an "aha!" reaction. An insight problem involves some trick and looking at the problem in a different way leads to the insight and the solution (an example is on page 15). Gardner argues that, in order to solve these problems, one must be free from past experience and interpret the problem without reference to past ideas. Once one does this, one's mind is waiting to welcome the insight and produce the solution. Everyone has undoubtedly experienced these so-called "aha" reactions, and the post-solution feeling of realizing that the problem was being approached in the wrong way; such instances exemplify the Gestalt view (Weisberg, 1986).

Luchins (1942) also provided evidence for the Gestalt view with his experiments using Water Jug problems. In these problems, one is given three jugs of different volumes and asked to measure out a specific amount of water using only the three jugs. Luchins gave subjects a series of these problems to solve, giving them the solution after each attempt. The first several problems could be solved using the same principle. Luchins found that subjects would use this principle to solve a new Water Jug problem that could be solved more quickly by using a much simpler principle. The subjects had become fixated on the prior experiences. Thus, the Gestaltists claimed that by

ignoring past experience entirely, negative influences of the past can be avoided (Weisberg, 1986).

The Gestalt view that a solution can materialize if one ignores past experience is optimistic because it compliments the individual's reasoning ability. It also implies that anyone could solve problems in any domain if one only gave oneself the chance. Attractive as this may seem, however, several experiments have yielded results which contradict the Gestalt view. For example, Burnham and Davis (1969) and Weisberg and Alba (1981) gave subjects the nine-dot problem. One must connect by pen nine dots which are arrayed as a 3 X 3 square without lifting the pen from the page; it is solved by drawing the lines outside of the square. The subjects were told that the solution necessitates drawing lines out of the square. So, according to Gestalt views, this hint should make the problem easy because fixation has been eliminated - it should help the subjects look at the problem in the right way. However, even with the hint, only about 25% of the subjects eventually solved the problem. The Gestalt view holds that once fixation is broken, the solution appears whole in a burst of insight or is produced smoothly as one step leads to another. In neither study, however, were such results observed. Even the few subjects who eventually solved the nine-dot problem after receiving the hint took a long time to do so. Weisberg and Alba examined other problems and reported no evidence to support the Gestalt view.

Indeed, on the contrary, common sense seems to suggest that past experience is a crucial factor in problem solving. Surely, problem-solving ability must rely heavily on expertise in the domain in

question, and individuals develop that expertise from experience. It just makes sense that a physicist is going to have more success solving a physics problem than someone who has never attended a physics class (Ashcraft, 1989).

Interest in the role of past experience and expertise was stimulated by deGroot (1966) who studied problem solving in the domain of chess with chess masters and less skilled players (see also Chase & Simon, 1973). DeGroot's results and those of others who investigated the same issue with problems from physics, geometry, computer science, and arithmetic, all indicate that past experience is crucial in determining how efficiently an individual solves a problem (Weisberg, 1986). Novices and experts within a domain show differential performance in problem solving and in the way in which they solve problems. The way that an expert tackles a problem compared to a novice is attributable to the expert's knowledge being organized differently than the novice's knowledge. Novices group problems together according to superficial similarity (that is, group according to whether the problems sound alike); experts, on the other hand, group together problems that can all be solved using the same principles (Best, 1986; Chi, Glaser & Rees, 1982).

On the basis of research in concept formation, Levine (1966, 1974) proposed his Hypothesis theory which placed heavy emphasis on past experience. This theory states that while solving a problem, the solver considers some "universe" of hypotheses from which he or she samples hypotheses to test. Presumably expertise, prior experience, and recent training help reduce the size of this universe, resulting in a quicker,

more efficient solution procedure. In the pretraining phase of an experiment, Levine's subjects tried to solve a series of problems, each of which had a simple solution (simple meaning that the concept was determined by one of four dimensions). If the subject could not solve the problem, the experimenter gave the solution. The two experiences of getting the solution, producing it on one's own or hearing it from the experimenter, were assumed to be roughly equivalent in communicating the solution to the subject. Levine argued that this pretraining phase changed the subject from a solver who might sample any place in the universe of hypotheses to one who sampled only from a small subset of hypotheses. The experience of the earlier similar solution(s) causes a narrowing of the universe of hypotheses - it gets smaller. The smaller the set through which the subject searches, the faster the solution will be located.

The role of past experience is central in other theories of problem solving, notably those of the associationists and behaviourists (for example, Watson, 1958). These theories state that the solution to a new problem is reached because the new episode is similar in important ways to an episode that preceded it. That is, even though the problem is essentially new, it has features that are similar and familiar. Because of this similarity, old associations are transferred or generalized to the new situation and the novel problem is solved. This view claims that novel problems are solved because they are not really novel, but instead are previous episodes cast in a different light. Becoming expert involves gathering knowledge about certain situations so that one can deal with a new situation on the basis of how closely it

matches an event one has encountered in the past (Weisberg, 1986). This idea also implies that solvers should likely have little difficulty recognizing the new problem as being an analogue to a previously encountered problem. These ideas sound very logical; solving by way of a previous example seems like an ideal strategy. Yet, does it occur with the regularity that the theory suggests? This thesis will address the issue of the conditions under which subjects use previously encountered information to help solve current problems.

This chapter does not, by any means, cover the entire area of problem solving and the facets of it in which cognitive psychologists are interested. It has, though, established problem solving as an intriguing, worthwhile enterprise. It has also shown that the issue of the subject's past experience is prominent in problem-solving research.

Chapter 2

TRANSFER IN PROBLEM-SOLVING TASKS: A REVIEW OF THE LITERATURE

Although Spearman's (1923) claim that all intellectual acts involve analogical reasoning is certainly open to debate, it does not seem unreasonable that current problem-solving efforts could be greatly influenced by previous attempts to solve problems. When confronted with a novel problem, one can frequently solve it by drawing an analogy between the novel problem and another similar problem that has a known and better understood solution. Using the information from one problem (the training problem) to solve a subsequent problem (the target problem) for which it is equally as applicable is called analogical transfer. This transfer is labelled "automatic" or "spontaneous" if it occurs without an explicit hint to the solver to use the information from the training problem. Clearly, analogical transfer can be a very useful tool for the problem solver, bringing "additional information to bear on the decision analysis and thus [filling] in some of the uncertainty surrounding the decision" (Gilovich, 1981, p. 797). Indeed, analogical transfer as a solving strategy permits the solver to circumvent having to devise a new plan of attack for the new problem.

As well, it is a strategy that, once implemented, produces a solution that is so immediate and so compelling that the solver can be very confident in the solution.

Although the attraction of analogical reasoning as a problem-solving tool is strong, it is a process that can be fraught with potential costs because correspondences between previous events and existing circumstances can occasionally be misleading. If an old problem's solution is to be used to determine or predict the solution to a current problem, the solver must be completely certain that the factors that determine their solutions are identical. Indeed, because a potential analogy may often be encoded in a different context from the situation in which one can use it, contextual barriers must be overcome for analogical transfer to occur (Gick & Holyoak, 1980; Gilovich, 1981).

In short, successful analogical problem solvers must construct mental representations of the old training problem and the new target problem. Then, they must retrieve the former and recognize it as a potential analogue to the target, mapping it onto the target. This mapping is initiated by the detection of similar scenarios or relations between the two problems. Finally, the solver must generate the parallel solution to the target. It is generally agreed that all these steps must occur for successful solving by analogy; however, they likely do not occur serially (Gentner & Toupin, 1986; Gick & Holyoak, 1980; Holyoak & Koh, 1987; Lockhart, Lamon, & Gick, 1988; Novick, 1988). As the upcoming literature review will demonstrate, the process frequently falls short because the recognition of the training passage as a potential analogue to the target often does not occur. The persistent

finding in the literature is that subjects often fail to use previous relevant information or analogous problems spontaneously to solve new problems. This failure implies that concepts are bound to the episodes in which they are first encountered. That is, much of what subjects learn appears to be stored with the context in which it is was acquired, and its access in a different context is difficult (Lockhart et al., 1988; Ross, 1989; Ross, Ryan, & Tenpenny, 1989).

It is the duty of educators to impart knowledge such that students can apply it to situations besides those in which it was taught (Bassok & Holyoak, 1989). As a result, researchers have tried to determine how one can make the relevant features of the two problems more salient so that the training problem can be recognized as a potential analogue for the target. Catrambone and Holyoak (1989) proposed that "a fruitful avenue of research may involve searching for ways of helping learners to focus on relevant features of training examples in a variety of domains and to learn to reliably identify these features in transfer problems" (p. 1154). All too often, however, researchers have attempted to produce spontaneous analogical transfer by manipulating the form of the training information in the hopes of inducing beneficial processing, or when they have decided to leave the information unchanged, they have chosen to have their subjects acquire that information under conditions that are likely incidental to problem solving. This thesis will show that when training information is processed in a problem-oriented manner, spontaneous analogical transfer is highly likely.

First, however, I now discuss the experimental literature.

Several studies demonstrate that without an explicit hint, subjects seldom transfer relevant information to a new problem. Other studies have specifically investigated analogical transfer and have concluded that without the hint, subjects rarely use a previous problem and its solution to solve an analogous target. Finally, I will describe some studies and parts of studies that provide support for the idea that problem-oriented processing of some sort is a worthwhile enterprise.

That subjects fail to make use of important relevant information spontaneously was demonstrated by Asch (1969). His subjects learned a list of letter-number paired-associates (e.g., L-34) to mastery. Subjects were then given a second list of items to learn, but unbeknownst to them, one of the pairs in this second list was a pair from the first list. Asch was interested in the number of trials it would take for subjects to learn this old pair compared with the number of trials needed to learn a new pair. Asch found that the old pair took as many trials to learn as did entirely new pairs if subjects failed to notice the old pair had previously been learned; .63 of the subjects (proportions will be reported in this thesis) failed to notice they had just learned the target pair.

Judson, Cofer, and Gelfand (1956) conducted one of the first studies of spontaneous transfer. Subjects attempted to solve Maier's (1931) Two-String problem (see Appendix B for a general version). This problem involves attaching two simultaneously unreachable cords by turning one of them into a pendulum. Prior to this solving attempt, subjects learned a list of words, in which appeared the three words "rope, swing, pendulum" one after the other. Of course, these three

words were meant as clues to the solution to the Two-String problem. Judson et al. found that, overall, subjects who had learned the list prior to the problem did not solve any more Two-String problems than did control subjects who never saw the list. Only a weak transfer effect was observed for males, and even this weak effect was not replicated by Maltzman, Belloni, and Fishbein (1964). However, when Judson et al. allowed the experimental subjects access to the list while solving the Two-String problem, they observed greater transfer than control subjects who did not have access to the list.

Another early study of spontaneous transfer was done by Weisberg, DiCamillo, and Phillips (1978). These investigators worked with Duncker's (1945) candle problem. This problem requires that subjects attach a candle to a wall so that it will burn properly. The materials available to the subject are a hammer, a small box of nails, a book of matches, and a candle. The most effective solution, to nail the box to the wall after the nails have been emptied out and to use the box as a platform for the candle is produced by fewer than .10 of control subjects (Duncker, 1945). Before trying to solve the candle problem, some of Weisberg et al.'s subjects memorized a list of paired-associates, one of which was "candle-box." After the list of nine pairs was presented, subjects had to repeat the list until they recalled two complete lists in a row. At that point, the candle problem was presented. Subjects were given the aforementioned materials and two minutes to say the correct solution. Subjects were divided into three groups. Informed subjects were explicitly told by the experimenter that a previously learned pair would provide a clue for solving the candle

problem. Association subjects were not informed of this relationship and control subjects were never given the "candle-box" pair to memorize. Of the informed subjects, .85 incorporated the box into at least one solution, and .45 used it in their initial attempt. Only .15 of the association subjects used the box in any solution and the box was never mentioned by control subjects. The informed group differed reliably from the other two groups, which did not differ from each other. Similar results were observed when the actual objects were presented in pairs prior to the candle problem, rather than a list of word pairs (.75 for informed subjects and .25 for association subjects). Therefore, the "candle-box" pair increased the number of correct solutions if, and only if, subjects knew of the connection between a pair and the candle problem.

Perfetto, Bransford, and Franks (1983), as well as Stein, Way, Benningfield, and Hedgecough (1986), argued that the pair "candle-box" and Duncker's candle problem shared little overlap in features and consequently "candle-box" conveyed little information in terms of solving the problem. There was nothing explicit in "candle-box" that told the subject to put the candle on the box after the nails had been emptied out. As a result, Perfetto et al. decided to use more informative pre-problem information. These experimenters had subjects try to solve 12 insight problems adapted from Gardner (1978). For each problem, the experimenters composed a clue statement that blatantly contained a problem's solution. A popular insight problem is the "multiple marriages problem" which reads as follows:

> "A man who lived in a small town in the U.S. married 20 different women of the same town. All are still

> living and he has never divorced one of them. Yet, he has broken no laws. Can you explain?"

The solution is that the man in the problem is a minister. The clue statement that Perfetto et al. wrote for this insight problem was "A minister marries several people each week."

Subjects were divided into three groups and all subjects had 40 seconds to solve each of the 12 insight problems. Control subjects received no clue statements. Other subjects read and rated the truth of the 12 clue statements for 20 seconds apiece, and following a five-minute break were given the 12 insight problems. Informed subjects were told that the earlier clue statements would help solve the insight problems, but uninformed subjects were not told of this relationship. Only subjects explicitly told of the connection between the statements and the subsequent insight problems accessed the previously presented statements to generate more correct solutions (.54 vs. .29 and .19, for the uninformed and control subjects who did not differ).

In a second experiment, other subjects had two opportunities to solve the insight problems. It was identical to the above experiment except that the uninformed subjects, between their first and second attempts, were informed by the experimenters of the connection between the clue statements and the problems. Their performance improved from their first attempt to their second attempt (from .26 to .41 correct solutions). In contrast, the informed subjects scored .56 and .58 respectively. The .58 vs. .41 discrepancy was caused by uninformed subjects forgetting much of the information presented in the clues. As well, these same subjects assumed that their answers from the first attempt were correct and therefore repeated them on the second attempt.

In any event, that a hint of some sort is necessary to promote transfer was reinforced by Perfetto et al.'s (1983) second experiment.

Bowden (1985) replicated Perfetto et al.'s (1983) procedure, using somewhat more blatant clue statements (e.g., for the multiple marriages problem, Bowden's clue statement was "a minister can marry several different men and women every month"). He also gave subjects two minutes to solve each insight problem (up from Perfetto et al.'s 40 seconds). The rationale behind the time increase was that Perfetto et al.'s subjects given 40 seconds to solve each problem spent only about 20 seconds engaged in the actual process of problem solving, assuming about 10 seconds were needed to read and understand the problem and another 10 seconds were needed to write the solution. For informed subjects, 20 seconds might have been sufficient, but perhaps not for uninformed subjects. Bowden found that uninformed subjects were able to access and use the relevant information to solve .54 of the insight problems, no different from the informed subjects' level of .58, but higher than the level of .29 attained by Perfetto et al.'s uninformed subjects. Interestingly enough, .36 of the insight problems were solved by Bowden's control subjects, who received no clues (.07 higher than Perfetto et al.'s uninformed subjects who had clue statements). Bowden concluded that increasing solving time increases the number of congruent solutions produced by uninformed subjects, as if increasing solving time compensates for being an informed subject.

Why should increasing the time available to uninformed subjects increase their solution rates to the level of their informed counterparts? Newell and Simon (1972) proposed that while problem

solving, the subject searches through a "problem space" that contains all possible solutions that might be considered in addition to the correct one. When subjects are alerted that the clues are relevant, their search of the problem space is constrained because the search is directed. As a result, the amount of time needed to produce the solution is decreased. With the extra time, subjects travel through their problem spaces and eventually arrive at the correct solution.

Bowden (1985) also considered whether the uninformed subjects might have caught on to the gist of the experiment. He was worried that one of the early insight problems could have been solved by the subjects on their own, without reference to a clue statement. When the subjects produced the solution by themselves, they recognized it as being one of the clue statements they rated earlier, and soon caught on to the trick of the experiment. Thinking of a clue statement <u>while</u> trying to solve an insight problem is one thing, but thinking of a clue statement <u>after</u> the solution has been produced is another. Bowden reasoned that if the uninformed subjects caught on during the experiment, their performance would change from the first five riddles to the last five more than would that of the informed subjects and control subjects. Finding no evidence of this, he argued that the data from the uninformed subjects were not attributable to catching on. Although 14 of the 20 uninformed subjects claimed to have caught on, when queried after the experiment, Bowden noted that such reports might have been inaccurate, as is frequently the case. In any event, Bowden provided evidence that subjects must at least have sufficient time to work on a transfer problem if they are to solve it using earlier information.

Ross et al. (1989) replicated Bowden's (1985) procedure exactly, yet found conflicting results. They found that the uninformed subjects solved reliably fewer problems than did the informed subjects (.58 vs. .73). After the experiment, Ross et al. asked their subjects if they noticed the relationship between the sentences and the problems, and if so, on which problem did they notice the connection. Ross et al., echoing the same concern that Bowden expressed, suggested that uninformed subjects solved one of the early insight problems on their own, without using an earlier clue, and the solution itself might have cued them to the significance of the clues. Approximately .75 of the subjects claimed to have caught on eventually, and the problem at which they caught on was scattered throughout the list. Ross et al. performed several complicated analyses that satisfied them that the subjects' reports were reasonable estimates of when they caught on. Granted, uninformed subjects did improve as they went along (.24 to .95), but so too did informed subjects (from .37 to 1.00). Furthermore, on the first insight problem (the problem at which there is likely the least chance of catching on), control subjects performed similarly to informed subjects (.32 vs. .37). However, the primary criticism of this study concerns the posttest questionnaire. It seems unlikely that after completing 12 insight problems that subjects would know <u>exactly</u> when they caught on. As well, what about the subjects who, looking back on the test after they have been queried, do notice the similarity, but at the time of test they did not; how would they respond? Also, can it ever be ruled out that a subject might lie to cover incompetency? Subjects who may have caught on towards the end of the list might say

they caught on earlier to "save face." These posttest questionnaires should reveal what was going on during the experiment, not create it.

Stein et al. (1986) examined the influence of two variables thought to affect spontaneous transfer - structural and surface similarity between training information and target problems. Structural features are those that pertain to the problem's principle; surface features concern the problem's scenario. As in the experiments above, prior to the insight problems, subjects rated the truth of clue statements that gave a problem's solution. Stein et al. manipulated the surface structure similarity between clues and problems by manipulating the similarity of words in the clues and problems. Similar surface implied problems and clues shared at least two content words. The clue statements' emphases on relevant properties of the solving principle were also manipulated. These manipulations created a 2 X 2 design, in which variable A was surface structure of the statement and problem (similar or dissimilar) and variable B was key concepts in the clue statements (concepts either caused subjects to focus on relevant principles for solving the problems or irrelevant principles). Subjects were either informed or uninformed about the connection between the clues and the problems.

Subjects transferred clue information to a problem spontaneously only if key concepts were embedded in the statements which emphasized relevant properties of the principle and had similar surface features as the problems. For example, the problem "The <u>home</u> was small because the <u>sun</u> came out; can you explain?" was solved more often if subjects rated "An igloo is a <u>home</u> that can be damaged by the <u>sun</u>" rather than "An

igloo can be damaged by the heat" or "Some Eskimos live in igloos" (the underlining is my own). Only the first clue presents "igloo" as a home in conjunction with the principle that the sun can be destructive. Even then, the level of spontaneous transfer obtained was only .40. Informed subjects performed reliably better in all comparisons than the uninformed subjects who, except for the one condition above, did not differ from control subjects who had no clue statements. For informed subjects, statements with relevant contexts produced reliably better performance than those with irrelevant contexts (.75 vs. .33). No significant difference was found between statements with similar surfaces and ones with dissimilar surfaces (.57 vs. .51).

The literature cited above refers to subjects' failure to access previously presented relevant information in statement form in order to solve a target problem. There is another body of literature that describes experiments that specifically address analogical transfer. In these experiments, subjects were given training problems that are analogous to target problems they were later asked to solve.

Gick and Holyoak (1980, 1983) had subjects attempt to solve Duncker's (1945) Radiation Problem, which is to discover how a physician can use X-rays to destroy a stomach tumour without harming the surrounding healthy tissue (see Appendix A). The so-called "convergence" solution is to focus multiple low-intensity X-rays on the tumour from many different directions simultaneously. Duncker (1945) found that this solution is usually produced by about .10 of people with no previous training. In the first experiment of Gick and Holyoak (1980), subjects read a story analogue describing a general's capture of

a fortress by having small platoons attack along several roads simultaneously (see Appendix A). They then proposed solutions to the radiation problem. Subjects were told to use the first story as a hint; also, the analogue could be re-consulted, thereby eliminating memory restrictions. About .76 of the subjects solved the radiation problem, suggesting that subjects can use a contextually-different story to solve an analogous problem.

Gick and Holyoak (1980) investigated whether subjects can use their own solutions to the training problem to help them solve the target. Subjects read the military analogue and offered possible solutions, before the radiation target was presented, accompanied by a hint ("... you may find that the first problem that you solved gives you some hints for solving the second problem, so you should try to use it if you can"). Subjects could look back and re-read the first problem and their solutions, but they were never told the correct solution to the military analogue even if they produced it themselves. The analogue was solved by .49 of the subjects. Of them, only .41 solved the radiation problem with the hint, significantly less than .76, when the solution was given in the story. Several factors could account for this discrepancy. First, the subject's own convergence solution was usually one of several possible solutions that were generated; therefore, the subject may have produced the correct answer, but was not aware that it was correct. When given the target and the hint, subjects who neglected to consider each of their guesses in relation to the radiation problem serially may have missed the critical analogy altogether. Also, some subjects may have simply failed to apply their prior solutions when

attempting to solve the radiation problem.

To this point, Gick and Holyoak (1980) simplified their subjects' task in several ways. Most importantly, subjects were explicitly told to use the analogue as an aid for solving the target. Although the hint was non-specific - that is, at no time were the subjects ever told the nature of the analogous connections - the hint still removed the need for subjects to notice the analogy spontaneously. Because the analogue was presented alone, subjects should have had no problem in seeing and understanding the analogy. In addition, that subjects were allowed to re-read the analogue if they wished eliminated any limitations of memory.

The final experiments of Gick and Holyoak (1980) investigated spontaneous analogical transfer directly as well as the effect of additional processing requirements on analogical problem solving. Subjects read three stories for three minutes each; one was the military analogue which was sandwiched between two comparably long but nonanalogous stories. After the three minutes, subjects had 15 minutes to recall the story as closely as possible, and to at least give the gist of it. After the 15 minutes, the next story was distributed and the procedure repeated. After the three problems and a five-minute break, subjects tried to solve the radiation target. Note that 23 minutes had passed since the military analogue was recalled. Subjects in a hint condition were given the same hint as above; the hint was deleted from the instructions given to subjects in the no-hint condition. After solutions to the radiation problem had been collected, subjects in the no-hint condition were asked if they thought to try and

use any of the three stories to help solve the target. Of subjects in the hint condition, .92 produced the convergence solution to the radiation problem compared to only .20 in the no-hint condition. Of the latter group, .80 said that it had never even occurred to them to use any of the earlier stories. Recall of the stories did not differ between the two groups.

Gick and Holyoak's (1980) final experiment eliminated the two distractor stories from the training phase, thereby reducing memory load. Story-first subjects read and recalled the military analogue, then tried to solve the radiation problem without a hint, and then tried to solve it with a hint. After recalling the story, .41 of subjects gave the convergence solution on their very first attempt; .35 more required the hint. Story-second subjects tried to solve the radiation problem for ten minutes, read and recalled the military analogue, had a second attempt at the radiation problem with no hint, and finally an attempt with a hint to transfer. The story-second condition is analogous to everyday events when one stumbles upon relevant information while trying to solve a problem. Before the military analogue was presented, .10 of subjects solved the radiation problem. After the military analogue and no hint, .35 solved it; another .30 solved it following the hint. There was no evidence that presenting the problem before the analogue increased use of the analogy. In both conditions, not all subjects who eventually used the story to generate the correct solution did so spontaneously. Collapsing over both conditions, .43 of subjects solved the radiation problem spontaneously, whereas a total of .76 eventually solved it.

Gick and Holyoak (1983) had subjects process the military analogue, then try to solve the radiation problem before and after a hint. Three conditions comprised Experiment 1. In the A-only condition, subjects read the standard military analogue. In the A+P condition, subjects received the story analogue supplemented with an explicit statement recapping its principle, which conveyed the essential aspects of the schema for convergence problems: "The general attributed his success to an important principle - if you need a large force to accomplish some purpose but are prevented from applying such a force directly, many smaller forces applied simultaneously from different directions will work just as well." In the P-only condition, subjects read only the statement of the principle. Before any hint, .29, .32, and .28 of the A-only, A+P, and P-only subjects solved the radiation problem compared with .50, .48, and .38 more, respectively, who solved it after a hint. Solution frequencies were not reliably different among the three conditions before a hint, after a hint, or in total. Thus, augmenting a story analogue with its principle did not increase spontaneous analogical transfer. The statement of the principle was not useless, however; the principle alone, not accompanied by any analogue led to the same amount of transfer as it plus the analogue. Once the analogue was presented, supplementing it with the principle yielded no further benefit.

A subsequent experiment by Gick and Holyoak (1983) demonstrated that the spatial diagrams  vs.  were ineffective additions to the basic military analogue. Before a hint, .23 of subjects who received the analogue and the diagrams solved the radiation

problem; not reliably different than the .40 solution rate of subjects who received only the analogue. Of subjects who received only the diagrams, .07 (or one subject) solved the radiation problem. It is likely that subjects who received only the diagrams assigned very little semantic importance to them. Following the hint, .60 of the subjects who were given only the diagrams solved the target, compared with .58 and .36 for subjects who received, respectively, both diagram and analogue and analogue only. The fact that so many subjects were able to produce the convergence solution following a hint suggests that the information to solve the problem was available in memory, yet that information was not noticed spontaneously. To this point, Gick and Holyoak (1983) have had little luck in obtaining evidence for much spontaneous analogical transfer.

What about multiple analogues? Spontaneous analogical transfer was not observed when subjects had one analogue from which to transfer the principle; would spontaneous transfer occur if subjects had two or three analogues, each providing the principle needed to solve the target? Gick and Holyoak (1983, Exp. 4) found evidence of spontaneous transfer if subjects read and made comparisons between two analogues. Of subjects working with two analogues, approximately .45 transferred the solution without a hint, compared with .21 of subjects who worked with only one analogue. However, Spencer and Weisberg (1986) were hesitant to accept these data as evidence for spontaneous transfer. They were worried about demand characteristics; that is, they argued that the spontaneous analogical transfer reported by Gick and Holyoak (1983, Exp. 4) was attributable to the subjects' beliefs that the target

had to be related to the analogues simply because they were participating in an experiment. Spencer and Weisberg typed the analogues and targets in different typefaces, printed them in different colours, and had them presented by a different individual; they separated the final training analogue from the target by six minutes. Changing inks and typefaces and adding a delay lessen the likelihood that the results could be attributable to demand characteristics. Only .05 of the subjects who had two analogues spontaneously transferred the convergence solution. Thus, presenting the analogues and targets in different contexts eliminated the unprompted transfer that Gick and Holyoak (1983) reported.

Holyoak and Koh (1987) found evidence of spontaneous transfer in the absence of demand characteristics. They implemented a delay of up to one week between the training problem and the target and altered the context in which each problem was presented. The radiation problem was the story analogue this time and a problem involving a lightbulb with a broken filament and a laser was used as the analogue (see Appendix A). Analogy subjects were students who learned the radiation problem in class (the problem is discussed in Gleitman's Psychology, 1986). Control subjects had no source analogue because they were not taught the problem in class. The testing took place from three to seven days after the Analogy subjects had gone over the problem in class. The lightbulb problem was given outside of the classroom and subjects suggested procedures to fuse the filament with the laser. To assure that subjects in the Analogy group had learned the radiation problem's solution, when subjects finished the lightbulb problem, they solved the radiation

problem. Of Analogy subjects, .81 solved the lightbulb problem and .86 solved the radiation problem. Of control subjects, .10 solved each problem.

Holyoak and Koh (1987) suggested that the spontaneous analogical transfer they reported was perhaps attributable to the fact that the radiation problem is a better training analogue than target, or, perhaps the lightbulb problem resembles the radiation problem more than does the military analogue. Because a laser resembles an X-ray more than does an army troop, it is an additional retrieval cue. The salient surface similarity and relatively complete structural mapping connect the two analogues. These ideas would be in keeping with Ross (1984), who found evidence that superficial similarity influences the retrieval of examples in statistics, and with Gilovich (1981), who showed that subjects' resolutions to several hypothetical political crises were influenced by superficial resemblances between the hypothetical crises and actual historical episodes.

Having offered this explanation, Holyoak and Koh (1987) studied surface feature and structural feature similarity as retrieval cues that facilitate spontaneous analogical transfer. Four analogues to the radiation problem were written and they served as training analogues to the radiation target. One analogue was the lightbulb story used before. The other three versions were created by altering surface (scenario) and structural (principle) similarities relative to the radiation problem. Replacing lasers with ultrasound waves and altering the constraint preventing administration of a force from one direction, varied the surface and structural similarities respectively. One analogue kept the

concrete context but altered the logical structure, one was the reverse, one kept both, and the fourth kept neither.

After reading and summarizing an analogue and a distractor task to reduce demand characteristics, subjects were given the radiation target. No hint was given before this point. When the training analogue retained high surface and high structural similarity, .69 of the subjects produced the convergence solution spontaneously, compared with .13 when both similarities were low. Relative to the .69, spontaneous transfer was hampered if either the surface similarity or the structural similarity was reduced (.33 vs. .38) while the other remained highly similar. When a hint was given to subjects unable to solve the radiation problem, a similar pattern of results was obtained, except that .81 (total before and after hint) of the high structure/low surface similarity group solved the problem, compared to .60 of the high surface/low structural similarity group. Holyoak and Koh (1987) proposed that although both surface and structural similarity had comparable effects on spontaneous transfer, only the latter had a significant impact on total transfer once a hint was given. Note that Holyoak and Koh's hypotheses focus heavily on the form of the analogous information, rather than on the specific processing by which the information is acquired.

Catrambone and Holyoak (1989) reported similar conclusions as Spencer and Weisberg (1986). Catrambone and Holyoak found that when two analogues (the military and fire-fighting stories) were presented prior to the radiation problem target, spontaneous transfer was reliably better than when one analogue was presented <u>only</u> when subjects were

asked to make specific comparisons between the two analogues (.47 vs. .16). When subjects made no comparisons between the two analogues, but merely read and summarized them, the same proportion of targets was solved as if one analogue had been presented (.16 vs. .25). The more extensive the comparisons made, the greater the spontaneous transfer. In subsequent experiments, .53 of the subjects solved the radiation problem when they were presented with three analogues and the instructions to make highly-directed, specific comparisons among the analogues. This conclusion held up if the target immediately followed the analogues or was separated from them by one week. However, in this particular experiment, subjects worked with three analogues and the target for about an hour, raising the possibility that they may have caught on to the gist of the experiment, and expected the fourth problem (the target) to be similar to the first three. Even so, the .53 level of transfer obtained is still surprisingly low.

In summary, the conclusion is that problem solving by analogy is not a strategy that is commonly adopted by university students; it is unusual for more than half the subjects to transfer an analogy spontaneously. Unless a hint is given, the prior knowledge seems to remain "inert" (Whitehead, 1929). This failure of spontaneous transfer seems to challenge common sense. "Real-world" problem solvers solve problems every day, yet they are seldom explicitly told what information they possess is relevant to a solution (Perfetto et al., 1983; Stein et al., 1986).

For what reason do subjects fail to make use of the solution from a training problem to solve an analogous target problem presented

shortly thereafter in a similar context? As mentioned earlier, theories of problem solving usually involve four requisites for success in using an analogy to solve a target problem. Transfer will not occur if there is failure to meet any of the requisites. Again, the gist of the theories is that the solver must (1) encode the target problem in a way that (2) retrieves the analogue and (3) selects the analogue rather than other irrelevant information that may come to mind during retrieval, then (4) adapt the solution procedure from the analogue to the needs of the target to solve it. Hence, transfer may not be observed for many reasons, among them, misinterpreting the target, failing to retrieve the analogue, selecting a nonanalogue, selecting an analogue whose solution was not encoded well enough to begin with, misapplying the solution procedure to the target, and so on.

Although there are several reasons for transfer to fail, subjects who receive explicit hints to use the earlier information generally achieve good solution rates on the targets. This suggests that the information sufficient for a solution is available in memory and is accessible to the solver. Therefore, failures of spontaneous analogical transfer are either because the target problem fails to retrieve the pertinent information or solving process from memory, or the information is retrieved but its relevance is not realized. One approach to overcoming such failures is to focus on problems as analyzable stimuli, training people to identify the key features of the problems. I suggest that the focus should be on how people process training problems, with an eye to tailoring that process to be like the process needed to succeed on a target problem.

In the experiments that I reviewed above, subjects were encouraged to pay attention to meaning and to process information intelligently. For example, they read analogues so that they could summarize them from memory or they made comparisons among multiple analogues. In the studies using insight problems, subjects tried to remember relevant information or they rated its general comprehensibility or truth. Although these processes are all active, intelligent, and meaningful processes, much of what they entail is incidental to the explicit needs of a problem solver. If subjects work with the training problems in the same manner as they work with target problems, perhaps an increase in spontaneous analogical transfer might be observed. The idea is to have subjects actually try to solve or explain the training analogues from scratch.

The importance of an active attempt to solve a problem is implied by memory research. Research on the generation effect shows that attempting to generate an item makes that item more memorable than if it were read intact (Slamecka & Graf, 1978). The generation component of experiments entails presenting an item in an incomplete form, and having subjects generate the complete form (e.g., generate CONTEMPORARY from C-NTEMPOR-RY). If the experimenter provides the complete form following a generative attempt, successful or otherwise, it is said that feedback has been given. If the incomplete form remains incomplete during the trial, no feedback has been given.

Kane and Anderson (1978) found that an attempt to generate followed by feedback exceeds reading and that the magnitude of the generation effect is not dependent on the success of the attempt so long

as feedback is provided. Kane and Anderson wrote several pairs of sentences; each pair had the same subject word and last word. Undetermined sentences had a last word which could not be determined from the first part of the sentence (The dove disappeared when the magician said peace). Determined sentences had a last word which could be determined from the first part of the sentence (The dove is the symbol of peace). Subjects in the read condition read complete sentences aloud for six seconds each. Subjects in the generate condition were given sentences with a blank in place of the last word. These sentences were presented for four seconds each while the subject read the sentence aloud and tried to guess the word the experimenter had chosen to complete the sentence. Then, the completed sentence was presented for two more seconds and subjects read the correct last word aloud. Subjects were given either all undetermined sentences, all determined sentences, or a mixture.

On the recall test, subjects were given the subject noun (dove), and asked to recall the last word (peace). Although the likelihood of generating the target in determined and undetermined sentences was extremely different (almost 1.00 vs. .09, according to a pilot study), the two conditions gave equivalent recall of target (.75), and both exceeded complete sentences that were read (.68). A generation effect was observed, the magnitude of which was unaffected by the success or failure of the attempt to generate the last word, so long as sufficient feedback to enable discovery of the completed form was provided.

Slamecka and Fevreiski (1983) replicated these findings using different stimuli. They assembled 48 pairs of relatively unfamiliar

opposites, such as MONOTONY-VARIETY. Varying the number of letters in the target word (VARIETY) allows a fair test of the effect of success versus failure of generation upon how well the target response can be recalled given the context (MONOTONY) as a cue. The experiment was within subjects and there were three input formats. A high-information generate format showed all of the target except two adjacent interior letters (MONOTONY-VAR__TY). A low-information generate format showed only the target's first letter (MONOTONY-V). Clearly, the target is more likely to be generated from the high-information format. The read format had the complete pair. Given the read format, subjects read the intact pair for four seconds. Given either generate format, subjects looked at the pair for four seconds and received feedback for three more seconds if they could not generate the target themselves. The findings revealed no dimunition of the generation effect by an inability to generate. No matter how Slamecka and Fevreiski analyzed their data, they demonstrated "that reading the response after trying and failing to generate it resulted in a level of recall superiority over simple reading which was fully comparable to that of successful generation" (p. 155).

These two studies showed that the size of the generation effect is the same if subjects produce the solution themselves or have it given to them by the experimenter after they have failed to produce it. That the generation effect transcends even success or failure in the generation task itself implies that the generation effect, rather than an effect of actual generating, is a consequence of whatever processing or encoding is going on during the attempt (Begg & Snider, 1987; Begg,

Snider, Foley, & Goddard, 1989). By analogy, will attempting to generate a solution to a training problem produce more spontaneous analogical transfer than reading the training problem for memory?

Rationale for Experiments in this Thesis:

Although it seems intuitive that people should routinely transfer solutions from old problems to analogous new problems, the research literature tells a different story; subjects rarely transfer the old solutions unless they are given explicit hints that the earlier information is relevant. My prediction is that more spontaneous analogical transfer will occur if training occurs under conditions that resemble the conditions under which the new problems are attempted. Why should an actual solution attempt or explanation attempt promote spontaneous transfer?

A passage is a complex stimulus that the reader can encode coherently in many ways, each of which makes some information central and other information peripheral. For example, a story can be organized on the basis of how a protagonist resolves a dilemma, or as an abstract schema that captures its gist (e.g., a convergence schema would capture the gist of the radiation problem, the military analogue, etc.). The attempt to solve a problem is different from other ways one could approach the very same passage. The solving process highlights the information and relationships that govern and determine the solving principle. Even if the subject fails to solve a problem, the attempt prepares the information so that the experimenter-provided solution is easily understood and readily integrated with it. Other coherent

organizations may not give the solving principle the same centrality; if subjects read a story in which a dilemma is solved, the solution may be encoded as just another piece of information, without the special status as a solution to a problem. Problem-oriented processing organizes information so that the solution is more salient than if subjects have read the same information. The later attempt to understand and solve a target problem may retrieve much from memory, but most of it is incidental to the solver's needs. The optimum is for the relevant training problem to stand out in the crowd on the basis of its principle, which itself is a cue for the solution procedure with which it was associated during training.

Other researchers have also proposed that how subjects process training information is the key to spontaneous transfer. Lockhart et al. (1988) investigated why subjects fail to solve insight problems despite receiving relevant information earlier. They considered a theoretical distinction proposed by James (1890) between the two aspects of elementary problem solving. One aspect is <u>learning</u>, the possessing of pertinent knowledge; the second aspect concerns the appropriate conception of a skill that James called <u>sagacity</u>.

To understand sagacity, recall the multiple marriages problem stated earlier. Solving this problem entails both the knowledge that clergymen perform marriages, and the sagacity to conceptualize the "man" in the problem as a clergyman. The subjects know that clergymen perform marriages, so the failure to solve the multiple marriages problem is a failure of sagacity. The difficulty of the problem is created entirely by not applying an appropriate conception.

The scenario of the multiple marriages problems creates problems because our dominant conception of "man" does not include multiple marriages as acceptable consequences. To solve the problem, the dominant conception must be replaced by an acceptable one. It is the need to reconceptualize that makes these insight problems difficult. Once the appropriate reconception is attained, its relevant implications become obvious. This analysis of conceptual operations needed to solve the problem suggests that there is no reason to expect spontaneous transfer from the clue statements used by Perfetto et al. (1983), because such sentences promote use of only the knowledge component (that clergymen perform marriages) and not the process of reconception. Similarly, nothing in the paired-associates training task of Weisberg et al. (1978) corresponds to altering the dominant conception of the box as a container to the less dominant conception of the box as a platform.

Lockhart et al. (1988) presented relevant information in a form that also entailed appropriate reconception. They used Perfetto et al.'s (1983) insight problems, but wrote new clue statements. Consider the difference between the statements - "It made the clergyman happy to marry several people each week." - and - "The man married several people each week because it made him happy" - followed three seconds later by the word "clergyman." These presentations are declarative and puzzle forms respectively. Although the goal state is the same for both forms, the declarative form induces the appropriate interpretation from the outset, whereas the puzzle form initially induces an inappropriate conception, but the clue word initiates a process of reconception.

Four groups of subjects were tested: control subjects solved

only insight problems and received no pre-problem information, one group of subjects read and rated for general comprehensibility a series of statements in puzzle form, another group of subjects read and rated statements in declarative form, and the fourth group read and rated the declarative statements twice. Only the puzzle form facilitated subsequent problem solving; .60 of the problems were solved. Even when declarative statements were presented twice, declarative information did not improve problem solving (.41 vs. .36; one presentation vs. two), no different from the control group (.33). Following the insight problems, subjects were given a free recall test of the acquisition statements. Subjects who received the puzzle forms and the declarative forms twice performed comparably (.50 vs. .53), and better than those subjects who read and rated declarative forms once (.28). Thus, "although information presented either in repeated-declarative sentences or in puzzle form facilitates free recall equally, only the puzzle form facilitates subsequent problem solving" (p. 39).

In a subsequent experiment, Lockhart et al. (1988) investigated whether statements in puzzle form served as a cue that alerted the subjects to the relationship between the acquisition and test phases of the experiment. If this were true, then presenting the subjects with only some acquisition statements in puzzle form should be sufficient to induce such an informed state, and all insight problems should reap the benefits regardless of the type of training sentences used. So, the primary purposes of this second experiment were to investigate the benefit of problem-oriented acquisition in a within-subjects design, and to see if the superiority is attributable to the differences in the

processing underlying particular sentences or if it is the result of a very general problem-solving set induced by the puzzle form of the acquisition task. Puzzle statements and declarative statements were randomly intermixed. This experiment showed that there was no difference between declarative and puzzle forms in terms of the percentage of insight problems solved (.59 vs. .57, respectively).

In Experiment 3, Lockhart et al. (1988) showed that "there is a substantial increase in the solution rate for declarative-acquisition problems when these problems follow a set of puzzle-acquisition forms [.78] than when they precede them [.51]" (p. 41). This suggests that a general problem-solving set has not been induced by the puzzle sentences in the acquisition phase. Therefore, the superiority of the puzzle-acquisition condition triggers an awareness of the relevance of the initial information and once such an awareness has been created, subjects become an informed group. It has been well-established that informed groups solve target problems fairly well.

Lockhart et al. (1988) concluded that the source of transfer lies not only in the content of the pre-problem information, but also in the processing underlying the acquisition of that information. Content relevance is necessary, but it is not sufficient to promote spontaneous transfer. "Problem solving is facilitated by previously presented information when this information is presented in a form that requires for its comprehension the same conceptual processing as that demanded by the subsequent problem" (p. 42).

Adams, Kasserman, Yearwood, Perfetto, Bransford, and Franks (1988) reported similar results as Lockhart et al. (1988). Adams et al.

compared solution rates on insight problems after people had rated the truth of statements that were oriented either as problems or as facts. Problem-oriented statements resulted in higher solution rates than fact-oriented statements (.54 vs. .36). For example, the multiple-marriages problem was solved more often if subjects first rated "You can marry several people each week, if you are a minister" than if they rated "A minister marries several people each week"; the former is problem-oriented whereas the latter is fact-oriented. Although the differences between the two forms appear slight, Adams et al. argued that the former does momentarily evoke a problem-solving orientation. They made reference to the memory literature and drew their own analogy with the concept of transfer-appropriate processing (Bransford, Franks, Morris, & Stein, 1979; Morris, Bransford, & Franks, 1977).

In their now classic series of experiments, Morris et al. (1977) gave subjects two different incidental acquisition tasks. One task required the subject to determine if a target word fit meaningfully into a sentence (e.g., "A _____ has ears": dog). The second task required the subject to make a rhyme judgement (e.g., "_____ rhymes with log": dog). Results indicated that target words were better recognized if they were processed semantically. However, on a test requiring recognition of words that rhymed with the target words, subjects trained on the second task exhibited superior performance. Morris et al. (1977) demonstrated that the similarity between processing at acquisition and a subsequent transfer task can affect performance. Therefore, Adams et al. (1988) concluded that the way people process problem-oriented statements is more like the processing that is appropriate for solving problems than is the way they process fact-oriented statements.

Although Adams et al. (1988) and Lockhart et al. (1988) proposed that transfer-appropriate processing is important for spontaneous transfer, their experiments manipulated the form in which information was presented to subjects, rather than processing. In the experiments conducted for this thesis, subjects received the same information before trying to solve target problems, but they worked with that information differently. After all, the goal of the education system is not to change the material so that the students can grasp it, but to change the students so they can grasp the material. As well, Adams et al. and Lockhart et al. were interested in transfer to insight problems; the interest here is with the transfer of information from training problems to analogous target problems. The idea is that Lockhart et al.'s puzzle forms and Adams et al.'s problem-oriented forms are similar to those training problems that subjects actively attempt to solve; declarative and fact-oriented forms are like training problems that subjects read for memory. Is a prerequisite for spontaneous analogical transfer the acquisition of relevant information in the manner required to solve the target problem?

In the literature, there is only weak support for my proposal. Although a few studies have had their subjects solve training problems, to my knowledge, no study has ever fully compared the consequences of different processes of acquisition of training information for subsequent transfer.

Bassok and Holyoak (1989) found evidence of spontaneous analogical transfer from analogous subdomains of algebra and physics (arithmetic progression problems in algebra and constant acceleration problems in physics; see Appendix A), after subjects had experience

solving analogues. Grade 9 and 10 students participated in the experiments of interest here. Some subjects worked with the algebra problems first and then tried to transfer principles to the physics problems; other subjects worked with the physics problems first and then tried to transfer principles to the algebra problems. The subjects' training phase was vigorous; subjects learned the training domain from textbooks and, in doing so, solved several problems for themselves. When subjects thought that they had successfully mastered the training domain, they were given a test. When the subjects had correctly answered the entire test, target problems which tested the other domain were presented. Only the subjects trained with algebra problems transferred the principles (.72 vs. .10). Bassok and Holyoak suggested that the spontaneous analogical transfer was only one-way because of an intrinsic difficulty in learning anything from physics problems (a subsequent experiment with University students found this to be the case). With respect to the correct solutions, algebra-to-physics subjects required less time to solve the transfer problems than physics-to-algebra subjects (1.31 min/problem vs. 2.37 min/problem). The extra time was attributed to the use of a more cumbersome principle, and not the efficient principle described in training.

Novick (1988) had subjects try to solve several algebra insight problems by following an experimenter-provided solution procedure, before being tested on a target problem that was analogous to one of the earlier problems (see Appendix A). Subjects were preassigned to two groups depending on their performance on SATs. Subjects preselected as poor problem solvers in general were labelled "novices" and subjects preselected as good problem solvers were the "experts." In one

experiment, Novick found no reliable difference in correct target solutions produced between the experts and novices (.81 vs. .63), although .563 of the experts used the procedure encountered during training, whereas only .063 of the novices used the trained procedure (no different from the .063 level attained by control subjects who had no training). In terms of time, the novices needed more time to solve the target than did the experts (11.3 min vs. 8.7 min).

In a second experiment, instead of training subjects on an analogue of the target, Novick gave her subjects a passage that contained a misleading procedure, although superficially, the passage sounded very much like the target (see Appendix A). The prediction was that novices might be coerced into applying an inappropriate procedure; that is, the novices might show negative transfer. Ross (1984, 1987) and Hardiman, Dufresne, and Mestre (1989) found that subjects who relied on the superficial features between two problems, as opposed to the more important structural features, often transferred an inappropriate procedure. Novick's prediction was partially confirmed when the novices showed negative transfer, but so too did the experts, and to about the same extent (.92 vs. .83). Novick's final experiment was similar to her second experiment except that in addition to the confusable nonanalogue, subjects were also given the analogue to solve during training. So, subjects had both the confusable nonanalogue and the analogue to work with during training and not just one or the other as in the first two experiments. Novick found a difference with respect to negative transfer: novices showed negative transfer by trying to apply inappropriate principles from nonanalogous training problems more often than did the experts (.73 vs. .46). Positive transfer was greater for

the experts than the novices (.54 vs. .26). Clearly, the experts were more able than the novices to go through the training passages and recognize the analogue and ignore the nonanalogue. Although the positive transfer results are encouraging, it should be kept in mind that the subjects who transferred were smarter subjects to begin with, subjects solved the training problem(s) successfully using an experimenter-provided procedure, and that Novick never contrasted different means of acquiring the training information.

Reed, Ernst, and Banerji (1974) designed a problem-solving experiment using the Missionaries and Cannibals problem and the Jealous Husbands problem (see Appendix A). These problems are related because they have identical solutions, interchanging husbands for missionaries and wives for cannibals. They are not entirely analogous, however, because the Jealous Husbands problem has one additional constraint (that husbands and wives must be paired). In one experiment, subjects solved the Missionaries and Cannibals problem first and then solved the Jealous Husbands problem. Other subjects solved the Jealous Husbands problem first and then solved the Missionaries and Cannibals problem. Subjects had to solve each problem in order within 30 minutes, and were never explicitly told of their connection. The experiment was designed to see if one problem's solution would lead to a significant reduction in the solving time, the number of required moves, and the number of illegal moves necessary to solve the second problem. Although .70 of the subjects solved both problems within 30 minutes, the analyses revealed no spontaneous transfer. Reed et al. (1974) ruled out the subjects' poor memories as a possible explanation of the results. Subjects do remember enough about how they solved a problem to reduce their solution

time when they are asked to solve the same problem a second time. Therefore, the results were attributable to the failure to recognize, or at least make use of, the analogy from the first problem. A subsequent experiment included the hint that the two problems were related. Subjects were told that "... the easiest way to solve the problem is to take advantage of your correct solution to the previous problem." The experimenter informed the subjects that the solution to the second problem was the same as the solution to the first problem if appropriate substitutions were made, e.g., missionaries for husbands. In this case, analogical transfer was observed, but only if subjects solved the Jealous Husbands problem first, suggesting that the additional constraint in the Jealous Husbands problem might be a significant factor.

Luger and Bauer (1978) investigated spontaneous analogical transfer using the Tower of Hanoi problem and the analogous Tea Ceremony problem. Half of the subjects solved the Tower of Hanoi problem first, followed by the Tea Ceremony problem; the other half solved the Tea Ceremony problem first and then the Tower of Hanoi problem. No reference was made at any time to the relationship between the problems. In fact, Luger and Bauer told their subjects that the two problems that they would have to solve were two different problems. As in Reed et al. (1974), transfer was concluded from a reduction in the solving time and number of moves needed to solve the second problem. Luger and Bauer found evidence for spontaneous analogical transfer in both groups of subjects; subjects took less time (160.5 seconds vs. 346.5 seconds) and fewer moves to solve the second problem. This study produced strong evidence for transfer between the two different problems of identical

structure. Such transfer was spontaneous because, once again, subjects were never explicitly told of the connection between the two problems. Indeed, when subjects were asked after the experiment if they noticed any similarity between the two problems, a majority of the subjects could only describe the full relationship after the experimenter had pointed it out. These results are, however, not supported by the results of Simon and Hayes (1976) and Hayes and Simon (1977), which were that subjects who solved the Tower of Hanoi problem did not show evidence of spontaneous transfer to the Tea Ceremony problem.

Reed, Dempster, and Ettinger (1985) argued that although the findings from studies such as Gick and Holyoak (1980, 1983), etc., are discouraging, the problems they used may not be representative of other kinds of problems that people encounter, such as algebra word problems. After all, algebra word problems are very easy to categorize (e.g., river-current problems, bank interest, distance-time) (Hinsley, Hayes, and Simon, 1977). The argument here is that "the categorization of problems should facilitate the use of analogy" (Reed et al., 1985, p. 106). That is, a subject trying to solve a river-current problem might try to recall previous river-current problems. Reed et al. (1985) used three different categories of algebra problems: distance, mixture, and work problems. Subjects in the related group attempted to solve a training problem followed by two target problems. They were shown the solution to the training problem after attempting to solve it, but targets were never solved, and while solving the target problems, the training problems and their solutions could not be consulted. One target problem (the <u>equivalent</u> target) was completely analogous to the training problem; that is, both it and the training problem could be

solved in the same way. The second target problem (the similar target) was similar to the training problem, but to solve it, a slight modification of the procedure used to solve the training problem was necessary (see Appendix A). These subjects were told that the solution to the training problem would help to solve the subsequent target problems. Control subjects received a training problem that was unrelated to the target problems, which were the same target problems as the related group received. The control and experimental groups did not differ reliably in terms of solving equivalent targets (.18 vs. .25) and similar targets (.07 vs. .06). The most striking difference between the two groups on the equivalent problems was that subjects who were given the related training problems generated three times as many correct equations as they tried to solve the targets as did control subjects (.29 vs. .10), suggesting that the related training problems were not useless.

In their second experiment, Reed et al. (1985) evaluated whether or not having the solutions to the training problems present while trying to solve the targets was important. Both groups of subjects received a training problem, tried to solve it, were provided with the solution procedure, and then were given an equivalent target and a similar target to solve. Again, subjects were told that the earlier training problem provided the principle necessary to solve the targets. Some subjects were treated like the related group in Experiment 1 in that they were not allowed to refer back to the training problem and its solution. The other subjects could refer back to the training problem and its solution while they were trying to solve the targets. Reed et al. (1985) found that having the solution available while the targets

were being solved helped students solve more equivalent targets than if it could not be reconsulted (.38 vs. .15), but the benefit did not generalize to similar targets (.08 vs. .07). These results indicate that the availability of a solution during problem solving is partially effective in producing more correct solutions. The failure of students to solve similar problems, even when they could consult the solution, suggests that they may not be able to modify the solution or principle enough to apply it correctly.

In their third experiment, Reed et al. (1985) combined the procedures from their first two experiments. Group 1 was the control group; it tried to solve the targets with no previous training. Group 2 tried to solve the targets with training. Group 3 was treated as was Group 2, except that subjects in Group 3 were given a much more elaborate solution and explanation to the training problem. The results were that Group 3 solved more equivalent targets than Group 2 (.69 vs. .56), who in turn, solved more equivalent targets than Group 1 subjects (.56 vs. .17). Note that this last result did not replicate the finding from Experiment 1; looking back to the solution is obviously critical for transfer. Groups 1, 2, and 3 did not differ with respect to transfer to similar targets (.04 vs. .04 vs. .09). The elaborated solution and explanation benefitted transfer to equivalent targets, but not similar targets. Note that this series of experiments investigated analogical transfer using algebra word problems, but all subjects in all groups were told that the training problem would help solve the subsequent targets (thereby eliminating the spontaneous application of analogy), and subjects in Experiments 2 and 3 could look back to the training problem and its solution.

Although a few studies have examined analogical transfer following an attempt to solve the training analogue, their results are mixed. Furthermore, I have come across only one experiment in one study investigating spontaneous analogical transfer that has compared methods for acquiring the training information, but this manipulation was not the focus of the experiment. Catrambone and Holyoak (1989, Experiment 5) gave subjects three analogues (see Appendix A) of the radiation target to work with prior to solving the target. One group of subjects had to make explicit comparisons among the three analogues after they had read them and summarized them. A second group read, summarized, and compared the first two analogues, but they were told to try and solve the third analogue (the Aquarium analogue; see Appendix A) using the information from the first two analogues. Of the subjects in the second group, .91 of them solved the Aquarium problem. These subjects solved more radiation targets than did the subjects who had read the third analogue (.83 vs. .64), however, the difference was not reliable, perhaps because of the small number of subjects (total N = 23).

In any event, the studies comparing and contrasting means of acquiring the training analogue are sparse. Given the findings of Lockhart et al. (1988) and Adams et al. (1988), the way in which the training analogues are acquired is potentially very important to the success of future problem-solving. This thesis will investigate the role of problem-oriented training in spontaneous analogical transfer.

Overview of the Experiments in the Thesis:

Three experiments investigated the role of problem-oriented processing of the training analogue in spontaneous analogical transfer.

Ten experiments compared problem-oriented training with memory-oriented training. The extent of transfer from training passages to analogous target problems was of interest. All transfer was spontaneous -- subjects were never informed of any relationship between training problems and target problems. Experiments 1, 2a, and 2b were pilot experiments, done to see if problem-oriented training can produce amounts of transfer exceeding the low amounts reported in the literature. In Experiments 3, 4, and 5, training analogues were presented as problems that some subjects tried to solve. In Experiments 6, 7, and 8, the training analogues were presented as stories describing a dilemma and its resolution; subjects tried to explain why the solution in each story was the correct solution. Following each training passage in Experiments 3 through 8, the experimenter provided the solution and its explanation. Other subjects in Experiments 3 through 8 received the same problems or stories and experimenter-provided explanations, but they were instructed to remember the training passages. Target problems either followed their analogous training passages immediately, or else no targets were tested until after subjects had worked with five different problems, only one of which was relevant to each target.

Experiments 9 through 12 were done to extend the conclusions from Experiments 1 through 8. In Experiments 9 and 10, I compared solution rates on targets after subjects had tried to explain or remember training stories. In Experiment 9, the experimenter re-read training stories without explaining their solutions. In Experiment 10, subjects tried to recall each story before trying to solve its analogous target. In Experiment 11, the way in which the training passages were processed was manipulated within subjects. Experiment 12 investigated

the problem-oriented training vs. memory-oriented training distinction in situations where several similar but inappropriate principles along with the correct principle are given to the subject to try and work through before they try to solve the target problem. These experiments, together, will demonstrate that spontaneous analogical transfer does occur frequently when the training information is processed in a problem-oriented manner and the processing is followed by appropriate feedback.

Chapter 3

PROBLEM SELECTION AND EXPERIMENTS 1, 2a, AND 2b

Problem Selection

The first task was to select difficult target problems that few subjects could solve without training. Twenty pilot subjects from the Introductory Psychology course at McMaster University volunteered to participate for course credit. Each subject received a booklet of 15 problems adapted from several sources (Fixx, 1978; Gick & Holyoak, 1983; Maier, 1931; Ross, 1987; Wallechinsky & Wallace, 1978), and spent three minutes trying to solve each problem. They were encouraged to do the best they could and were assured that although difficult, all the problems they were given were solvable. They were asked to write down whatever came to mind when solving the problems. The experiments to follow used the five problems with the lowest solution rates (see Appendix B; no subjects solved the Probability, Liar/Truth-teller, and Two-String problems, one subject solved the Poisoned Cups problem, and two subjects solved the Apples and Oranges problem). The five targets were all very different and the principle from one could not be used to solve another. Because several earlier experiments that failed to find much evidence of spontaneous analogical transfer used Duncker's

Radiation Problem as the target problem (see also Keane, 1985), I had hoped to use it in my experiments. Unfortunately, .80 of the subjects in the pilot study solved one of its analogues. Furthermore, the radiation problem is discussed extensively in Gleitman (1986), which is the textbook for McMaster University's Introductory Psychology course.

The second step was to write training analogues. Alternate forms for each problem were written. For example, the "Poisoned Cups" problem tells of a punishment that a king imposes on an embezzler, who must arrange ten cups of poison and ten cups of water into two boxes to maximize the odds that a randomly chosen cup from a randomly chosen box contains water. The solution is to put one cup of water into one box and all the remaining cups into the other box. Analogues were prepared that had a similar scenario (a queen presents the dilemma to a forger as a punishment, with eight cups of arsenic and eight cups of cider) and ones with a different scenario (a boss presents the dilemma to his street vendor employee as a prank, with 15 navy shirts and 15 white shirts). Nonanalogues were also written that changed the nature of the problem entirely (see Appendix B). For example, the nonanalogue of the Poisoned Cups problem tells of a king who tried to cheat an embezzler by presenting two slips of paper both labelled "poison," but the embezzler became aware of this and picked out one piece of paper and said "This is the one I do not want to drink." This nonanalogue is irrelevant to the Poisoned Cups target.

Experiments 1, 2a, and 2b

The purpose of Experiments 1, 2a, and 2b was to find out if

spontaneous analogical transfer will occur after subjects try to solve a training analogue and then are given the solution immediately following their attempt. I will compare solution rates on target problems after training on analogous problems with solution rates on those analogues and with solution rates on the targets after training on nonanalogous problems. I also manipulated the similarity of training problems to target problems. Holyoak and Koh (1987) proposed that new problems retrieve old information that shares relevant features with the new problems. They contrasted surface features, which include scenario and content, with structural features, which include the relations between the surface features and the principle underlying the solution. Each current feature activates memory for other problems sharing that feature. Activation from common features summates, and if the activation caused by the training problem exceeds some threshold, it becomes available for further processing.

With this in mind, I prepared, for each target, training problems with the same scenario and principle, the same scenario and a different principle, a different scenario and same principle, or a different scenario and principle. The intent was to see if, as Holyoak and Koh (1987) reported, spontaneous analogical transfer occurs only (or more) if both the scenarios and principles of the analogue and target problems are similar. Finally, the issue was investigated both between subjects and within subjects. In Experiment 1, subjects received five consecutive training-target problem pairs of the same sort. In Experiments 2a and 2b, subjects received one of each of the four sorts in random order.

These pilot experiments stacked the deck to maximize transfer. When the training was on analogous problems, the training analogue immediately preceded the target problem. Subjects tried to solve the training problems, and then they heard the correct solution and explanation. The solving principle that had just been explained was the principle needed to solve the target, and the information remained on the blackboard while the target was attempted. If I did not observe spontaneous analogical transfer under these loaded conditions, there would not be any support for the hypothesis that problem-oriented training promotes spontaneous analogical transfer.

Method

Subjects

The subjects for these and all other experiments reported in this thesis were Introductory Psychology students at McMaster University who participated in the experiments as a course requirement. Each subject could participate in only one experiment. In Experiment 1, 44 students participated; 26 were trained on analogues of the target problems, and 18 were trained on nonanalogues. In Experiment 2a, 29 students were assigned at random to four conditions with 7 or 8 subjects each. In Experiment 2b, 32 subjects were assigned at random to four conditions with from 6 to 9 subjects each.

Materials: Experiment 1

Each subject received a typewritten booklet of 10 problems, each on a separate page. The five target problems were the second, fourth, sixth, eighth, and tenth problems in the sequence. The order of targets

was as follows: Apples and Oranges, Two-String, Liar/Truth-teller, Probability, and Poisoned Cups.

Analogue condition. For subjects in the analogue condition, each target problem was preceded by an analogous training problem (see Appendix B). Two training analogues were prepared for each target, one of which preserved the basic scenario of the target, and one of which described a different scenario. As will be shown, the manipulation of scenario had no reliable effects, so the data were averaged. The analogues with different scenarios are in Appendix B; note that the training analogues shared some words in common with the target problems, which may account for the lack of effect observed when the scenario was changed (Gentner & Landers, 1985).

Nonanalogue condition. For subjects in the nonanalogue condition, each of the above analogues was rephrased to change the nature of the problem (see Appendix B). It would be useless to apply the principle of the nonanalogue to the target.

Procedure: Experiment 1

Subjects were told that their contribution to the experiment consisted of solving ten problems. Like subjects in all the experiments to be reported in this thesis, they were encouraged to do their best, and told that although the problems were difficult, they were all solvable. They were asked to write down whatever came to mind when solving because it might be an important part of the solution. They were told that if a problem called for mathematical manipulation, they need not compute the answer, but should write down the steps and numbers needed to get to the answer (this instruction was applicable only to the

Probability target and its analogues and nonanalogues). Subjects were told to work on each problem for the time allowed, and not to flip ahead until given the signal by the experimenter. Because of Bowden's (1985) findings, subjects were given three minutes to attempt each problem. Then, the correct solution and its explanation were given to the subjects by the experimenter, using the blackboard to facilitate understanding. It took between 60 and 75 seconds to explain each solution to the subjects. Training and target problems were solved and the essence of the solution remained on the blackboard for the three minutes that the subjects attempted the next problem. Subjects were informed at the start of the experiment that all problems would be solved for them. Training problems could not be re-read, and no hints were ever given about the similarity between training analogues and target problems. The session lasted approximately 45 minutes.

Materials and Procedure: Experiments 2a and 2b

In Experiments 2a and 2b, each subject was trained both on analogues and on nonanalogues before trying to solve targets. Target problems were the second, fourth, sixth, and eighth problems in an eight problem sequence, and each problem occupied the same position it occupied in Experiment 1; the Poisoned Cups problem was not used. Recall from above that there were two training analogues and two nonanalogues for each target. For subjects in Experiment 2a, there were four presentation conditions, so that each problem was preceded by each alternate form. Each subject was trained on analogues of two targets and nonanalogues of the two other targets; although one of these was the "same scenario" version and one was the "different scenario" version,

these data will be averaged because there were no reliable differences. The only difference between Experiments 2a and 2b was that new training analogues and nonanalogues were prepared for Experiment 2b (see Appendix B). All instructions and procedures were identical to those in Experiment 1.

Results and Discussion

In these and all subsequent experiments reported in this thesis, performance on target problems was scored independently by two individuals, to ensure reliability. Responses were scored as 1 (correct) or 0 (incorrect). Responses were correct if subjects wrote the solution; no explanation was needed except for the Apples and Oranges target, and even then, only a brief explanation was required. A stringent scoring system was used for all the experiments. Answers that were "nearing the right track," although few, were scored wrong; such answers merely noted the resemblance between the problems without using the information from the first to solve the second. It would do little good if one could recognize two problems as similar if one could not use the information from the first to solve the second. The definition of analogical transfer requires that the information from the first problem be used to solve the second, not simply that the resemblance between the two problems be noted. The reported means are proportions, MSe's are squared proportions, and α was .05 for all statistical inferences in this thesis. See Table 1 on page 61 for the tabled results.

Experiment 1

Experiment 1 compared subjects who were trained on analogues of

the target problems with subjects who were trained on nonanalogous problems. Mean solution rates are shown in the left column of Table 1. Without training, subjects rarely solved the targets. For the 18 subjects trained on nonanalogues, the mean solution rate for targets was .056. Similarly, the 26 subjects trained on analogues rarely solved the analogues, with a mean solution rate of .031. These two solution rates did not differ reliably [$F(1,42) < 1$, $MSe = 0.0086$]. In contrast, after relevant training, subjects were nearly perfect on the targets, with a mean solution rate of .938 (.986 vs. .883; same vs. different scenario). Of course, this solution rate exceeded the rate achieved by the same subjects on the training analogues [$F(1,25] = 926$, $MSe = 0.012$] and it reliably exceeded the rate achieved by the subjects whose training was on irrelevant problems [$F(1,42) = 455$, $MSe = 0.018$].

The low solution rates on the targets following irrelevant training validate the difficulty of the target problems. Nonetheless, nearly all the targets were solved after subjects had tried to solve a training problem that called for the same principle; they usually failed in the attempt, which means that the principle was learned when the training problem was explained to them. Because subjects received no hints, they transferred the analogous principle spontaneously from the training problem to the appropriate target. Furthermore, .96 of the subjects solved the very first target problem when it was preceded by a training problem with the same principle.

Details. Subjects tended to solve all the target problems after training but none of them otherwise. Of the 18 subjects trained on irrelevant problems, 14 solved no targets, three subjects solved one

target, and one subject solved two targets. Of the 26 subjects who first tried to solve analogues, 22 solved no analogues, four solved one each; after training, 21 solved all five targets, three solved four, one solved three, and one solved two. The first target problem was Apples and Oranges: before training, 0/26 solved an analogue, but after training 25/26 solved the target, compared with 2/18 subjects whose training was on irrelevant problems. The second target was the Two-String problem: before training, 0/26 subjects solved an analogue, but after training 25/26 solved the target, compared with no subjects trained on a nonanalogue. The third target was the Liar/Truth-teller problem; before training, no subjects solved an analogue, but after training all 26 subjects solved the target, compared with no subjects whose training was on nonanalogues. The fourth target was the Probability problem; before training, 1/26 subjects solved an analogue, yet after training, 23 of them solved the target, compared to one of the subjects trained on nonanalogues. Finally, the fifth target was Poisoned Cups; before training, 3/26 subjects solved an analogue, but after training, 23/26 solved the target, compared with 2/18 of the subjects who were trained on nonanalogues.

Experiments 2a and 2b

Each subject attempted two targets after training on analogues, and two targets after training on irrelevant, nonanalogous problems. As shown in Table 1, subjects in Experiment 2a solved .138 of the training analogues. They solved .845 of the targets after analogous training, but they solved only .017 of the targets after training on nonanalogues [$F(2,56) = 135$, $MSe = 0.043$, LSD = .109]. In Experiment 2b, the

Table 1. Proportion of Targets solved in Experiments 1, 2a, and 2b.

	Experiment 1	Experiment 2a	Experiment 2b
Problem Type			
Training Analogues	.031	.138	.031
Target Problems following Analogous Training	.938	.845	.734
Target Problems following Nonanalogous Training	.056	.017	.078

solution rate on analogues was .031, the rate for targets following analogous training was .734, and the solution rate on targets following irrelevant training was reliably lower, .078 [$F(2,62) = 84.9$, $MSe = 0.058$, LSD = .121]. A possible reason for the .845 vs. .734 discrepancy was that in Experiment 2b, the training nonanalogues were rewritten to sound more like the target problems, with the intent to see if subjects could be enticed into applying an inappropriate solution. This may have created an air of uncertainty that may have passed over to targets following analogous training; that is, subjects were reluctant to transfer an appropriate principle because of their earlier inability to transfer what they had believed to be an appropriate principle. However, there was no adhered-to system for writing these training nonanalogues and for making comparisons amongst them; therefore, the entire manipulation was not evaluated. In each case, solutions were rare without training but common with training.

Details. What follows are the descriptive data for the four

problems, summed over Experiments 2a and 2b. First was Apples and Oranges; its analogues were solved by 7/29 subjects, after training it was solved by all 29 subjects, compared with 2/32 subjects who solved it after nonanalogous training. Second was the Two-String problem which for some reason was especially difficult; before training, its analogues were solved by no subjects, but with analogous training it was solved by 15/32 subjects and with irrelevant training, it was solved by no subjects. Third came the Liar/Truth-teller problem; before training, no subjects solved its analogues, yet after training, the target was solved by 26/32 subjects and with irrelevant training, it was solved by no subjects. The fourth target was the Probability problem; before training it was solved by 3/29 subjects, and after training it was solved by 25/29 subjects and with irrelevant training, it was solved by 5/32 subjects. Despite the occasional variability in solution rates, each problem was much more often solved after analogous training than either before training or after irrelevant training.

Summary and Conclusions

On their own, the target problems used are very difficult. Subjects rarely solved the training analogues and rarely solved the targets unless they had experienced training on relevant principles. Despite the difficulty of the target problems, the subjects solved them with regularity following training on problems that were analogous in principle to the targets. This positive spontaneous transfer was apparent on the very first analogous target problem whether all targets were preceded by an appropriate analogue (Experiment 1) or only some

were preceded by an analogue (Experiments 2a and 2b). Although the amount of transfer (around .84 on average) was fairly impressive given the earlier literature, it may not be all that surprising. After all, the training problem was solved and the principle explained immediately before the target and what was told to the subjects remained on the blackboard while the target was being attempted. Similarly, the lack of success on the targets for the subjects trained with nonanalogues might not be all that surprising either. After all, the targets were chosen because of their inherent difficulty. Subjects trained on nonanalogues really had nothing relevant to transfer.

In the experiments that follow in this thesis, all subjects will have had relevant training before attempting target problems. The contrast will be based on what sort of training they had with the training problems. If the transparency of the relationship between each training analogue and its target is the reason for the relatively high levels of transfer obtained, then similarly high levels should be observed whenever the solutions to the analogues have been explained to the subjects. If it is the processing of the training analogue that is the important factor then the explanation following the training problem should benefit only those subjects who process the training analogue appropriately. These pilot experiments suggest that problem-oriented processing leads to high levels of spontaneous analogical transfer, but would equally as high levels be reached with another type of processing? The following experiments will answer that question and extend these conclusions further.

Chapter 4

PROBLEM-ORIENTED TRAINING VERSUS MEMORY-ORIENTED TRAINING WHEN TRAINING ANALOGUES ARE PRESENTED IN PROBLEM FORM: EXPERIMENTS 3, 4, AND 5

Experiments 3, 4, and 5 examined solution rates on target problems after people were trained on analogous problems. Training information was presented in problem form, that is, as problems ending with a question mark, needing a solution (see Appendix B). A few procedural modifications were made in Experiments 3, 4, and 5 (and subsequent experiments as well) to rule out possible objections to Experiments 1, 2a, and 2b as demonstrations of spontaneous analogical transfer. First, all training problems had the same principle needed to solve the targets, but they each had a different scenario than their corresponding target. Second, target problems were not solved for the subjects by the experimenter, in case solving the targets highlights the relationship between each target and its analogue because of the similarities in the wording of their solutions. Third, the blackboard was again used to explain the solutions of the training problems, but it was erased before each target was presented. Fourth, different orders of problems were used in case the particular order of problems in the

pilot experiments was responsible for the high solution rates.

In Experiments 3, 4, and 5, two training procedures were contrasted. In memory-oriented training, subjects tried to remember each analogue. In problem-oriented training, subjects tried to solve each analogue. After each training problem was processed in the required way for three minutes, the experimenter solved the problem and explained the solution to all subjects.

Experiments 3, 4, and 5 each had a different sequence of events. In Experiment 3, each target problem immediately followed its analogue. Thus, Experiment 3 could be likened to five "mini" experiments. This procedure was used to allow comparison with the research reviewed earlier, most of which used only one problem and its analogue in the entire experiment. In Experiment 4, all five training analogues were presented, and then the targets were tested in the same order as the training analogues had been presented. This gave subjects a stockpile of principles from which to select when solving the targets. Note that the subjects had no way of knowing that the sixth problem in the sequence, which was the target for the first analogue, was anything other than a brand new problem. In Experiment 4, the delay between a training problem and its analogous target was approximately 16 minutes. In Experiment 5, the order of targets was different from that of training problems. This experiment would rule out the possibility that any high levels of spontaneous transfer, if observed, in Experiment 4 were because of any significant retrieval cue that a yoked order might have provided. Experiments 4 and 5 provide stringent tests of whether problem-oriented training promotes learning, rather than just priming

the solution for the very next problem encountered. This procedure resembles that used by Ross (1987) and Novick (1988), except that their subjects had experimenter-provided procedures to follow when solving training problems, whereas my subjects had nothing beyond their own wits of which to avail themselves.

Other subjects received the same training problems and experimenter-provided explanations as the subjects who tried to solve the training problems, but these other subjects were told to remember the training analogues. Memory-oriented training was chosen as a comparison for several reasons. First, the experimental literature well documents the fact that intentional memory instructions promote meaningful processing of materials. Second, many previous researchers have used procedures that, like memory, require meaningful processing of the information, but do not require actual attempts to solve the training analogues. Third, the comparison between solving and remembering is directly analogous to the contrast used in experiments that investigate the generation effect. Fourth, if the relationship between each training analogue and its target is transparent, then the rememberers should show improvement over problem pairs in Experiment 3, in which the analogue-target pairs were blocked together. And fifth, because many students' preferred way of preparing for an examination is memorizing the to-be-tested information, remembering as a strategy has ecological validity.

In summary, Experiments 3, 4, and 5 examined spontaneous analogical transfer from training analogues to targets after subjects tried to remember training problems or tried to solve them. If trying

to solve a problem makes its solution procedure more salient than trying to remember it, solutions to training analogues will be transferred more readily after an attempt to solve the analogue than after an attempt to remember it, even though each training analogue had the same principle as its target, and the solution and principle were stated and explained by the experimenter after each training problem. This is what the idea of transfer-appropriate processing would predict.

Method

Subjects

In Experiment 3, 71 students from the subject pool were assigned at random to two conditions. Subjects in the memory-oriented condition received their problems in one of the three orders, with 17, 5, and 11 subjects receiving each order; subjects in the problem-oriented condition received their problems in the same three orders, with 20, 7, and 11 subjects receiving each order. In Experiment 4, 57 other subjects were assigned at random to two conditions, with 33 students in the memory-oriented condition and 24 in the problem-oriented condition. In Experiment 5, 22 other students were assigned at random to two conditions; 12 subjects were in the memory-oriented condition and 10 subjects were in the problem-oriented condition.

Materials

Subjects were given a ten-page booklet with one problem typed at the top of each page, with space beneath it for the solution. Five problems were the five target problems from the previous experiments. The other five problems were the training analogues, three of which were

identical to ones from the earlier experiments. The other two analogues were rewritten, but for no specific reason (see page 153 of Appendix B). Training information was presented in problem form, that is, as problems ending in a question mark, without a solution. The difference between Experiments 3, 4, and 5 was in how the analogues and the targets were sequenced.

Experiment 3. Training problems were problems #1, #3, #5, #7, and #9 and the target problems were #2, #4, #6, #8, and #10 in the sequence. The first training problem was an analogue of the first target (problem #2), the second training problem was an analogue of the second target (problem #4), and so on. Three presentation orders were used; order of targets was randomly determined such that the first target in each order was different, as well as the last target. Each target problem occupied three of the five positions, and each position was occupied by three of the five targets. The three orders used were as follows:

Order #1: Apples and Oranges, Two-String, Liar/Truth-teller, Probability, Poisoned Cups;

Order #2: Liar/Truth-teller, Poisoned Cups, Probability, Two-String, Apples and Oranges;

Order #3: Poisoned Cups, Probability, Two-String, Apples and Oranges, Liar/Truth-teller.

Experiment 4. The five training problems were presented in a block, followed by the five target problems in a block. The first training problem was an analogue of the first target (now the sixth problem in the decade), the second training problem was an analogue of

the second target (now the seventh problem in the decade), and so on. The average delay between the training and target problems was 15.75 minutes. The order used was Order #3 from Experiment 3.

Experiment 5. Again, training problems were problems #1 to #5, and targets were #6 to #10 in the sequence. And again, the average delay between the training and target problems was 15.75 minutes. This time, however, training problems and target problems were blocked randomly. That is, the first training problem was analogous to the fifth target, which arrived 30.25 minutes later. The second training problem was analogous to the fourth target, which came 23 minutes later. The third training problem was analogous to the second target, which followed 12.75 minutes later. The fourth training problem was analogous to the first target (5.5 minutes later). The fifth training problem was analogous to the third target (7.25 minutes later). The order of targets used was Order #1 from Experiment 3.

Procedure

All subjects were told that they would receive a series of problems. Training problems were presented for three minutes, after which the experimenter solved the problem and explained the solution. The correct solution and explanation required 60 to 75 seconds, and were read to the subjects, using a blackboard to facilitate understanding (see Appendix C). The blackboard was erased before the next problem was presented. Target problems were also presented for three minutes, during which time all subjects tried to solve the problems, writing their answers; training problems could not be reconsulted. Targets were never solved by the experimenter. Subjects

were always reminded of their task before each problem was presented. The subjects were not told of the relationship between the targets and their analogues. Sessions lasted about 45 minutes.

Problem-oriented condition. Subjects in the problem-oriented condition were told that their contribution to the experiment consisted of solving ten problems. Subjects were encouraged to do their best, and told that although the problems were difficult, all were solvable. They were asked to write down whatever came to mind when solving. Subjects were told to work on each problem for the time allowed and not to flip ahead in the booklet until given the signal to do so by the experimenter.

Memory-oriented condition. Subjects in the memory-oriented condition were told that they would be presented with problems, some of which they would have to memorize, and others that they would have to solve. They were told that they would have to recall the problems, so they should work hard at remembering them (because of time constraints, this test was not administered). The problems that the subjects had to remember were the training analogues, and the ones that they had to solve were the target problems. Each training analogue was explained as in the solution condition. In Experiment 3, subjects were to remember each training analogue, which was then explained, after which they attempted the related target which was never solved for them. In Experiments 4 and 5, no solutions were attempted until all five training analogues had been presented to memorize, with explanations following each one.

Results and Discussion

Spontaneous analogical transfer was assessed from performance on target problems. Target problems were scored as before. Subjects rarely solved the training problems, with solution rates less than .05 in each group in each of the three experiments. To test the prediction that problem-oriented training will lead to superior performance than memory-oriented training, the problem-oriented and memory-oriented conditions in each of the three experiments will now be compared.

Experiment 3

The three orders of presentation did not differ in solution rates (memory-oriented condition: .600, .680, and .636; problem-oriented condition: .860, .857, .891) so they were averaged for analyses. Solution rates on targets were reliably higher for the subjects in the problem-oriented condition than for those in the memory-oriented condition [.868 > .624; $F(1,69) = 21.6$, $MSe = 0.049$], as shown in Table 2 on page 72. The purest measure of spontaneous analogical transfer is from performance on the very first target in the conditions, because performance on the later targets could be influenced, either for better or worse, by the earlier trials. Solution rates on the first problem were higher for the problem-oriented condition than for the memory-oriented condition [.816 > .485; $F(1,69) = 9.57$, $MSe = 0.202$].

Details. Neither condition showed improvements in performance over the five target problems [memory-oriented condition: .485, .727, .727, .515, .667, $F(4,128) = 2.26$, $MSe = 0.0080$; problem-oriented condition: .816, .974, .868, .816, .868, $F(4,148) = 1.48$, $MSe = 0.0043$]. Over the three orders, each target occupied three of the five positions,

Table 2. Proportion of targets solved in Experiments 3, 4, and 5; training analogues were in problem form.

	Proportion of Targets Solved	
	All 5 Targets	1st Target Only
Experiment 3		
Problem-oriented condition	.868	.816
Memory-oriented condition	.624	.485
Experiment 4		
Problem-oriented condition	.867	.917
Memory-oriented condition	.655	.667
Experiment 5		
Problem-oriented condition	.920	.900
Memory-oriented condition	.483	.250

Table 3. Proportion of subjects who solved each number of targets in Experiments 3, 4, and 5.

	Number of Targets Solved					
	0	1	2	3	4	5
Experiment 3						
Problem-oriented condition	.000	.000	.079	.053	.342	.526
Memory-oriented condition	.030	.061	.242	.303	.152	.212
Experiment 4						
Problem-oriented condition	.000	.000	.000	.125	.417	.458
Memory-oriented condition	.030	.061	.182	.212	.363	.152
Experiment 5						
Problem-oriented condition	.000	.000	.100	.000	.100	.800
Memory-oriented condition	.000	.167	.417	.250	.167	.000

and each position was occupied by three of the five targets, resulting in 15 target X position cells. In the memory-oriented condition, only two of these 15 cells contained solution rates greater than .800 (the Two-String problem in Orders #1 and #2). In the problem-oriented condition, all but two cells were solved by over .800 of the subjects (the Probability target in Order #1 at .750, and the Liar/Truth-teller target in Order #2 at .571). Furthermore, in 14 of the 15 individual cell comparisons, performance in the problem-oriented condition exceeded that in the memory-oriented condition; the average difference was .257. The exception was with the Two-String problem in Order #2; all five subjects solved it in the memory-oriented condition, whereas only six of seven subjects solved it in the problem-oriented condition. Despite a little variability, subjects tended to be very successful on any target if they had tried to solve its analogue and they tended to have more modest success after trying to remember the analogue. Overall, for subjects in the problem-oriented conditions, .868 solved four or five targets, whereas for subjects in the memory-oriented conditions, only .364 solved four or five targets (see Table 3 on page 72). Table 3 has been included to show that the mediocre performance of the subjects in the memory-oriented conditions is not due to a bimodal distribution; that is, it is not the case that subjects in the memory-oriented conditions can transfer the analogies either perfectly or not at all. On average, the number of targets solved by most subjects in the memory-oriented condition of Experiment 3 was three.

Because only three problem orders were used, it is not possible to compare positions without confounding by problems. However, it is

possible to have an unconfounded comparison between mean performance on the first two targets and mean performance on the last two targets, with means weighted equally regardless of how many subjects were in the conditions. For the memory-oriented condition, mean solution rates for the first two and the last two problems were .577 and .645 respectively. For the problem-oriented condition, the respective values were .866 and .900. Neither condition showed much improvement over trials. It seems that subjects in the memory-oriented condition did not learn to learn; the memory-oriented condition certainly had much more room to improve than the problem-oriented condition.

Furthermore, for each individual target problem, there was no evidence of improvement as a function of where the problem was positioned in the orders. For example, for the memory-oriented condition, when the Apples and Oranges problem was the first target, .353 of subjects solved it, compared with .545 when it was the fourth target, and .400 when it was the final target. In the problem-oriented condition, the corresponding values for the Apples and Oranges target were .900, .909, and 1.000. In fact, for the problem-oriented condition, performance on the target was always very high no matter where the target appeared in the group, and as the individual cell comparisons above demonstrate, it was almost always higher than the corresponding comparisons with the memory-oriented condition.

Experiment 4

In Experiment 4, performance on the five targets differed in the memory-oriented condition [$F(4,128) = 7.13$, $MSe = 0.0068$]; the Two-String target (the third target, .970) exceeded the other four (.576)

which did not differ [$F(3,96) = 1.28$, $MSe = 0.013$]. There was not a reliable difference in solution rates over the five targets in the problem-oriented condition [$F(4,92) = 1.67$, $MSe = 0.0047$]. In any event, as Table 2 shows, more targets were solved by subjects in the problem-oriented condition than by the subjects in the memory-oriented condition over all five targets [.867 > .655; $F(1,55) = 13.5$, $MSe = 0.046$], over the four targets, omitting the Two-String target [.854 > .576; $F(1,55) = 16.7$, $MSe = 0.064$], and on the very first target problem [.917 > .667; $F(1,55) = 5.21$, $MSe = 0.167$].

Details. In the problem-oriented condition, performance levels were .917, .750, .917, .792, .958 over the five targets, compared to the respective values of .667, .606, .970, .455, .576 in the memory-oriented condition. Transfer was not greater for the solvers than the rememberers for the Two-String problem. Surprisingly, even after enjoying great success with the third target, the performance of memory-oriented subjects on the fourth and fifth targets was still very low. Even including the Two-String problem, however, .515 of the memory-oriented subjects solved four or five targets, compared with .875 of the subjects in the problem-oriented condition (see Table 3).

Experiment 5

In Experiment 5, as Table 2 shows, more targets were solved by subjects in the problem-oriented condition than by subjects in the memory-oriented condition over all five targets [.920 > .483; $F(1,20) = 26.9$, $MSe = 0.039$], and on the very first target [.900 > .250; $F(1,20) = 14.6$, $MSe = 0.158$].

Details. There were no reliable effects of position in the

memory-oriented condition or the problem-oriented condition [$F(4,44)$ = 2.33, MSe = 0.0096; $F(4,36) < 1$, MSe = 0.0021]. For interest, I now show the mean solution rates for both conditions for each of the five problems, and compare the results with the results for the subjects in Experiment 3 who received the five targets in the same order, but interleaved with the training problems. The overall means from Experiment 3 for the problem-oriented condition and memory-oriented condition were .860 vs. .600, with respective values of .920 vs. .483 in Experiment 5. For Apples and Oranges, the respective means in Experiment 3 were .900 vs. .353, and they were .900 vs. .250 in Experiment 3. For Two-String, means for the respective experiments were .950 vs. .824, and 1.000 vs. .667. For Liar/Truth-teller, they were .850 vs. .705 and .900 vs. .417. For Probability, they were .750 vs. .353 and .900 vs. .333. For Poisoned Cups, they were .850 vs. .764 and .900 vs. .750. The point to note is how little difference it makes to go from having each target immediately follow its training analogues to having five training analogues first, then testing transfer to targets presented an average of 15.75 minutes later, in an unpredictable order. The solvers were given no reason to believe that the first target would be anything other than just another novel problem.

Summary and Conclusions

The memory-oriented subjects in Experiments 3, 4, and 5 showed more transfer (about .60) than in previous research, and were well beyond the .05 solution rate achieved by problem-oriented subjects on the training problems. Although memory-oriented processing was fairly

successful in promoting transfer, subjects solved many more target problems after trying to solve training problems than after trying to remember training problems. Instructions to remember may reduce the chance that information is processed in a problem-like way. If so, the solution provided by the experimenter may be just one more thing to remember, rather than the missing piece that completes the puzzle.

Subjects who tried to solve training problems usually succeeded on targets that required the same principle, despite the fact that their attempts to solve the training problems failed .95 of the time. Whatever processing transpires during the attempt allows the subject to grasp the solution in a way that ensures that it can be applied later to the appropriate target. Like the research on the generation effect, the present research shows an advantage of advance effort for later performance. The advance effort is insufficient for later success because subjects fail in the training phase; they cannot transfer a solution to another problem if they do not know the solution. The benefit of advance effort is that it prepares the system to accept the solution as feedback to the attempt, rather than as just another fact that may be no more important than any others the subjects have encountered.

In Experiment 3, each target immediately followed a training analogue whose solution was explained to the subjects. The results from Experiment 4 were nearly the same, even though target problems followed training problems by about 16 minutes, at which time subjects had five different principles to select from if they thought to do so. The results from Experiment 5 were nearly the same, although there was again

an average delay of about 16 minutes between each training problem and its target, and the targets were tested in a different order than the training problems were explained. Thus something relatively long-lasting is learned if subjects try to solve the training problems.

These experiments clearly show an advantage for trying to solve problems on one's own over trying to remember problems, even though in each case the solutions were provided and explained to the subjects, and even though the problem-oriented subjects nearly always failed to generate the correct solutions. A metaphor that captures the concept is tilling the soil before planting a seed. Tilling is advance effort that will not accomplish anything unless a seed arrives, and it does not matter whether the gardener has a seed to plant or the seed arrives by some other means. Furthermore, the seed alone is useless without the tilling.

The results of Experiments 3, 4, and 5 are in complete accordance with both the generation effect and transfer-appropriate processing. The attempt to generate followed by feedback led to greater transfer than the memory effort followed by feedback. In terms of transfer-appropriate processing, the attempt to solve the training problem involves the same processes that are needed to solve the target, whereas the memory attempt involves different processes than those needed when solving the target.

Chapter 5

PROBLEM-ORIENTED TRAINING VERSUS MEMORY-ORIENTED TRAINING WHEN TRAINING ANALOGUES ARE PRESENTED IN STORY FORM: EXPERIMENTS 6, 7, AND 8

In Experiments 3, 4, and 5, a clear benefit was shown for problem-oriented training over memory-oriented training when the training passages were presented in problem form. The studies reviewed in the Introduction presented training material as stories describing a dilemma and its solution. It was therefore of interest to see if the advantages of problem-oriented training would be as prevalent with training materials presented in story form. These training passages were created by taking the final line or two out of the problem form version and adding a few sentences which contained the solution (see Appendix B).

What type of problem-oriented training could be used with passages that already contain a solution? Instead of trying to solve problems, subjects in the problem-oriented conditions tried to explain why the solutions were correct. The experiments in this chapter compare spontaneous analogical transfer for subjects who tried to explain the solutions in training passages with subjects who tried to remember the

stories for a later recall test. It is not the attempt to solve per se that is responsible for transfer, but rather the processing carried out during the attempt. The attempt to explain, like the attempt to solve is a case in which materials are processed in problem-oriented, puzzle-like ways. If so, Experiments 6, 7, and 8 should demonstrate the same benefit for problem-oriented training instructions as was observed in the preceding three experiments.

Because the problems that are being used are so difficult, it is highly unlikely that subjects will explain them well. The difference between rememberers and explainers lies in how the subjects incorporate the experimenter-provided explanation of the principle underlying the solution. Much earlier research has investigated the use of explanation in problem-solving tasks, although not comparing it to an alternative. For example, Brown and Kane (1988) found that children who explained analogues were more likely to transfer to target problems than children who received an explanation supplied by the experimenter. However, the problems that these investigators used were easy, and the children generally came up with the correct explanations on their own. Chi, Bassok, Lewis, Reimann, and Glaser (1989) found a positive correlation between the quality of subjects' explanations of training problems and their success with target problems. Dominowski (1990) gave subjects the nine-dot problem to solve and found that the solution accompanied by its explanation led to greater performance on a second try with the same problem than just the solution. Recall that Reed et al. (1985) found evidence of analogical transfer using algebra word problems when the explanation of the training analogue was extensive. Klaczynski,

Gelfand, and Reese (1989) and Berry (1983) worked with versions of Wason's (1966) four-card problem. Thematic versions involved real-world situations ("If a person is driving a car, he must be 16 or older") and abstract versions involved abstract concepts ("If there is an A on one side, there must be a 7 on the other"). Klaczynski et al. found that explanations of abstract reasoning problems facilitated transfer to other abstract problems, and Berry found that reasoning transferred from thematic problems to abstract problems when subjects heard an explanation and verbalized the reasoning behind it.

So, will a failed attempt to explain a solution prepare the subject for the experimenter-provided explanation better than an attempt to memorize, and therefore lead to an increase in spontaneous analogical transfer? Given that explaining is problem-oriented and memorizing is not, the prediction is that an attempt to explain will result in higher levels of spontaneous analogical transfer than memorizing.

Experiments 6, 7, and 8 were exactly parallel to Experiments 3, 4, and 5. The only difference was that in the problem-oriented conditions, subjects were told to explain how and why the solution given in the passage was the correct solution. In Experiment 6, the problems were sequenced so that each training story was explained and was followed immediately by the target problem for which the solution was relevant. In Experiment 7, the training stories were the first five passages, followed by the five targets in the same order as the training analogues, with an average delay of approximately 15 minutes. Before encountering the first target problem, subjects will possess a stockpile of five principles. Experiment 8 was similar to Experiment 7 except

that in Experiment 8 the order of testing the targets was different from the order in which their principles were explained during training.

Method

Subjects

In Experiment 6, 85 subjects from the subject pool were randomly assigned to two conditions. In the memory-oriented condition, 12, 8, and 20 subjects received the problems in each of three orders; in the problem-oriented condition, the same three orders were presented to groups of 14, 10, and 21 subjects. In Experiment 7, 53 subjects were assigned at random to two conditions with 25 in the memory-oriented condition and 28 subjects in the problem-oriented condition. In Experiment 8, 23 subjects were randomly assigned to two conditions with 13 subjects in the memory-oriented condition and 10 subjects in the problem-oriented condition.

Materials

The materials were the same as those used in Experiments 3, 4, and 5, except that each analogue was rewritten as a story in which a dilemma is described and the solution stated in the final lines of the passage (see page 156 of Appendix B). All subjects received the five training stories, each of which was analogous to one of the five target problems. Note that subjects in Experiments 6, 7, and 8 encountered the solution to each training problem twice, once in the training passage and once when the experimenter explained the solution to them.

Experiment 6. Training stories were #1, #3, #5, #7, and #9, and target problems were #2, #4, #6, #8, and #10 in the 10-item sequence,

presented in the same three orders as in Experiment 3. Each target problem was immediately preceded by its analogous training story.

Experiment 7. The five training stories were presented in a block followed by the five targets in a block, presented in the same order as in Experiment 4. The first training story was analogous to the first target, the second training story was analogous to the second target, and so on. The average delay between the end of a training story and the presentation of its target was approximately 16 minutes.

Experiment 8. The five training stories were presented in a block followed by the five targets in a block, presented in the same order as in Experiment 5. The first training story was analogous to the fifth target, the second training story was analogous to the fourth target, the third training story was analogous to the second target, the fourth training story was analogous to the first target, and the fifth training story was analogous to the third target. The average delay between the end of a training story and its analogous target was approximately 16 minutes, with a range from about five minutes to 30 minutes.

Procedure

All subjects were told that they would be presented with a series of story passages and problems. Training stories were presented for three minutes, after which the experimenter explained the solution, using the blackboard and taking about 60 to 75 seconds. Target problems were also presented for three minutes, during which time all subjects attempted to solve them, writing their answers in the space provided. They were never told of the relationship between the training stories

and targets, and training stories could not be reconsulted. Experimental sessions lasted approximately 45 minutes.

Memory-oriented condition. Subjects in the memory-oriented condition were treated the same as subjects in the memory-oriented condition of Experiments 3, 4, and 5, except that training passages were stories and not unsolved problems. These subjects were told that they would be presented with a series of passages that pose a problem, and that some problems would be solved in the final lines of the passage. Their task was to remember these passages for a recall test that was supposed to be given at the end of the session, but that, because of time constraints, was never administered. They were told they would get some problems that would appear without their solutions, and that for these items their task was to try and solve them as best they could. In sum, the subjects were to remember training passages and solve targets; they were reminded before encountering each problem whether to remember it or solve it.

Problem-oriented condition. Subjects in the problem-oriented condition were treated identically to subjects in the memory-oriented condition except for instructions on how to process the training stories. They read the training stories, and were instructed to figure out how and why the solution stated was correct. They were asked to work at understanding the solution, which they were assured was correct, so they could explain it if necessary. They were told that although not necessary, it might help them to write down their explanation attempts. After the subjects attempted to explain the solution, the solution was explained to them by the experimenter as above. That is, these subjects

received feedback to a generative attempt - the attempt to generate an explanation.

Results and Discussion

The same two-person scoring system was used again. All information required for an answer to a target to be scored correct was contained in the original passage the subjects worked with during training. The explanation provided by the experimenter, in addition to repeating the solution, contained additional information, but none of that needed to be transferred for a target answer to be scored correct. Subjects in the problem-oriented conditions explained the solutions very poorly, although a quantitative measure of their poorness does not exist.

Experiment 6

Again, the three orders of presentation were averaged because their means did not differ reliably (memory-oriented condition: .633, .600, and .600; problem-oriented condition: .943, .900, and .819). Subjects in the memory-oriented condition showed an improvement from the first four targets to the last target (.475, .625, .575, .575, vs. .800). The main effect of position was reliable over all five targets [$F(4,156) = 2.70$, $MSe = 0.0084$], but not over the first four targets [$F(3,117) < 1$, $MSe = 0.014$]. Analysis of the problem-oriented condition revealed no effects of position over the five problems (.867, .822, .933, .844, .911) [$F(4,176) < 1$, $MSe = 0.0041$]. When the fifth target was excluded, there was still no effect of position [$F(3,132) < 1$, $MSe = 0.0069$].

Comparisons between problem-oriented processing and memory-oriented processing were made with respect to the subjects' performance on all five targets, the first four targets, and the very first target (see Table 4 on page 87). When all five targets were analyzed, problem-oriented subjects solved .876 of the targets, reliably more than the solution rate of .610 for the memory-oriented subjects [$F(1,83) = 33.5$, $MSe = 0.044$]. On the first four targets, problem-oriented subjects solved .867 of them, reliably greater than the solution rate of .563 for the memory-oriented subjects [$F(1,83) = 36.8$, $MSe = 0.053$]. The advantage for problem-oriented training over memory-oriented training was just as dramatic even when only the first target was analyzed [.867 > .475; $F(1,83) = 17.8$, $MSe = 0.183$].

Details. What follows are the solution rates for the three problems that were the first ones tested in each order. Respective solution rates for subjects in the problem-oriented and memory-oriented conditions were .929 vs. .333 for Apples and Oranges, .800 vs. .375 for Liar/Truth-teller, and .857 vs. .600 for Poisoned Cups. Again, analyses of the individual 15 problem by position cells are possible. In the memory-oriented condition, only four of the 15 cells gave solution rates of more than .800; these were the Two-String target in Order #1, the Poisoned Cups target in Order #2, the Probability target in Order #2, and the Apples and Oranges target in Order #2. For the problem-oriented condition, in only one case was there a solution rate of less than .800; it was the Probability target in Order #3. Furthermore, in all 15 cell comparisons between explanation and memory, problem-oriented processing was superior to memory-oriented processing, with an average difference

of .276. Finally, as Table 5 on page 88 shows, .822 of the subjects in the problem-oriented condition solved four or five targets, but only .400 of the subjects in the memory-oriented condition reached that level of success.

Table 4. Proportion of Targets solved in Experiments 6, 7, 8, 9, and 10; training analogues were in story form.

	Proportion of Targets Solved		
	All 5 Targets	1st Target Only	4 Targets
Experiment 6			
Problem-oriented condition	.876	.867	.867
Memory-oriented condition	.610	.475	.563
Experiment 7			
Problem-oriented condition	.843	.750	.813
Memory-oriented condition	.640	.600	.580
Experiment 8			
Problem-oriented condition	.860	1.000	.850
Memory-oriented condition	.615	.308	.519
Experiment 9			
Problem-oriented condition	.696	.640	.700
Memory-oriented condition	.582	.318	.511
Experiment 10			
Problem-oriented condition	.620	.300	---
Memory-oriented condition	.563	.375	---

Table 5. Proportion of subjects who solved each number of targets in Experiments 6, 7, and 8.

	Number of Targets Solved					
	0	1	2	3	4	5
Experiment 6						
Problem-oriented condition	.000	.000	.022	.156	.244	.578
Memory-oriented condition	.000	.150	.175	.275	.275	.125
Experiment 7						
Problem-oriented condition	.000	.000	.071	.107	.357	.464
Memory-oriented condition	.000	.040	.160	.400	.360	.040
Experiment 8						
Problem-oriented condition	.000	.000	.000	.200	.300	.500
Memory-oriented condition	.000	.000	.308	.462	.077	.154

I have included Table 5 to show that the poorer performance of subjects in the memory-oriented condition was not due to a bimodal distribution; that is, it was not the case that subjects in the memory-oriented conditions transferred the analogies either perfectly or not at all.

Again, as with Experiment 3, it is possible to have an unconfounded comparison between mean performance on the first two targets and mean performance on the last two targets, with means given equal weight regardless of the number of subjects in each condition. For the memory-oriented condition, mean solution rates for the first two and the last two problems were .528 and .673 respectively. There was a

.145 improvement, attributable to the fact that the fifth target was solved particularly well. For the problem-oriented condition, the mean solution rates for the first two and the last problems were .855 and .890 respectively.

Experiment 7

Performance on the five targets did not differ reliably for the memory-oriented condition [$F(4,96) = 2.11$, $MSe = 0.0095$], although the Two-String target was arithmetically better solved (.880) than the other four targets (.580). There was also no difference between the targets in the problem-oriented condition [$F(4,108) = 1.70$, $MSe = 0.0049$], and the Two-String target was again arithmetically better solved (.964) than the other four targets (.813), although not to the extent as in the memory-oriented condition. As Table 4 shows, more targets were solved by the problem-oriented subjects than by the memory-oriented subjects when all five targets were analyzed [.843 > .640; $F(1,51) = 16.22$, $MSe = 0.034$] and when all four targets were analyzed, omitting the Two-String problem [.813 > .580; $F(1,51) = 15.88$, $MSe = 0.045$]. The advantage for explaining over remembering was again present on the first target, although it was not reliable [.750 > .600; $F(1,51) = 1.35$, $MSe = 0.221$].

Details. In the problem-oriented condition, performance levels were .750, .821, .964, .786, .893 over the five targets compared to .600, .640, .880, .560, .520, respectively, for the memory-oriented condition. Even though rememberers enjoyed good success with the Two-String problem (.880), performance on the two problems that followed it remained poor. Of explainers, .821 solved four or five targets, but only .400 of the rememberers performed that well, as Table 5 indicates.

Experiment 8

Performance over the five targets differed in the memory-oriented condition [$F(4,48) = 4.59$, $MSe = 0.0077$], because the fourth target (The Two-String problem, 1.000) exceeded the other four (.519), which did not differ [$F(3,36) = 1.58$, $MSe = 0.015$]. Performance did not differ in the problem-oriented condition over all five targets or the four targets excluding the Two-String problem [$F(4,36) = 1.09$, $MSe = 0.0048$; $F(3,27) = 1.29$, $MSe = 0.0081$]. In any event, as Table 4 shows, more targets were solved by the explainers than by the rememberers when all five targets were analyzed [.860 > .615; $F(1,21) = 9.33$, $MSe = 0.037$], and when four targets, excluding the Two-String problem, were analyzed [.850 > .519; $F(1,21) = 12.0$, $MSe = 0.052$]. As well, when the first target was analyzed, explainers performed much better than rememberers [1.000 > .308; $F(1,21) = 20.5$, $MSe = 0.132$].

Details. Of explainers, .800 of subjects correctly solved four or five targets, but only .231 of the rememberers did that well (see Table 5). Performance in Experiment 8 will now be compared with performance for the same problems tested in the same order as in Experiment 6; recall that in Experiment 6, each target immediately followed its training analogue. The means for problem-oriented and memory-oriented conditions in Experiment 6 were .943 vs. .633, compared to .860 vs. .615 in Experiment 8. For Apples and Oranges, the means in Experiment 6 were .929 vs. .333, compared to 1.000 vs. .308 in Experiment 8. For Liar/Truth-teller, the means were 1.000 vs. .500 in Experiment 6, and .800 vs. .615 in Experiment 8. For the Probability target, the means were .857 vs. .667 in Experiment 6, and .700 vs. .462

in Experiment 8. For the Poisoned Cups target, the means were .929 vs. .833 in Experiment 6, and .900 vs. .692 in Experiment 8. For Two-String, the comparison from Experiment 6 showed the usual benefit for explainers, 1.000 vs. .833, but the comparison for Experiment 8 provided the one exception, .900 vs. 1.000. Again, note how similar the results are when the target immediately follows its analogue (Experiment 6) or the five targets follow the five analogues in an unpredictable order (Experiment 8). At this point, I would like to mention an experiment not described in this thesis, but reported in Needham and Begg (accepted for publication in Memory & Cognition, Experiment 1). This experiment was identical to Experiment 8 except that it presented the training analogues and target problems in several different orders. The results were comparable; target problems enjoyed reliably higher solution rates after problem-oriented training than after memory-oriented training, .900 > .693.

Summary and Conclusions

Although Experiments 6, 7, and 8 used attempted explanations rather than attempted solutions, as in Experiments 3, 4, and 5, the results were remarkably similar between the two sets of experiments. Again, the superiority of problem-oriented training has been demonstrated. The attempt to explain, like the attempt to solve, tills the system, organizing knowledge about the problem to highlight aspects of the explained solution when it arrives. The attempt at explanation organizes knowledge about the problem so that the key principle can be transferred spontaneously. The explained solution is particularly

salient for these subjects; for rememberers, it is simply another piece of information assigned no more importance than any other piece of information in the story. The rememberers had similar solution rates to the rememberers in Experiments 3, 4, and 5 even though the explanations in Experiments 6, 7, and 8 contained repetitions of information that was present in the passages. The rememberers again achieved levels of transfer that exceeded the levels in most previous experiments in the literature, in conditions that showed reliable transfer, and they are well above untrained levels.

The high solution rates in Experiment 6 occurred for target problems that were tested immediately after the relevant principle had been explained to the subjects. The results from Experiment 7 were about the same, although in Experiment 7 there was a 16-minute delay, after which subjects had stockpiled five different effective principles. The results from Experiment 8 were like Experiments 6 and 7, although the targets were tested in an unpredictable order. Hence, attempting to explain, like attempting to solve, fosters learning.

These experiments echo the others in showing benefits of generating over remembering. Something reasonably long-lasting happens when subjects expend "problem effort" and try to explain the solution to the training analogues. Perhaps the most striking aspect of these data and the data from the previous trio of experiments is how little difference it makes if the targets are tested immediately after training, or are tested later in an order that is unpredictable from the order encountered during training.

Chapter 6

PROBLEM-ORIENTED TRAINING VERSUS MEMORY-ORIENTED TRAINING: MORE FINDINGS

Chapter 6 describes five experiments that extend the conclusions of the first nine experiments.

Experiments 9 and 10

Experiments 3 through 8 have demonstrated the superiority of problem-oriented training over memory-oriented training with respect to spontaneous analogical transfer. These results are consistent with a transfer-appropriate processing account. Whether people try to solve a training problem or explain the solution to the dilemma posed in a story, they attain great success in solving a problem that requires for its solution the principle and procedure introduced during training. However, the subjects' attempts to solve or explain were seldom successful; the materials are so difficult that the appropriate problem-oriented process rarely leads to a correct solution or explanation. Therefore, the experimenter-provided explanation of the training passage was an important contributor to their success on the target problems.

That information was not sufficient to ensure success, however, because subjects who tried to remember the training analogues before receiving the explanation achieved less success in solving the target problems. The metaphor that I have used to frame some issues is tilling the soil, which stresses the joint necessity and complementarity of advance preparation and the subsequent arrival of important relevant information. The hypothesis has been that problem-oriented training organizes the information so that the principle underlying the problem is identifiable and is capable of retrieving the solution, given that the solution and its principle become known during training. Experiments 9 and 10 test this hypothesis.

In Experiment 9, subjects tried to remember stories or tried to explain their solutions as in Experiments 3 through 8. Then, rather than provide an explanation of the solution, the experimenter simply repeated the entire story without giving any explanation. Subjects were then tested on the analogous target. The removal of the experimenter-provided explanation allows a comparison between the different orientations as methods of advance preparation. The prediction is that the advantage to problem-oriented training will decrease because the feedback to the explanation attempt has been removed. Experiment 10 was the same as Experiment 9, but the experimenter did not repeat the story; instead, subjects tried to recall the story themselves immediately following its presentation. They then were tested on the analogous target. The prediction is that the subjects' own attempt to recall the story will reduce the special status the solution would enjoy, and further reduce the advantage of problem-oriented training as advance

preparation.

Auble, Franks, and Soraci (1979), using insight problems, found that presenting clue statements in puzzle form (as in Lockhart et al., 1988) resulted in better recall of the information in the statements compared with presenting that information in declarative form. Lockhart et al. found no difference in recall for information presented once in puzzle form and twice in declarative form, although both exceeded information presented once in declarative form. This recall task, however, was conducted after the subjects tried to solve the insight problems, and this might have created a confound. As a result, in a subsequent experiment, Lockhart et al. gave subjects an interpolated recall task between study and test. They found that information presented in declarative form was remembered better than information presented in puzzle form (.67 vs. .46). An interpolated recall test is used in Experiment 10 here.

Method

Subjects

In Experiment 9, 47 subjects were randomly assigned to two conditions with 22 and 25 subjects each. Two orders were used in each condition, with 11 subjects in each group for the memory-oriented condition and 14 and 11 subjects in the groups for the problem-oriented condition. In Experiment 10, 26 students were assigned at random to two conditions, with 16 subjects in the memory-oriented condition and 10 subjects in the problem-oriented condition.

Materials and Procedure

Experiment 9. Experiment 9 was identical to Experiment 6 in that each target immediately followed its analogous training story. However, in Experiment 9, in between each training story and its target problem, the experimenter re-read the story without explaining the solution. Memory-oriented subjects were instructed to study the training passages so they could recall them later, and problem-oriented subjects were told to work at understanding the solution given in the training passage so they could explain it if they were asked. All subjects were reminded of their task before each problem. Sessions lasted approximately 45 minutes.

Experiment 10. Experiment 10 was identical to Experiment 9 except that in the interval between the training story and its analogous target problem, all subjects tried to recall the story before the target was presented. Subjects were told to recall the story in as much detail as they possibly could, and to give its gist at the very least. Subjects were told that point-form was acceptable and advised that they should write quickly because they had only about a minute or so for the interpolated recall task. Sessions lasted approximately 45 minutes.

Results and Discussion

Target problems were scored by the same two individuals using the same scoring criterion as before. Subjects' explanations were poor, although there exists no quantitative measure of just how poor they were.

Experiment 9

As in Experiment 6, subjects in the memory-oriented condition

were more successful with the final target problem (.864) than with the others (.511). The main effect of position over the five targets was reliable [$F(4,84) = 4.34$, $MSe = 0.0080$] but not over the first four targets [$F(3,63) = 1.78$, $MSe = 0.015$]. In the problem-oriented condition, there was no main effect of position over the five targets [$F(4,96) = 1.03$, $MSe = 0.0067$] or the first four [$F(3,72) = 1.58$, $MSe = 0.0089$]. The results are in Table 4 on page 87, along with results from Experiments 6, 7, and 8 for easier comparison. Solution rates were higher for problem-oriented subjects than for memory-oriented subjects in analyses of the first four targets [.700 > .511; $F(1,45) = 4.92$, $MSe = 0.084$] and of the very first target [.640 > .318; $F(1,45) = 5.18$, $MSe = 0.234$]. Over the full five problems, however, the .114 difference was not reliable [.696 vs. .582, $F(1,45) = 2.14$, $MSe = 0.071$].

Experiment 10

Solution performance did not differ over the five problem positions in either the memory-oriented condition or the problem-oriented condition [$F(4,60) = 1.96$, $MSe = 0.0064$; $F(4,36) = 2.31$, $MSe = 0.0081$]. As shown in Table 4, problem-oriented subjects no longer had a reliable edge over memory-oriented subjects in solution rates [.620 vs. .563; $F(1,24) < 1$, $MSe = 0.096$]. Nor was there a reliable difference between problem-oriented subjects and memory-oriented subjects on the very first target [.300 vs. .375; $F(1,24) < 1$, $MSe = 0.0098$]; in fact, memory-oriented subjects did slightly better than their problem-oriented counterparts, although not reliably better.

The explicit recall attempts for both groups were scored as if they were solution attempts. That is, a recall protocol that contained

the analogue's solution was given a score of 1. Subjects in the memory-oriented condition recalled more of the analogues' solutions than subjects in the problem-oriented condition [.563 > .300, $F(1,24) = 4.81$; $MSe = 0.0882$]. The problem-oriented subjects solved .87 of the targets whose analogues' solutions were recalled and .51 of the targets whose analogues' solutions were not recalled, with respective values of .71 and .37 for the memory-oriented subjects. For the aggregate data, the respective gamma coefficients were .72 vs. .61, and they did not differ. Although there was a small and unreliable advantage in solution rates for the problem-oriented subjects over the memory-oriented subjects, there was a large and reliable difference on the recall task favouring the memory-oriented subjects. This result demonstrates that subjects in memory-oriented conditions remember their training at least as well as subjects in problem-oriented conditions, suggesting that the advantage of problem-oriented subjects on the transfer task cannot be memory-based. These results conflict with the findings of Auble et al. (1979) because a memory benefit for the passages that were memorized (i.e., not problem-oriented acquisition) was found. They are in accordance with Lockhart et al.'s (1988) findings that declarative information (i.e., fact-oriented acquisition) was better remembered than puzzle information (i.e., problem-oriented acquisition) on an interpolated recall task. There are, however, two points to keep in mind when considering these comparisons. First, both Auble et al. and Lockhart et al. altered the form of the training information, while keeping the training information constant. In the experiments in this thesis, it is the processing that is manipulated and the form of the information remains the same.

Second, in Experiment 10, recall attempts were scored as in solution attempts. There are many more pieces of information to remember in the training stories besides the solution. The results are interesting in their own right, but they need to be explored further, and these results probably provide a good foundation on which to base future research in this area. In fact, the results from this experiment prompted an experiment dedicated to investigating these results in much more detail. It is reported in Needham and Begg (accepted for publication in Memory & Cognition, Experiment 5), and is described in the General Discussion in Chapter 7.

Summary and Conclusions

Experiment 9 demonstrated that the attempt to understand a solution presented in a story promotes better learning of the principle than does the attempt to remember the story. The difference was not as large as in Experiment 6; the solution was explained in Experiment 6, whereas it was simply repeated in Experiment 9. In contrast, there was no reliable advantage for problem-oriented processing over memory-oriented processing in Experiment 10. The only difference between Experiments 9 and 10 was that the subjects tried to recall the stories themselves in Experiment 10, whereas the experimenter repeated the stories verbatim in Experiment 9. As usual, in each case, the following target problem could be solved using the same principle as the training analogue. Yet, the difference in solution rates between the two experiments was dramatic on the very first problem they tried to solve. Explainers in Experiment 9 solved .640 of the first problems, compared

to only .300 for the problem-oriented subjects in Experiment 10. In contrast, solution rates of memory-oriented subjects changed little between the experiments on that first problem; .318 and .375 for Experiments 9 and 10 respectively. The drop by the problem-oriented subjects cannot reflect initial processing of the training story because the two conditions were treated identically at that stage. The change from hearing the story repeated to attempting to recall the story removed the advantage of studying with an explicit intent to explain its solution. Experiment 10 demonstrated that the act of recalling stories that people had tried to explain reduced transfer to the level observed when memory-oriented subjects are given targets to solve.

It is interesting that the memory-oriented subjects' inferiority to the problem-oriented subjects is task-dependent. On the analogical transfer task, they were inferior. Yet, when the subjects were given an explicit memory test, memory-oriented subjects did better than problem-oriented subjects. This is evidence for a double task dissociation; problem-oriented training is better than memory-oriented training for solving analogous targets, but memory-oriented training is better than problem-oriented training for remembering training. There is clearly more value in performing appropriately when given demands than in remembering training. (See the General Discussion in Chapter 7 for details of an experiment that investigated the double task dissociation further.)

Experiment 11

To this point, the way in which subjects worked with the

training analogue has been manipulated between subjects; that is, all subjects within a condition either memorized the training analogues or else they tried to solve or explain them. Experiment 11 investigated the effects of manipulating study instructions within subjects. After Experiments 3 and 6, I was surprised that the memory-oriented subjects failed to avail themselves of the opportunity to encode later problems or stories in a way that would help them solve targets. Experiment 11 investigates whether memory-oriented subjects would spontaneously adopt problem-oriented processing, despite memory-oriented instructions, if they had previous rewarding experience with problem-oriented processing.

Recall that Lockhart et al. (1988) found that when subjects read information in both puzzle form and declarative form, all insight problems benefitted as if studying information in puzzle form was equivalent to making the subjects an informed group. Ross et al. (1989) found evidence that subjects caught on to the gist of their experiment; will subjects who attain good success on targets following an explanation attempt catch on and consequently attain that same success on targets following a memory attempt? Keeping these experiments in mind, one might predict that in Experiment 11 all subjects will do well on all problems, regardless of whether they memorized or tried to explain their training analogues so long as an explanation attempt came first. If, though, the process effects are that strong, then, the usual outcome will be observed; that is, the target following a memory attempt will not be solved as well as those following an explanation attempt, regardless of the within-subjects manipulation.

Method

Subjects

In Experiment 11, 96 subjects were tested in eight groups of from 10 to 15 subjects each. All subjects performed the same sequence of tasks. The reason for the unusually large number of subjects was that these eight groups participated in another experiment and there was time remaining in the hour.

Materials and Procedure

Subjects tried to explain two stories, each of which was followed by an experimenter-provided explanation and an attempt to solve an analogous target problem. Between the two attempts to explain was one attempt to memorize, which was followed by an explanation, but not by a target problem. Instead, subjects used the three minutes post-explanation to try to recall the story. After these other events had occurred, subjects were given another training story to memorize, and the solution was explained. This time, however, they were given the analogous target problem to solve post-explanation.

In greater detail, for example, subjects had three minutes to work on an explanation for the solution to an analogue of the Poisoned Cups problem, after which the experimenter explained the solution as before. The subjects then had three minutes to attempt to solve the Poisoned Cups target. Next, subjects worked on another story for three minutes, but this time they were instructed to memorize it for an immediate recall test. The story was an analogue of the Probability problem, and the experimenter then explained it as usual. After the explanation, subjects were given three minutes to recall the story in as much detail as possible. Thus, the subjects had one experience with

solving and one with memorizing and recalling. The next sequence was the same as the first, except that the training story was an analogue of the Two-String problem, which was the target. The final sequence was another memory attempt. Subjects were asked to read the story analogue of Apples and Oranges for memory. Immediately following the explanation of this training analogue, subjects had to try and solve the Apples and Oranges target -- not recall its analogue. Subjects were reminded of their task before they worked on each story or target problem. Sessions lasted about 35 minutes.

Results and Discussion

Of interest are the solution rates on the two targets that followed an attempted explanation of their analogues, compared to the solution rate on the target that followed memorization. Explanation was the goal for the first and third story, which were analogues of Poisoned Cups and Two-String, respectively. The respective solution rates for these two targets were fairly high and did not differ [.771 vs. .802; $F(1,95) < 1$, $MSe = 0.173$]. Both of these solution rates, however, exceeded the solution rate for the Apples and Oranges problem, .625 [$F(1,95) = 5.39$, $MSe = 0.189$; $F(1,95) = 7.95$, $MSe = 0.189$]; although Apples and Oranges was the last target in the sequence, its immediately preceding analogue was studied with the intent to remember it rather than to explain it. Good performance was followed by bad performance, with the bad performance being attributable to the way in which the training analogue was processed. The intent to remember is thus capable of disrupting whatever beneficial processing goes on during an attempt

to explain a solution, even after there have been two successful solving episodes following explanation attempts.

Experiment 12

In the previous experiments, the principles of the training analogues were all very distinctive, making it highly unlikely that the principles of the individual analogues would be confused with each other. For example, no solver would attempt to solve the Probability target using the solution to the Two-String analogue. Therefore, if subjects thought to use an earlier learned principle to solve a new target, there would be only a single candidate that would be sensible to adapt. Will the benefit to generating one's own solution or explanation over memorizing be attenuated when the principles of the training analogues are confusable with each other? Will problem-oriented training make the analogues' principles more distinct than will memory-oriented training, thereby leading to increased levels of spontaneous transfer? Or, will the fact that the analogues are very similar to each other obliterate any advantage that problem-oriented training has been shown to have? In other words, will the confusable analogues make it such that the problem-oriented subjects will not know which analogue's principle to transfer, thus destroying the advantage of problem-oriented training? Experiment 12 addressed these issues. Often, we encounter problems that look and sound very similar, the only differences between them are subtle differences in principle. It would certainly be impressive if problem-oriented training could help make these subtle differences in principle less subtle.

Method

Subjects

In Experiment 12, 223 subjects from the subject pool were randomly assigned to eight conditions with between 16 and 37 subjects in each condition. Two or three groups were tested in each condition with 9 to 15 subjects per group.

Materials and Procedure

All subjects tried to solve the Liar/Truth-teller target. Before receiving the target, subjects received three training passages, only one of which was analogous to the target problem. The analogue was the quiz-show analogue used in the previous experiments. Two non-analogues that maintained the quiz-show scenario and telling truths and lies were written (see page 159 of Appendix B). These non-analogues had very subtle differences in principles that I believed might not be easily distinguishable, and therefore, might create some confusion for the subjects. A 2 X 2 X 2 experimental design was used; all variables were manipulated between subjects. One variable was the form of the training information; it was presented in either problem form or story form. The second variable was the instructions to the subjects on what to do with the training analogues (solve vs. memorize if problem form, or explain vs. memorize if story form). Memory-oriented subjects were instructed as before and problem-oriented subjects were instructed as before. The third variable was the position of the analogue among the three training passages; it was either the first training passage or the third training passage. The same nonanalogous training passage was

always presented as the second passage of the trio. Following each training passage, its solution and its explanation were read to the subjects using the blackboard to facilitate understanding. Subjects worked with each problem for three minutes and the solution and explanation lasted about 75 seconds. The subtle differences between the principles of the training passages were never pointed out, and as usual, no hints were given to the subjects. Sessions lasted about 25 minutes.

Results and Discussion

The targets were scored as before. No training problems were solved by any of the subjects in the solution conditions. The mean proportion of targets solved for each condition in Experiment 12 are presented below in Table 6.

Table 6. Proportion of targets solved in Experiment 12.

Form of Training Passages	Training Instruction	Analogue Position 1st	3rd
Problem Form	Memory-oriented	.343	.367
Problem Form	Problem-oriented	.484	.688
Story Form	Memory-oriented	.514	.500
Story Form	Problem-oriented	.636	.789

Analyses revealed a main effect of training orientation; problem-oriented subjects solved significantly more target problems than their

memory-oriented counterparts [.626 > .479; $F(1,215) = 10.21$, $MSe = 0.240$]. There was no main effect of analogue position [$F(1,215) = 1.80$, $MSe = 0.240$]; when the analogue was in the first position, .493 of the targets were solved, compared to .552 when it appeared in the third position right before the target. Training orientation and analogue position did not interact [$F(1,215) = 1.60$, $MSe = 0.240$], although .743 of the targets were solved by the problem-oriented subjects when the analogue occupied the third position, compared to .563 when the analogue was presented first; the difference was .180. The comparable difference was -.008 for the memory-oriented subjects; they solved .431 of the targets when the analogue was the first training passage, compared to .423 when the analogue was the third training passage. More targets were solved when the training information was presented in story form than when it was presented in problem form [.595 > .438; $F(1,215) = 4.17$, $MSe = 0.240$]. This result is not surprising; subjects who worked with passages in story form encounter the solutions twice, once in the passage itself and again during the experimenter-provided feedback. The other interactions were not reliable.

Overall, the similarly-worded training passages and explanations confused the subjects; the amount of spontaneous analogical transfer dropped for both memory-oriented subjects and problem-oriented subjects relative to the values from Experiments 3 through 8. To return to the central issue, the benefit of problem-oriented training over memory-oriented training was preserved. In all four appropriate comparisons, problem-oriented training resulted in higher performance on the targets (.484 > .343, .688 > .367, .636 > .514, .789 > .500), but more so when

the analogue immediately preceded the target than when it was presented first (differences of .321 and .289 vs. differences of .141 and .122).

The scenarios of the training analogues were very similar, and it could be argued that, although similar solution principles and procedures are encountered in the "real world," they are not typically encountered in passages with similar scenarios. Therefore, a possible follow-up experiment might have subjects work on three training passages, each of which has a different scenario from each other and the target. The training passages would still have confusable solution principles and procedures, and again only one would be the analogue of the target. The rationale behind this would be that the principles might become more distinct, and therefore less confusable and consequently more likely to be transferred, if the scenarios were different. Passages with more distinct scenarios might have more distinct solving principles. Particularly in an educational environment, people encounter principles embedded in different scenarios. This possible experiment might therefore be considered more applicable to real-world situations and an increase in spontaneous transfer from the levels observed in Experiment 12 might be observed. Nonetheless, the benefit of problem-oriented training over memory-oriented training endured in the challenging task when the analogues' principles were confusable.

Chapter 7

GENERAL DISCUSSION

Spontaneous Analogical Transfer

This thesis has demonstrated that the way in which the training information is processed is an important factor in the likelihood of spontaneous analogical transfer. The experiments in this thesis show substantial amounts of analogical transfer, with no hints ever given to the subjects to use the prior information. The subjects spontaneously transferred knowledge from the training passages to target problems that could be solved by the same principle. The major difference between the research reported in this thesis and the previous spontaneous analogical transfer research in the literature lies in the subjects' role in training. In particular, spontaneous analogical transfer is the rule rather than the exception, if training explicitly requires problem-oriented processing; that is, spontaneous analogical transfer is observed if the process at study matches the process at test. Subjects who approach training passages as problems are very likely to apply the solution principles from those problems to target problems that are analogous to them, with solution rates that rival those found in previous research when subjects were explicitly told of the relevance of

the training information for the task at hand.

Subjects in Experiments 1, 2a, and 2b solved nearly all the target problems after they had tried to solve training problems that required the same principle for solution, even if the target and its analogue had different scenarios. Furthermore, solution rates were high on the very first target problem that was preceded by an analogue, even if previous targets had been preceded by training problems with very different principles. In contrast, subjects almost never solved targets if the training problems needed a different principle for solution than the one needed for the target.

Experiments 3 through 8 showed that problem-oriented training is superior to memory-oriented training with respect to spontaneous analogical transfer. Subjects assigned to memory-oriented conditions received all the same information and experience as subjects in the problem-oriented conditions. They differed only in how they approached the training passages; only in the problem-oriented conditions was that information processed in a manner appropriate to solving target problems. In the problem-oriented conditions, solution rates for targets were high on the very first target problem. As well, the value of problem-oriented training was independent of whether the information was presented in story form or in problem form. Furthermore, the advantage of problem-oriented training over memory-oriented training was just as robust when the first target was presented after five training problems had been attempted, each with a different principle, than when the target immediately followed the training passage. Although the memory-oriented subjects fell short of the problem-oriented subjects in

their solutions of targets, they were successful in over 60% of their attempts. Memory-oriented processing is, therefore, a reasonably good training procedure, because it is a meaningful and intelligent way to approach information. Indeed, its value makes the advantage of problem-oriented processing more impressive. I was somewhat surprised that memory-oriented subjects did not spontaneously adopt problem-oriented strategies over the course of attempting five interleaved training-target pairs (Experiments 3 and 6); after all, the problems are very compelling. Perhaps the level of success they achieved was high enough to satisfy them and not call their strategies into account.

Experiment 11 showed the benefit to problem-oriented training in a within-subjects design. Subjects achieved good success on two targets following an explanation attempt before they received the third target, which followed a memory attempt. Yet, in spite of the earlier success, subjects' solution rates on the third target were significantly lower. One can conclude the high performance on the first two targets was because the subjects recognized the analogies. Then, why the decrease in performance on the third target? It seems to suggest that subjects did not learn to learn. Even when subjects have had rewarding experience with problem-oriented processing, the switch to memory-oriented processing was enough to push transfer to the lower level characteristic of memory-oriented processing.

My findings support the conclusions of Lockhart et al. (1988) and Adams et al. (1988) that transfer of previous information to targets is most likely if the to-be-transferred information is processed in a problem-like manner. However, this conclusion can be extended further.

First, Lockhart et al. and Adams et al. varied processing by presenting information in different forms. I explicitly varied the processing while keeping the form of the information constant. Second, Experiment 9 showed that the advantage of problem-oriented training decreased a little when the experimenter-provided explanation was eliminated, and in its place the experimenter repeated the training story. Experiment 10 showed that this advantage disappeared entirely when, in place of the experimenter-provided explanation, subjects tried to recall the training story for themselves. These two experiments demonstrate that problem-oriented training in itself is not enough to ensure spontaneous analogical transfer. Because the processing usually fails to come up with the principle needed to solve the target, it is necessary for the experimenter to provide it; the potential value of problem-oriented processing remains unrealized if the experimenter-provided explanation does not occur. The value of the experimenter-provided feedback is clearly of importance when problem-oriented subjects must solve the analogue; one cannot expect subjects to transfer solution principles when the subjects do not even know the solution.

Although problem-oriented processing promotes excellent levels of spontaneous analogical transfer, it cannot guarantee this transfer. Subjects nearly always failed to solve or explain their training problems. By my account, problem-oriented processing encodes problems so that the solution procedure is central, even if it is supplied by the experimenter. Consequently, the solution procedure becomes available for application when called up by the target problem. On the other hand, the attempt to remember a passage, even when the solution is

included, gives the solution procedure less of a central role in the memorial organization of the training information. As a result, the target problem has less chance of mobilizing the solution from a training problem. It is, therefore, better to have tried and failed than never to have tried at all!

Transfer-Appropriate Processing

Transfer-appropriate processing is a useful way to capture the results of the experiments. The concept, originally stated by Morris, Bransford, and Franks (1977), was that performance at test is best if conditions induced at study match those evoked at test. Begg (1976) specifically measured transfer of training, and found that the ability of nonsense syllables to serve as cues or as responses on a transfer test was dependent on how the syllables were learned; syllables trained to evoke images were good cues but poor responses in transfer, whereas syllables trained as responses to images were good responses but poor cues. Transfer-appropriate processing may be viewed as a complement to some older similar ideas. From McGeoch (1932, 1942) on, it was accepted that the excellence of performance was maximal if conditions of performance resembled conditions of learning. McGeoch had environmental stimuli in mind, but the idea is similar. Likewise, Thomson and Tulving's (1970) encoding-specificity principle shifted the focus to internal encodings, but the concept is similar. Theories of context-dependent learning and state-dependent learning (Eich, 1977; Smith, 1979) are pertinent, but they continue to place the emphasis on stimuli, albeit external ones. The advantage that I see to transfer-appropriate processing over these related concepts is that transfer-appropriate

processing places the explicit stress on processing rather than on nominal or functional stimuli.

However, even an appropriate process cannot promote transfer if the process fails to come up with the needed principle and the environment also fails to deliver it. This mutual interdependence has been captured by the metaphor of tilling the soil. Tilling is labouring in vain unless a seed arrives, just as the seed's potential will not be realized unless the soil has been prepared for its arrival. Problem-oriented processing is advance preparation that will be in vain unless the solution principle becomes available, just as the potential value of the solution principle will not be completely realized unless the subjects is prepared for its arrival. Therefore, an explanation alone is not sufficient to produce any learning. The value of problem-oriented processing is similar to what Ausubel (1960) called an advance organizer. The attempt to solve, like the attempt to generate in memory research (Kane & Anderson, 1978; Slamecka & Fevreiski, 1983), has value even if the attempt fails, so long as the sought-after information arrives as experimenter-provided feedback.

The tilling-the-soil metaphor does not account for why memory-oriented subjects derive less benefit from the experimenter's explanation than the problem-oriented subjects do. What is it about memory-oriented processing that reduces the value subjects gain from hearing the explanation of a problem's solution? Time for speculation: it is possible that the explanations were so fluent and well rehearsed that memory-oriented subjects understood the experimenter's words easily and failed to appreciate the difficulty of the problems. In this way,

the solution procedure does not enjoy any special status. Because problem-oriented subjects had already failed to come up with an explanation of their own, they would be less likely to misattribute their easy understanding of the explanation to the easiness of the problem. Although I have no direct evidence that such misattributions occurred, the memory literature contains evidence of similar types of misattribution. For example, Jacoby and Kelley (1987) had subjects rate how difficult it would be to unscramble anagrams that were presented alone (fscar) or with their solutions (scarf fscar); anagrams with solutions were rated to be easier than anagrams alone, and the ratings were less predictive of actual difficulty as well. Similarly, easily processed items give an illusion of being memorable (Begg, Duft, Lalonde, Melnick, & Sanvito, 1989).

This brief tour of the memory literature provides a possible explanation for why problem-oriented processing and memory-oriented processing are not equally good ways to train for a test of problem solving. The value of problem-oriented processing is that it prevents subjects from mistaking easy understanding for easy problems; the disadvantage of memory-oriented processing is that it does not give subjects an opportunity to use their own solving experience as a guide to the difficulty of a problem. Cross fertilization with memory research has another important advantage. It calls our attention to the other side of transfer-appropriate processing. Memory-oriented processing is much better than problem-oriented processing as a way to study for recall.

Future Directions: Dissociation of Solving from Remembering

The results of Experiment 10 revealed an interesting double task dissociation between problem-oriented training and memory-oriented training. This result was investigated in more detail in an Experiment not reported in this thesis, but it is reported in Needham and Begg (accepted for publication in Memory & Cognition, Experiment 5). Briefly, subjects first approached a training story as a to-be-explained problem (the problem-oriented condition) or as a to-be-remembered story (the memory-oriented condition). Then, the experimenter explained the solution as usual. Next, subjects were asked either to recall the training story in as much detail as possible, or to solve an analogous target problem. Subjects initially tested for recall were then tested for solution of the target, and subjects initially tested for solution of the target were then asked to recall the preceding training story. Each subject worked with only one target and its analogue. As usual, problem-oriented subjects solved more target problems than did memory-oriented subjects. The subjects' recall data were scored two ways. As in Experiment 10, recall data were scored as if they were attempted solutions, and they were also scored in terms of idea units (gist recall). Memory-oriented subjects recalled more solutions, idea units, and non-solution idea units than did problem-oriented subjects. The order of test made no difference, and subjects rarely succeeded on the incidental task if they failed on the intentional task to which their study was dedicated.

So, recall of training information was much better in the memory-oriented subjects than in the problem-oriented subjects, but transfer of principle to new problems was much better in the problem-

oriented subjects than in the memory-oriented subjects. This finding is exactly what the idea of transfer-appropriate processing would predict. Training in memory will be superior to training in solving if the test is memory-based; training in solving will be superior to training in memory if the test is a test of problem solving. Although this double task dissociation is a sideline to the primary focus of this thesis, I included it because it suggests that different laws underlie memory for training and transfer of that training to a new task. It suggests that the advantage to the problem-oriented subjects in transfer is not memory-based; that is, the problem-oriented subjects do not remember their training information better than their memory-oriented counterparts who fare poorer on the transfer tasks.

It appears that memory-oriented processing and problem-oriented processing are both meaningful, but in different ways, and that their meaning cannot be defined adequately without mentioning the context of use. Solving a problem indirectly tests memory for the solution from a prior story, but it directly tests the applicability of that solution to a problem; recall directly tests memory for prior solution but only indirectly tests their applicability to new problems. From this point of view, the subjects did better on whichever task directly required them to perform in the way their initial processing prepared them to perform, and worse on whichever test required processing that was incidental to what they did. Much of what one does to prepare effectively for a test of memory is incidental to the needs of a test of problem solving, and much of what one does to prepare effectively for solving problems is incidental to the needs of a test of recall.

Perhaps it should not be all that surprising that subjects can successfully apply a solution to a problem yet fail to produce that solution when recalling training stories. The recalled solution and the applied solution may be the same string of words, but they do not have the same meaning, and understanding them in one sense does not imply they have been understood in the other. This double task dissociation is in accordance with the results of Gick and Holyoak (1980, 1983) and others. Their subjects were instructed to memorize the training story, recall it, and then try to solve the target. The subjects' recall scores were high, yet they could not use the information that they recalled to help solve an analogous target.

In any event, the double task dissociation serves as a foundation for subsequent research in problem solving. Much past work has asked why there are so many failures to use remembered solutions when faced with new problems that can be solved with those solutions. I am suggesting that an inappropriate training procedure is responsible. Future research will ask why there are so many failures to recall solutions that people use spontaneously to solve a new problem. The boundaries for this dramatic dissociation must be established, for it would be depressing to think that if students remembered material from lectures then they would be unlikely to use the principles explained therein to solve later problems.

Concluding Comments

The conclusions of this thesis stress the importance of transfer-appropriate processing in problem solving by analogy. Training that requires doing the procedures that are needed to solve a target

promotes learning, which is defined as an increase in the probability that the appropriate response is emitted. The conclusion that I have reached is optimistic; subjects who are active participants during learning usually transfer information to most of the problems for which the information is useful.

When subjects attempted to solve training problems or explain training stories, then heard the appropriate solution and explanation, they transferred that information spontaneously to analogous target problems much more often than if they memorized the training information. The value of problem-oriented training was independent of whether the training information was presented in problem form or story form. The extent of the benefit to problem-oriented training is just as robust when the target immediately follows the analogue as when the target follows the analogue and other information by over 15 minutes. The benefit was observed within subjects also, as well as when the target was preceded by training stories with similar scenarios and confusable principles. The benefit decreased a little when the experimenter-provided explanation was eliminated, and it disappeared entirely when the subjects were asked to recall the training information instead of hearing the explanation. The final finding was that although problem-oriented training was superior to memory-oriented training on tests of spontaneous analogical transfer, memory-oriented training was superior to problem-oriented training when the test required recall.

All things considered, I would like to offer to educators a generalization of the conclusions that pertain to spontaneous analogical transfer. Students will be able to use the knowledge imparted to them

in any context if they become active participants and collaborators in the learning process. Instructors, let your students try, let them fail, and then tell them the answer, but most importantly, let them try.

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Appendix A

Appendix A contains several of the problems referred to in the literature review in Chapter 2 of the thesis.

Duncker's (1945) Radiation Problem; (used in Catrambone & Holyoak, 1989; Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987; Spencer & Weisberg, 1986):

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

Military Analogue from Catrambone & Holyoak, 1989; Gick & Holyoak, 1980, 1983; Spencer & Weisberg, 1986:

A small country fell under the iron rule of a dictator. The dictator ruled the country from a strong fortress. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads radiated outward from the fortress likes spokes on a wheel.

A great general arose who raised a large army at the border and vowed to capture the fortress and free the country of the dictator. The general knew that if his entire army could attack the fortress at once, it could be captured. His troops were poised at the head of one of the roads leading to fortress, ready to attack. However, a spy brought the general a disturbing report. The ruthless dictator had planted mines on each of the roads. The mines were set so that small bodies of men could pass over them safely, since the dictator needed to be able to move troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road and render it impassable, but the dictator would destroy many villages in retaliation. A full-scale direct attack on the fortress therefore appeared impossible. The general, however, was undaunted. He divided his army up into small groups and dispatched each group to the head of a different road. When all was ready, he gave the signal, and each group charged down a different road. All of the small groups passed safely over the mines and the army then attacked the fortress in full strength. In this way, the general was able to capture the fortress and overthrow the dictator.

Fire-Fighting Analogue from Catrambone & Holyoak, 1989; Gick & Holyoak, 1980, 1983; Spencer & Weisberg, 1986:

One night, a fire broke out in a wood shed full of timber on Mr. Johnson's place. As soon as he saw flames he sounded the alarm, and within minutes, dozens of neighbours were on the scene armed with buckets. The shed was burning fiercely, and everyone was afraid that if it wasn't controlled quickly, the house would go up next. Fortunately,

the shed was right beside a lake, so there was plenty of water available. If a large volume of water could hit the fire at the same time, it would be extinguished. But with only small buckets to work with, it was hard to make any headway. The fire seemed to evaporate each bucket of water before it hit the wood. It looked like the house was doomed. Just then, the fire chief arrived. He immediately took charge and organized everyone. He had everyone fill their bucket and then wait in a circle surrounding the burning shed. As soon as the last man was prepared, the chief gave a shout and everyone threw their bucket of water at the fire. The force of all the water together dampened the fire right down, and it was quickly brought under control. Mr. Johnson was relieved that his house was saved, and the village council voted the fire chief a raise in pay.

The Lightbulb Target Problem from Holyoak & Koh, 1987:

In a physics lab at a major university, a very expensive lightbulb which would emit precisely controlled quantities of light was being used in some experiments. Ruth was the research assistant responsible for operating the sensitive lightbulb. One morning, she came into the lab and found to her dismay that the lightbulb no longer worked. She realized that she had forgotten to turn it off the previous night. As a result, the lightbulb overheated, and the filament inside the bulb had broken apart. The surrounding glass bulb was completely sealed so there was no way to open it. Ruth knew that the lightbulb could be repaired if a brief, high-intensity laser beam could be used to fuse the two parts of the filament into one. Furthermore, the lab had the necessary equipment to do the job. However, a high-intensity laser

beam would also break the fragile glass surrounding the filament. At lower intensities, the laser would not break the glass, but neither would it fuse the filament. It seemed that the lightbulb could not be repaired, and a costly replacement would be required. Ruth was about to give up when she had an idea. What was it?

For the Lightbulb Training Analogue (Holyoak & Koh, 1987), add:

Ruth placed several lasers in a circle around the lightbulb and administered the low-intensity laser beams from several directions all at once. The beams all converged on the filament, where their combined effect was enough to fuse it. Since each spot on the surrounding glass received only a low-intensity beam from one laser, the glass was left intact. Ruth was greatly relieved that the lightbulb was repaired, and she then went on to successfully complete the experiment.

The Aquarium Problem from Catrambone & Holyoak, 1989:

A major aquarium in a city on the East Coast decided to create a large aquarium display containing a replica of the sunken ocean liner the Titanic amid the sea environment of its resting place, which is deep in the Atlantic Ocean off the coast of Newfoundland. A professional aquarium designer was assigned to the project. She placed a small replica of the vessel in the center of a large tank, with a realistic sea bed. Then she added to the tank sea plants and fish of the sort that live in the Atlantic at the depth of the sunken Titanic. The display was virtually finished when the designer was confronted with a major problem she failed to anticipate. In order to maintain the deep-water environment required by the fish and plants, the tank had to be

kept quite dark, as the deep-water organisms were not adapted to light. However, if the tank was kept completely dark, people would not be able to see the small replica of the Titanic in the center of the tank, which, after all, was the main point of the exhibit. Putting lights inside the model of the wreck looked too artificial. The designer considered shining a powerful spotlight on the model of the vessel. However, if the spotlight was located inside the tank, it would raise the temperature of the water too high; and if it was located outside the tank, the bright beam seriously disrupted the feeding habits of some of the fish. So, it looked like the display was going to have an embarrassing shortcoming. What could be done to light the display?
Solution: Just before the display was to open, the designer hit upon a new idea. She had several low-powered spotlights placed at different locations around the outside of the tank, all focussed on the replica of the ship. Each of the lights was quite dim, so the light-averse fish were not disturbed as they swam around the Titanic. But, since all of the lights were focused on the ship, their beams added up so as to illuminate enough that its realistic details could be seen by viewers. When the display opened, everyone thought it was both realistic and esthetically striking.

Target Problem from Novick, 1988:

Members of the West High School Band were hard at work practicing for the annual Homecoming Parade. First, they tried marching in rows of twelve, but Andrew was left by himself to bring up the rear. The band director was annoyed because it didn't look good to have one row with only a single person in it, and of course, Andrew wasn't very

pleased either. To get rid of this problem, the director told the band members to march in columns of eight. But, Andrew was still left to march alone. Even when the band marched in rows of three, Andrew was left out. Finally, in exasperation, Andrew told the band director that they should march in rows of five in order to have all the rows filled. He was right. This time, all the rows were filled and Andrew wasn't left alone any more. Given that there were at least 45 musicians on the field but fewer than 200 musicians, how many students were there in the West High School Band?

Analogue to the Target Problem from Novick, 1988:

Mr. and Mrs. Renshaw were planning how to arrange vegetable plants in their new garden. They agreed on the total number of plants to buy, but not on how many of each kind to get. Mr. Renshaw wanted to have a few kinds of vegetables and ten of each kind. Mrs. Renshaw wanted more different kinds of vegetables, so she suggested having only four of each kind. Mr. Renshaw did not like that because if some of the plants died, there wouldn't be very many left of each kind. So they agreed to have five of each vegetable. But then their daughter pointed out that there was room in the garden for two more plants, although then there wouldn't be the same number of each kind of vegetable. To remedy this, she suggested buying six of each vegetable. Everyone was satisfied with this plan. Given this information, what is the fewest number of vegetable plants the Renshaws could have in their garden?

Nonanalogue to the Target Problem from Novick, 1988:

Two assistant deans were planning how to seat the recipients of

the University Service Award on the auditorium stage. They couldn't figure out how many award recipients to put in each row. The first assistant dean wanted to put nine people in each row, but with that plan there would be one person left over. So the second assistant dean suggested seating the award recipients in columns of six. But the first dean remarked that this was the same as his seating arrangement so one person would still be left over. Their next idea was to put four people in each row, but that was no good either, because then three people would be left over. At that point, the dean walked in and told them to put five people in each row. This arrangement was good because there wouldn't be any award recipients left over. Given that there were at least 20 but fewer than 120 award recipients, how many people did the assistant deans have to seat?

The Missionaries and Cannibals Problem from Reed et al. (1974):

Three missionaries and three cannibals having to cross a river at a ferry, find a boat but the boat is so small that it can contain no more than two persons. If missionaries on either bank of the river, or in the boat, are outnumbered at anytime by cannibals, the cannibals will eat the missionaries. Find the simplest schedule of crossings that will permit all the missionaries and the cannibals to cross the river safely. It is assumed that all passengers on the boat unboard before the next trip and at least one person has to be in the boat for each crossing.

The Jealous Husbands Problem from Reed et al. (1974):

Three jealous husbands and their wives having to cross a river at a ferry, find a boat but the boat is so small that it can contain

no more than two persons. Find the simplest schedule of crossings that will permit all six people to cross the river so that none of the women shall be left in company with any of the men, unless her husband is present. It is assumed that all passengers on the boat unboard before the next trip, and at least one person has to be in the boat for each crossing.

Example of an algebra problem from Bassok & Holyoak (1989):

Kate O'Hara has a job that pays $7,500 for the first six months, with a raise of $250 at the end of every six months thereafter. What was her total income after 12 years?

Example of a physics problem from Bassok & Holyoak (1989):

An object dropped from a hovering helicopter falls 4.9 meters during the first second of its descent, and during each subsequent second it falls 9.8 meters farther than it fell during the preceding second. If it took the object 10 seconds to reach the ground, how high above the ground was the helicopter?

Examples of a Target problem, an Equivalent problem, and a Similar problem from Reed et al. (1985):

Target: Ann can type a manuscript in 10 hours, and Florence can type it in five hours. How long will it take them if they both work together?

Equivalent: Sam can mow a lawn in 20 minutes, while Mark can mow the same lawn in 30 minutes. How long will it take them to mow the lawn if they both work together?

Similar: A carpenter can build a fence in 3 hours, but his apprentice

needs 6 hours to do the same job. When they work together to build the fence, the apprentice works 2 more hours than the carpenter. How long does each work?

Appendix B

Appendix B contains the target problems and their various analogues used in my experiments reported in this thesis.

The Five Target Problems:

The Apples and Oranges Target (adapted from Fixx, 1978):

A grocer ordered a box of apples, a box of oranges, and a box of apples and oranges from his distributor. A week later, the grocer received three boxes of fruit from the distributor. The boxes were labelled 'oranges', 'apples and oranges', and 'apples'. The distributor's representative warned the grocer that although the order had been filled correctly, each label on the boxes was wrong. The grocer realized that he could label each box correctly by selecting one fruit from just one box without looking inside. From which mislabelled box should the grocer select a fruit? Explain.

The Two-String Target (adapted from Maier, 1931):

Before the Inaugural Gala, organizers were hurriedly trying to decorate the hall. Everything was nearly ready, and it was about ten minutes before the President-Elect was scheduled to arrive. Mr. Smith was decorating the walls and ceiling with balloons and party streamers made out of ribbon. He had nearly completed a fancy decoration pattern when he noticed two final pieces of ribbon were left dangling from the tiled ceiling above. He had planned to knot these two final pieces of ribbon together in order to attach balloons to them. However, when he

grabbed the end of the green ribbon, he was unable to grasp the end of the blue ribbon at the same time. The ribbons could simply not be knotted together in this way. Since everyone had momentarily left the room, Mr. Smith thought that he would have to abandon this bit of decoration altogether. Suddenly, an idea struck him, and he was able to knot together these two ribbons. How?

The Poisoned Cups Target (adapted from Wallechinsky & Wallace, 1978):

The King of a distant land sentenced an embezzler to death. Being a gambler at heart, the King offered the prisoner a way out. The King's attendant brought the prisoner two identical boxes, 10 cups labelled 'poison' which were filled with some poisonous concoction, and 10 cups labelled 'water' which were filled with ice water. The attendant instructed the prisoner to distribute the cups any way he wished between the two identical boxes, but that he may not put all 20 cups into one box. When the task is finished, the King will at random reach into one of the boxes, pull out a cup, and force the prisoner to drink the contents of that cup. How should the prisoner arrange the cups so as to maximize his chances of living (i.e. maximize his chances of drinking water)?

The Liar/Truth-teller Target (adapted from Wallechinsky & Wallace, 1978):

A traveller comes to a fork in the road and has no idea as to which way to go to reach his destination. There are two soldiers standing at the fork, and they both know which way is the correct way to go. One soldier is from Bedelred and he always lies. The other soldier is from Narex and he always tells the truth. The traveller knows that

one soldier always lies while the other always tells the truth. Unfortunately, however, he does not know which is which. He may ask one soldier only one question to find out which direction he should take. What question should the traveller ask, and to whom?

The Probability Target (adapted from Ross, 1987):

The local weatherman is forecasting sun for the next full week. Each day, there is a 5/9 chance that it will be sunny, and a 4/9 chance that it will not be sunny. What is the probability that the first sunny day of the week is the sixth day of the week?

Alternate Forms of the Targets for Experiments 1 and 2a:

For the Apples and Oranges Target:

Same Scenario/Same Principle:

A fruit vendor ordered a crate of lemons, a crate of limes, and a crate of lemons and limes from his distributor. A month later, the fruit vendor received the three crates of fruit from his distributor. The crates were labelled "lemons," "lemons and limes," and "limes." The distributor warned the vendor that each label was wrong, but that the order had been filled correctly. The grocery vendor realized that he could label each box correctly by selecting one fruit from just one box without looking inside. How can this be done?

Different Scenario/Same Principle:

A coin collector has three clay pots of coins. One pot is labelled "pennies" and contains some rare pennies. The second pot is

labelled "nickels," and contains some rare nickels. The third pot is labelled "pennies and nickels" and contains both rare pennies and rare nickels. The coin collector's sister switched the labels. She told her collector brother that although each label was wrong, she did not alter the contents of any of the pots. The coin collector realized that by choosing just one coin from one pot, he could correctly label all three pots. How could this be done?

Same Scenario/Different Principle:

The fruit vendor has three crates of fruit. One is labelled "apples" and has 20 apples inside, one is labelled "oranges" and has 50 oranges inside, and one is labelled "apples and oranges" and has 10 apples and 5 oranges inside. The vendor empties the contents of all three crates into one large wooden box. He reaches into this box without looking to pull out some fruits. How many fruits must he take out to make sure that he has at least five of the same kind of fruit?

Different Scenario/Different Principle:

A coin collector has three boxes. One is labelled "nickels and has 40 nickels inside, one is labelled "pennies" and has 25 pennies inside, and one is labelled "pennies and nickels" and has 20 nickels and 55 pennies inside. He then empties the contents of all three boxes into one larger wooden crate. He reaches in without looking to pull out some coins. How many coins must he remove to be sure of having eight of the same kind of coin?

For the Two-String Target:

Same Scenario/Same Principle:

Minutes before her daughter's birthday party, Mrs. White was rushing around her living room trying to finish the decorations. She was decorating the room with balloons and streamers made out of ribbon. She had nearly finished a decoration pattern, when she saw that two streamers were left dangling from above. She thought it would look attractive to knot these two streamers together in order to attach balloons to them. However, when she held onto the end of the blue ribbon, she could not grab the yellow ribbon simultaneously. The streamers were not long enough to be knotted together in this way. Since she was alone in the house, she thought that she would have to give up, when an idea hit her and she finished the pattern. How?

Different Scenario/Same Principle:

An explorer travelling through the jungle decided to stop for the night. Since the jungle he was exploring was full of snakes, he decided to sleep in a hammock-like device suspended over a little river. He began unfolding the blanket that would serve as the base for the hammock. When this was through, the explorer grabbed two vines hanging down and tied them together. This served as support for one end of the blanket. However, the two vines at the other end presented a problem. When the explorer grabbed the end of one vine, he was unable to grasp the end of the other vine at the same time. The two vines could not be knotted together in this way. The explorer thought he would have to give up and move camp elsewhere since these two vines hanging from above could not be knotted together. Suddenly, an idea struck the explorer and he was able to knot together the two vines. How?

Same Scenario/Different Principle:

Prior to the Inaugural Ball, organizers were feverishly trying to get the hall decorated. Mr. Jones was decorating the walls and ceiling with party streamers made out of ribbon. One of Mr. Jones' and the President-Elect's associates, Mr. Drake, was a gambler. and he bet Mr. Jones that he (Mr. Drake) could pick up a streamer, one hand holding each end, and tie a knot in the streamer without letting go of either end. Mr. Jones made the bet, and lost -- Mr. Drake could tie knot in the streamer. How did he do it?

Different Scenario/Different Principle:

Two explorers travelling through the jungle decided to stop and set up camp for the night. One explorer was a gambler and he decided that he needed some extra money. So, this explorer (Mr. Klem) bet the other explorer (Mr. Kaiser) that he (Mr. Klem) could pick up a vine that had fallen from the trees, one hand holding each end, and tie a knot in the vine without letting go of either end. Mr. Kaiser made the bet -- and lost. Mr. Klem could tie the knot in the vine. How did he do it?

For the Poisoned Cups Target:

Same Scenario/Same Principle:

A mythical queen condemned a forger to death. However, because of some bizarre law, the prisoner was allowed a way out. The queen's servant brought the prisoner 8 cups labelled "arsenic" which were filled with arsenic, 8 cups labelled "cider" which were filled with cider, and two identical boxes. The servant commanded the forger to place the cups any way he wanted in the two identical boxes, but that he may not put

all 16 cups into one box. When the forger is through, the queen will reach into one of the boxes at random, and pull out one cup, and the prisoner must drink the contents of that cup. How should the prisoner arrange the cups so as to maximize his chances of living, i.e. to maximize his chances of drinking cider?

Different Scenario/Same Principle:

A street vendor sells navy shirts and white shirts that come in dark brown wrappers (so the contents of each package is unknown to the vendor, but his boss, who packs the shirts into the wrappers and appropriate boxes, knows.) The vendor has two identical boxes, one for the white shirts and one for the navy shirts, and everyday he starts out with 15 of each colour of shirt. His boss, wanting to have some fun with his employee, mixed up the shirts between the two boxes. His boss made sure that no box was empty and he maximized the probability that, at random, a navy shirt would more likely be selected from the boxes than a white shirt. How were the shirts distributed between the two boxes?

Same Scenario/Different Principle:

In a far-away Kingdom, a King sentenced an embezzler to death. However, because of some bizarre law, any victim is always given the opportunity to escape their punishment. The victim is offered a choice of two slips of paper and told that one says "water" and the other says "poison." Their punishment is to drink whatever is written on the paper. However, the King was certain of the embezzler's guilt, and wanted the ultimate punishment. So, he put "poison" on both slips of paper. The Queen warned the embezzler of her husband's actions and he

managed to avoid drinking the poison. How was he able to do this?

Different Scenario/Different Principle:

A street vendor sells white shirts and blue shirts. He makes $5 for every white shirt he sells and $8 for every blue shirt. At the depot every morning, he would reach into a hat and pull out a slip of paper to see what colour of shirt he would be selling that day. The two slips of paper were put in the hat by his boss -- one said "blue" and the other said "white." One morning, the vendor's boss wanted the vendor to sell white shirts, so both slips of paper in the hat said "white." The vendor heard about this stunt from a janitor, and, wanting to make more money per shirt sold, devised a plan so that he could still sell blue shirts in spite of his boss' stunt. He reached into the rigged hat, and later that day was selling blue shirts. How?

For the Probability Target:

Same Scenario/Same Principle:

The airport meteorologist is forecasting snow for this week. Each day, there is a 3/5 chance that it will snow, and a 2/5 chance that it will not snow. What is the probability that the first snowy day of the week is the third day of the week?

Different Scenario/Same Principle:

A Pen Company makes a variety of pens. On 2/7 of their pens, their company name is written in white letters, while on 5/7 of their pens, their company name is written in gold letters. Marty's job is to inspect the pens to see if their name is written in white or gold

letters, for purposes of packaging. What is the probability that the first pen with the name in white letters is the second pen she inspects?

Same Scenario/Different Principle:

The local weatherman is forecasting snow for this week. Each day, there is a 4/7 chance that it will snow, and a 3/7 chance that it will not snow. What is the probability that it will snow on at least one of the first four days of the week?

Different Scenario/Different Principle:

A Pen Company has a variety of pens. On 2/8 of their pens, the company name is written in white letters, and on 6/8 of their pens, the company name is written in gold letters. Lynn's job is to inspect the pens to see if their name is written in white or gold letters. What is the probability that at least one of the first five pens she inspects has the name written in white letters?

For the Liar/Truth-teller Target:

Same Scenario/Same Principle:

A woman journeying up north comes to two bridges and she is unsure of which one to take to arrive at her destination. There are two men standing between the two bridges. One man is from Hendeltown, and he always lies. The other man is from Saskatown and always tells the truth. The woman knows that one man always lies and the other one always tells the truth; however, she does not know which person is which. She may ask only one man one question to find out what bridge to take. What question should the woman ask, and to whom?

Different Scenario/Same Principle:

On a television quiz program's Bonus Round, the lucky contestant is given the opportunity to select one of two doors. Behind one door is a package of prizes and cash beyond the contestant's wildest dreams; but behind the other door is a sign informing the contestant that he/she has lost everything that they accumulated during the day. Standing in front of the two doors are two models. The contestant is told that one model always lies while the other model is always truthful. However, the contestant is not told which is which. The contestant can ask only one question to one of the models to decide which door to choose and hopefully win the prizes. What question should the contestant ask, and to whom?

Same Scenario/Different Principle:

While on a journey northwards, a traveller meets up with two men. He knows that one man comes from Springtown, and the other he knows comes from Wintertown, but he does not know which is which. Furthermore, he knows that the inhabitants of Wintertown always lie, while the inhabitants of Springtown always tell the truth. The traveller wants to know from which town the balder man is from. How can he find that out by asking only one question to one man?

Different Scenario/Different Principle:

On a television program, the contestant is given the opportunity to win $20,000. He is introduced to two people and he is told that one person is from Yellowtown and that one person is from Greentown, but he is not told which is which. Furthermore, he is told that everybody from

Greentown always tells the truth, whereas everybody from Yellowtown always lies. He is allowed to ask one question to one person in order to find out what town the shorter person is from. What question should be asked, and to whom?

The Alternate Forms of the Targets for Experiment 2b:

For the Apples and Oranges Target:

Same Scenario/Same Principle:

The owner of a delicatessen had customers with very unusual taste. As a result, he had to order a sack of eggplants, a sack of turnips, and a sack of turnips and eggplants, in order to make a particularly unusual sandwich. In time for the lunch-hour crowd, he received the three sacks from his distributor. They had printed labels on them that read "turnips," "turnips and eggplants," and "eggplants." The deli-owner was told that because of the haste with which the order had to be filled, the sacks were all mislabelled, but that the order had been filled correctly. The deli-owner realized he had to have the sacks labelled correctly, and that by reaching into only one sack and pulling out only one vegetable without looking, he could correctly label all three sacks. How?

Different Scenario/Same Principle:

The local car dealership has three automobiles that look identical from the outside. However, one car is equipped with cruise control and has no electronic dashboard. Another car has an electronic dashboard, but no cruise control. The other car, which the wealthier

clients prefer, has both cruise control and an electronic dashboard. Unfortunately, all three cars have tinted windows, so prospective customers cannot just look in and observe the dashboard and control panel. Therefore, it is impossible to tell what car has what options without opening a door. A salesman, realizing this, put three signs on the hoods of the proper cars. These signs read "cruise control," "electronic dashboard," and "cruise control/electronic dashboard." Another dealership, wanting to frustrate their rival's customers, switched all three signs late one night, so that each of the three cars had the wrong sign. If the dealer, upon whom this trick was being played, knew this, how could he place the correct signs on all three cars, by not opening up any cars, but instead by finding out one option from one car by a computer search?

Same Scenario/Different Principle:

A vendor's best-selling vegetables were turnips and eggplants. So, he ordered a box of turnips, a box of turnips and eggplants, and a box of eggplants. A week later, the vendor received three boxes of vegetables from his distributor. The boxes were labelled "turnips," "turnips and eggplants," and "eggplants." The distributor warned the vendor that although the order had been filled correctly, two of the boxes were labelled incorrectly and that the box labelled "eggplants" was one of those incorrectly labelled. The vendor realized that he could label each box correctly by opening up just one box. Which box? Explain.

Different Scenario/Different Principle:

The local car dealership acquired three automobiles that look identical from the outside. The only difference between thee cars is

their interior options. One car is equipped with cruise control and has no electronic dashboard. Another car has an electronic dashboard, but no cruise control. The other car, which the wealthier clients prefer, has both cruise control and an electronic dashboard. Unfortunately, all three cars have tinted windows, so prospective customers cannot just look in and observe the dashboard and control panel. Therefore, it is impossible to tell what car has what options without opening a door. A salesman, realizing this, placed a sign on each of the car hoods. These signs read "cruise control," "electronic dashboard," and "cruise control/electronic dashboard." When the owner came into work the next day, he received a letter from a prankster telling him that two of the cars' signs had been switched and that the car now with the "electronic dashboard" sign was incorrectly labelled. The dealer realized that he could label each car correctly by only opening up one car and inspecting the options. Which car? Explain.

For the Two-String Target:

Same Scenario/Same Principle:

Just minutes before her daughter's birthday party, Mrs. McIntyre was rushing around the house trying to decorate the living room and wrap her daughter's presents. She was decorating the living room with balloons and colourful streamers made out of ribbon. She thought she had completed the decorations when she noticed that two final streamers were left dangling from above. She thought that, rather than to pull the streamers down, she could knot these two streamers together in order to attach a balloon to them. However, when she held onto the end of the blue ribbon, she could not grab the yellow ribbon simultaneously. The

streamers were not long enough to be knotted together in this way. Since she was alone in the house and still had gifts to wrap, she thought that she would have to give up, when an idea hit her and she finished the decoration pattern. How?

Different Scenario/Same Principle:

(As in Experiment 2a)

Same Scenario/Different Principle:

Mr. Rennart, who was about 6 feet tall, was the sole decorator of the hall where a Hollywood Awards Ceremony was scheduled to be held. He had two very long gold-coloured streamers made. He attached the end of one streamer to the ceiling (which was about 10 feet above the floor) at one end of the 215 foot wide hall. The length of the streamer in the bundle on the floor at this one end was 115 feet. At the other end of the hall, he attached the other streamer to the ceiling. The length of the streamer in the bundle on the floor at this end was 90 feet. Mr. Rennart's plans were to attach the streamers together and form an elaborate design of streamers that weave in and out of each other. However, the first step was to attach these two streamers together. How could this be done given that 115 + 90 equals 205, and the hall is 215 feet wide, reasoned the decorator. However, after thinking for a minute, he finally knotted the streamers together, without disattaching (detaching) them from the ceiling. How?

Different Scenario/Different Principle:

An explorer, who was about 6 feet tall, was hoping to capture a rare species of elephant that roamed the African Range. The beast

supposedly returned each night to a 215 foot wide cave. The distance from the floor of the cave to the 'ceiling' was 10 feet. At both ends of the cave, there were two very long vines hanging down from the 'ceiling.' The length of the vine in the bundle on the floor at one end of the cave was 115 feet, and the length of the vine in the bundle on the floor at the other end of the cave was 90 feet. The explorer's plans called for an elaborate trap. The first step was to tie together these two vines. The explorer panicked since he realized that 90 and 115 add up to 205, and the cave is 215 feet wide. However, after a minute, the explorer realized he could tie the two vines together. How?

For the Liar/Truth-teller Target:

Same Scenario/Same Principle:

(As in Experiment 2a)

Different Scenario/Same Principle:

(As in Experiment 2a)

Same Scenario/Different Principle:

A traveller comes to two bridges and she is unsure of which one to take to arrive at her destination. There are two gardeners standing between the two bridges. One gardener is from Wallacetown and he always lies. The other gardener is from Brookville and he always tells the truth. However, the traveller does not know which person is which. The traveller was warned in a dream the night before, that she can ask only one question to one man. If the answer to that question is "no," she will be told the correct bridge to take. What question should the

traveller ask, and to whom, to guarantee that she receives a "no" answer, and therefore is told the correct bridge to take?

Different Scenario/Different Principle:

On a television game show, a lucky contestant is given the opportunity to win $20,000. He is introduced to two individuals and told that one person will write out a cheque for $20,000, and that the other person will do nothing but laugh at the contestant. However, the contestant is not told which is which. Furthermore, he is informed that the man who will do nothing but laugh always lies whereas the other man is always honest. The contestant is permitted to ask one question to one person. If the response to that question is "no," the man who writes the cheques will step forward and award the cash. What question should the contestant ask, and to whom, to guarantee that he receives a "no" answer and therefore wins the $20.000?

For the Poisoned Cups Target:

Same Scenario/Same Principle:

(As in Experiment 2a)

Different Scenario/Same Principle:

(As in Experiment 2a)

Same Scenario/Different Principle:

In a far-away Kingdom, a King sentenced an embezzler to death. However, being a gambler at heart, the King always gives a prisoner an opportunity to escape the punishment. The King's attendant brings the

guilty prisoner two identical boxes and two cups -- one of which contains water and the other contains cyanide (a poisonous substance). A cup is placed in each box and the King reaches into one box at random, pulls out a cup, and the prisoner must drink the contents of the cup. Thus, he has a 50% chance of survival. However, the King's attendant was certain of the embezzler's guilt and wanted the ultimate punishment. So, he put the poisonous mixture into both cups. The honest Queen warned the embezzler of the attendant's actions and the prisoner managed to avoid drinking the poison after the King made his selection. How was he able to do this?

Different Scenario/Different Principle:

(As in Experiment 2a)

For the Probability Target:

Same Scenario/Same Principle:

The television meteorologist predicted a very cold week last week. Each day, there was a 31% chance (31/100) that the high temperature for the day would be between zero and five degrees, and a 69% chance that the high temperature for the day would be below zero degrees. As it turned out, the first day of the week with a high temperature of below zero degrees was the fifth day of the week. What is the probability of this happening?

Different Scenario/Same Principle:

A Pen Company has a machine that makes a variety of pens. There is a 17% chance (17/100) that the machine will produce a red pen, and an

83% chance that the machine will produce a blue pen. When the machine has finished producing pens for the day, Bob reaches into the box of pens at random and starts pulling out pens to see if they are red or blue. What is the probability that the first red pen he gets is the ninth pen he selects?

Same Scenario/Different Principle:

This week, the local weatherman is forecasting snow. Each day, there is a 54% chance (54/100) that it will snow and a 46% chance that it will not snow. What is the probability that it will snow on the fourth day, the fifth day, and at least one other day of the week?

Different Scenario/Different Principle:

A Pen Company has a machine that makes a variety of pens. There is a 17% chance (17/100) that the machine will produce a red pen, and an 83% chance that the machine will produce a blue pen. When the machine has finished producing pens for the day, Bob reaches into the box of pens at random and starts pulling out pens to see if they are red or blue. What is the probability that of the first seven pens he selects, the second, the third, and at least one other pen are blue?

The Analogous Training Problems in Problem Form used in Experiments 3, 4, 5, and 12:

For the Apples and Oranges Target:

A certain casino has three boxes of poker chips. One box is labelled '$5' and contains $5 poker chips. The second box is labelled '$10' and contains $10 poker chips. The third box is labelled '$5 and

$10' and contains both $5 and $10 poker chips. One evening, a prankster switched all the labels. He told the casino operator that although each label was wrong, he did not alter the contents of any of the boxes. The casino operator realized that by choosing just one chip from one of the boxes without looking inside, he could correctly label all three boxes. How could this be done?

For the Two-String Target:

An adventurous explorer travelling through the jungles of Africa decided to stop for the night. Since the jungle he was exploring was full of snakes, he decided to sleep in a hammock-like device suspended over a babbling brook. He began unfolding the blanket that would serve as the base for the hammock. When he finished this, the explorer grabbed two vines hanging down and tied them together. This served as support for one end of the blanket. However, the two vines that were to support the other end presented some difficulty. When the explorer grabbed the end of one vine, it was impossible for him to grasp the end of the other vine at the same time. The two vines simply could not be knotted together in this way. The explorer thought he would have to give up and move camp elsewhere because these two vines hanging from above could not be knotted together. Suddenly, an idea struck the explorer and he was able to knot together the two vines. How?

For the Poisoned Cups Target:

A street vendor sells navy shirts and white shirts. The vendor has two identical boxes, one for the white shirts and one for the navy shirts, and everyday he starts out with 15 of each colour of shirt. His boss, wanting to play a practical joke on his employee, mixed up the

shirts between the two boxes, making sure though that neither box was empty. His boss told the janitor about the trick, and the janitor in turn told the street vendor. So, the vendor opened up his two boxes before leaving the depot. Upon looking in them both, he realized that his boss had arranged them such that the probability of randomly selecting a navy shirt over a white shirt was maximized. How were the shirts distributed between the two boxes?

For the Liar/Truth-teller Target:

On a television quiz program's Bonus Round, the lucky contestant is given the opportunity to select one of two envelopes (a yellow one and a red one). Inside one envelope is a cheque for $25,000. In the other envelope is a slip of paper informing the contestant that he/she has lost everything that they accumulated during the regular game. There are two models, each holding an envelope. The models know the contents of each envelope. The contestant is told that one model always lies and the other model always tells the truth. Unfortunately, the contestant is not told which is which. The contestant can ask only one question to one of the models to decide which envelope to select and hopefully win the $25,000. What question should the contestant ask, and to whom, to guarantee that he/she wins the $25,000?

For the Probability Target:

The Toronto Blue Jays and the Montreal Expos are playing seven games for charity next week. Experts have concluded that for each game, there is a 2/7 chance that the Expos will win, and a 5/7 chance that the Blue Jays will win. If so, what is the probability that the first game the Blue Jays win is the fifth game they play?

The Five Analogous Training Problems in Story Form used in Experiments 6, 7, 8, 9, 10, 11, and 12:

For the Apples and Oranges Target:

A certain casino has three boxes of poker chips. One box is labelled '$5' and contains $5 poker chips. The second box is labelled '$10' and contains $10 poker chips. The third box is labelled '$5 and $10' and contains both $5 and $10 poker chips. One evening, a prankster switched all the labels. He told the casino operator that although each label was wrong, he did not alter the contents of any of the boxes.

The casino operator realized that by choosing just one chip from one of the boxes without looking inside, he could correctly label all three boxes. He reached into the box mislabelled '$5 and $10'. If he pulled out a $5 chip, this crate must contain $5 chips because all crates are mislabelled. Then, by a process of elimination, the others can be labelled. If a $5 chip is drawn from the box, the box mislabelled '$5' must contain $10 chips, and the box mislabelled '$10' must contain both $5 and $10 poker chips. Once the prankster's identity was determined, the casino operator decided to close his line of credit.

For the Two-String Target:

An adventurous explorer travelling through the jungles of Africa decided to stop for the night. Since the jungle he was exploring was full of snakes, he decided to sleep in a hammock-like device suspended over a babbling brook. He began unfolding the blanket that would serve as the base for the hammock. When he finished this, the explorer grabbed two vines hanging down and tied them together. This served as

support for one end of the blanket. However, the two vines that were to support the other end presented some difficulty. When the explorer grabbed the end of one vine, it was impossible for him to grasp the end of the other vine at the same time. The two vines simply could not be knotted together in this way. The explorer thought he would have to give up and move camp elsewhere because these two vines hanging from above could not be knotted together.

Suddenly, an idea struck the explorer and he was able to knot together the two vines. He took a rock and attached it to the end of one vine. Next, he grabbed the rock and vigorously swung the vine to which it was attached in the direction of the other vine. He then ran quickly to this other vine, grabbed it, and walked as close as possible to the swinging vine, which was now swinging back and forth. He then waited until the swinging vine came his way and caught it on the upswing. Now, while holding both vines, he removed the rock and knotted the two vines together. He was then able to enjoy a safe night's sleep.

For the Poisoned Cups Target:

A street vendor sells navy shirts and white shirts. The vendor has two identical boxes, one for the white shirts and one for the navy shirts, and everyday he starts out with 15 of each colour of shirt. His boss, wanting to play a practical joke on his employee, mixed up the shirts between the two boxes, making sure though that neither box was empty. His boss told the janitor about the trick, and the janitor in turn told the street vendor. So, the vendor opened up his two boxes before leaving the depot. Upon looking in them both, he realized that his boss had arranged them such that the probability of randomly selecting a navy shirt over a white shirt was maximized. He saw that in

one box, there was one navy shirt. In the other box were 14 navy shirts and all the white shirts. The vendor laughed for a few seconds and threatened revenge.

For the Liar/Truth-teller Target:

On a television quiz program's Bonus Round, the lucky contestant is given the opportunity to select one of two envelopes (a yellow one and a red one). Inside one envelope is a cheque for $25,000. In the other envelope is a slip of paper informing the contestant that he/she has lost everything that they accumulated during the regular game. There are two models, each holding an envelope. The models know the contents of each envelope. The contestant is told that one model always lies and the other model always tells the truth. Unfortunately, the contestant is not told which is which. The contestant can ask only one question to one of the models to decide which envelope to select and hopefully win the $25,000.

After thinking it over for the allotted time limit of 30 seconds, the contestant realized that by asking either model "what would the other model say is the correct envelope" and then picking the opposite envelope, he/she would win the $25,000. Sure enough, he/she asked the question, and is now enjoying a cruise around the Caribbean.

For the Probability Target:

The Toronto Blue Jays and the Montreal Expos are playing seven games for charity next week. Experts have concluded that for each game, there is a 2/7 chance that the Expos will win, and a 5/7 chance that the Blue Jays will win. Joe is in a betting pool and he has bet his life's savings that the first game the Blue Jays win is the fifth game that they will play against the Expos.

Joe's wife is furious. She calculated that given that the experts are correct, the likelihood of Joe winning is less than 1 percent. She reasoned that if the Blue Jays are to win first in Game 5, the Expos must win the first four games. The chance of the Expos winning one game is 2/7; thus, the chance of winning four games in a row are 2/7 x 2/7 x 2/7 x 2/7. She then multiplied this result by 5/7, the likelihood of the Blue Jays winning Game 5. Needless to say, she plans on divorcing Joe.

The "Confusable" Passages for the Liar/Truth-teller Target used in Experiment 12:

Problem Form:

On a television quiz show's Bonus Round, a lucky contestant is given the opportunity to select one of two envelopes (a blue one and a green one). Inside one envelope is a key to a luxury automobile. The other envelope is empty, and if chosen, the contestant wins nothing. There are two models each holding an envelope. The contestant is informed that one model always tells the truth and the other model always lies. However, the contestant does not know which is which. He can ask only one question to one of the models. If the answer to that question is "NO", the contestant is told which envelope to pick to win the car. What question should the contestant ask, and to whom, to guarantee that he receives a "NO" answer, and therefore, wins the car?

On a television quiz show's Bonus Round, a contestant has the opportunity to select one of two envelopes (a black one and a white

one). Inside one envelope is a cheque for $50,000, and inside the other envelope is a cheque for $.50. He is introduced to two men and he is told that one man is the director of the show, and that the other man is the producer of the show - but he is not told which is which. Furthermore, he is told that the director always lies, whereas the producer always tells the truth. He is allowed to ask one question to one of the two men in order to find out the occupation of the balder man. If he is successful, the contestant is told which envelope to pick to win the $50,000. What question should be asked, and to whom to guarantee the contestant of winning the $50,000?

Story Form:

On a television quiz show's Bonus Round, a lucky contestant is given the opportunity to select one of two envelopes (a blue one and a green one). Inside one envelope is a key to a luxury automobile. The other envelope is empty, and if chosen, the contestant wins nothing. There are two models each holding an envelope. The contestant is informed that one model always tells the truth and the other model always lies. However, the contestant does not know which is which. He can ask only one question to one of the models. If the answer to that questions is 'NO', the contestant is told which envelope to pick to win the car.

The contestant thought it over for the allotted time limit of 30 seconds and realized that by asking either model "what would the other model say if I asked her if the moon was in the sky?" Sure enough, he asked the question, and is now driving about town in a new set of wheels.

On a television quiz show's Bonus Round, a contestant has the opportunity to select one of two envelopes (a black one and a white one). Inside one envelope is a cheque for $50,000, and inside the other envelope is a cheque for $.50. He is introduced to two men and he is told that one man is the director of the show, and that the other man is the producer of the show - but he is not told which is which. Furthermore, he is told that the director always lies, whereas the producer always tells the truth. He is allowed to ask one question to one of the two men in order to find out the occupation of the balder man. If he is successful, the contestant is told which envelope to pick to win the $50,000.

After thinking it over for the allotted time of 30 seconds, the contestant realized that by asking the balder man a nonsense question (e.g. "do I have seven eyes?"), he could determine the balder man's occupation. Sure enough, he asked a nonsense question, won the $50,000, and is now enjoying a cruise of the Caribbean.

Appendix C

Appendix C contains the solutions and explanations read to the subjects after they worked with the training analogues in Experiments 3 through 12.

For the Apples and Oranges Target:

In this passage you are told of a casino operator who has three boxes of poker chips. One box is labelled $5 and contains $5 poker chips, a second box is labelled $10 and contains $10 poker chips, and the third box is labelled $5 and $10 and contains a mixture of both $5 and $10 poker chips. However, in the passage you are told that a prankster comes in and switches the labels on all three boxes, but he does not alter the contents of any of the boxes. The casino operator realizes that by reaching in and pulling out a chip from one of the boxes without looking, he can correctly label each box. Here's what he does. He reaches into the box labelled $5 and $10 and pulls out a chip. Whatever chip he pulls out of that box is the sole contents of that box, because all boxes are mislabelled. If he pulls out a $5 chip from the box mislabelled $5 and $10, then he knows the box contains only $5 chips because they cannot contain a mixture or else the label is correct, and you are told that the prankster switched all three labels. Than, through a process of elimination you can correctly label the other two boxes. The box mislabelled $10 must contain the mixture, and the box mislabelled $5 must contain the $10 chips. So, by reaching in to the

box mislabelled as having the mixture inside and pulling out a chip, the casino operator can correctly label all three boxes. Whatever he pulls out is representative of the sole contents of that box, and through a process of elimination, he can label all boxes correctly.

For the Two-String Target:

In this passage, you are told of an explorer who must tie two vines together to make his sleeping apparatus. However, when he tries to grab the one vine to bring it over to the other one to tie, he finds that he cannot do it. The two vines are too far apart for him to grab onto at the same time. So, he takes a rock and attaches it to the end of one of the vines. Then, he sets the vine to which he attached the rock in swinging motion. Then, while it's swinging, he runs over to the stationary vine, grabs it, and walks with it towards the vine that is swinging. When the swinging vine comes back to him on the upswing, he can grab it, while still holding the other vine, and attach the two of them together. Because of pendulum motion, this solution works. So, by turning one of the vines into a pendulum, the explorer is able to attach the two vines together.

For the Liar/Truth-teller Target:

The game show contestant is given the choice between two envelopes, one containing big money, the other containing bad news. With the two envelopes are two models, one of whom always lies and the other always tells the truth - and the contestant does not know which is which. The contestant is given one question to ask either of the two models which envelope to pick to win the money. Now the question the

contestant should ask must be applicable to either model, that is, the question must yield the answer from a liar and truth-teller, because the contestant does not know which is which. The question the contestant should ask to either of the models is this: "What would the other model say is the correct envelope to choose" and then given this answer, the contestant would take the opposite. Let's suppose the lucky envelope is the red one. Let's suppose that the model you happen to ask is the liar. So, you say to her "what would the other model say is the correct envelope to choose?" You are, in fact, to her, saying "what would the truth-teller say is the correct envelope to choose?" Well, the truth-teller would say to pick red, but since the liar lies, she'll say "Oh, the other model would say to pick yellow" and then given this answer the contestant would pick red. If the model you happen to ask is the truth-teller. So, you say to her "what would the other model say is the correct envelope to choose?" You are, in fact, to her, saying "what would the liar say is the correct envelope to choose?" Well, the liar would say to pick yellow, and since the truth-teller tells the truth, she'll say "Oh, the other model would say to pick yellow" and then given this answer the contestant would pick red. So by asking either model what the other model would say and then picking the opposite, will give the contestant the money.

<u>For the Poisoned Cups Target:</u>

In this passage, you are told of a street vendor who has two boxes of shirts. Ordinarily, he has 15 white shirts in one box, and 15 navy shirts in the other box. However, on this particular day, his boss has mixed up the shirts between the two boxes. His boss mixed up the

shirts between the two boxes, ensuring that neither box was empty. The vendor was alerted to the prank, and opened up the boxes. When he opened them up, he found that the shirts had been arranged such that the probability of reaching into one of the boxes at random and randomly pulling out a navy shirt had been maximized. One box contained one navy shirt, and the other box contained 14 navy shirts and 15 white shirts. The reason why this maximizes the probability of selecting a navy shirt is this: If the vendor would reach into the left box, and there is a 50% chance he would randomly do this, then there is a 100% chance that he would pick out a navy shirt. If he should go to the right box, and there is a 50% chance that he would do this, there is a 14/29 chance of picking out a navy shirt. When you add this expression together, you get about a 75% chance of picking out a navy shirt. If you try any other possible combinations, you will never get a value as high as 75%. So, by putting one navy shirt in one box, and everything else in the second box, the probability of randomly picking a navy shirt is maximized.

<u>For the Probability Target:</u>

The Toronto Blue Jays and Montreal Expos are playing seven games for charity next week. For each game there is a 2/7 chance the Expos will win, and a 5/7 chance that the Blue Jays will win. We are interested in the probability of the Blue Jays' first victory coming in the fifth game that they play out of the seven. So, we are not interested in the results of Game 6 and 7. According to our problem, the Blue Jays must win game 5 and there is a 5/7 chance of them winning any game, so for game 5 there is a 5/7 chance of a Blue Jays victory.

Now, if that is to be their first win, they must lose the first four; that is, the Expos must win the first four. The odds of the Expos winning any game are 2/7, so the odds of winning the first four straight are 2/7 x 2/7 x 2/7 x 2/7. You then multiply this result by 5/7, the odds of the Blue Jays winning Game 5. When you work this probability out, you get a result of less than 1%.