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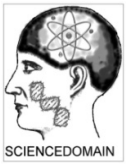

Increasing the Transfer of Source Solutions in Analogical Problem Solving

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Authors' contributions

This work was carried out in collaboration between all authors. Author BH designed the study, wrote the protocol and supervised the work. Authors LT, ME and KJ carried out all laboratories work. Authors BH and LT performed the statistical analysis. Author BH wrote the first draft of the manuscript. Author LT managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The aim of the present study is to examine whether spontaneous analogical transfer might be increased by enhancing the relationship between the source problem and solution and/or the gist-level knowledge of the source and target problems.
Study Design: All three experiments use a between-subjects design.
Place and Duration of Study: The University of Texas at San Antonio, Department of Psychology, 2004-2009.
Methodology: Five hundred and twelve fluent English speaking students from the Introductory Psychology classes from the University of Texas at San Antonio participated in this research for course credit. As in typical administrations of analogical problem solving tasks, students encoded a source problem and solution and then read and generated solutions for a target problem. However, one unique feature of our study was the inclusion of a manipulation that specifically enhanced the

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strength of the relationship between the source problem and solution. Experiment 1A used *why* questions to strengthen this relationship and Experiments 1B and 2 used multiple-choice questions.
Results: The results of the first two experiments revealed increases in both the complexity and frequency of solutions for the target problems when all three enhancements were present, min χ^2 (4) = 13.78, P = .009. Further, the results of the third experiment showed that all three enhancements were necessary for spontaneous transfer to be equivalent to a non-spontaneous hint condition, χ^2 (8) = 17.73, P = .03.
Conclusion: Taken as a whole the present findings emphasize the importance of enhancing the relationship between the source problem and solution as well as gist-level knowledge of the source and target problems in the context of analogical problem solving and Kintsch's (1988) construction-integration framework for comprehension.

Keywords: Analogical problem solving; spontaneous transfer.

1. INTRODUCTION

In our daily lives we frequently encounter novel problems that are reminiscent of earlier problems. Our realization that an earlier problem is analogous to the present problem and our application of the solution of a former problem to the present one is called *analogical problem solving.* Analogical problem solving usually occurs in one of two forms: cued or spontaneous transfer [1,2]. *Cued transfer* occurs when people are supplied with an explicit cue or *hint* that a previously-learned problem (i.e., *source problem*) might help with solving a current problem (i.e., *target problem*); for example, when a teacher reminds a student that a solution for an earlier math problem (i.e., *source problem*) might help with solving the present problem (i.e., *target problem*). On the other hand, *spontaneous transfer* occurs when a previously-learned problem is used to solve a novel one in the absence of a hint; for instance, when a student applies an earlier solution to a new problem without reminding. People frequently spontaneously transfer the solution from a source to a target when these two problems share similar contents or domains of knowledge, such as when they both are related to medical conditions [3,4]. Unfortunately, when the domains of knowledge are different, people often fail to realize the relevance of the source problem, let alone apply its solution to the target problem [3,4]. That is, across different domains of knowledge spontaneous transfer rarely occurs. The goal of the present study was to examine whether spontaneous transfer might be increased by emphasizing key elements in the source and target problems.

The difficulty of spontaneous transfer across different domains of knowledge is well documented [1-3,5-16]. Indeed, as Gick and Holyoak [1] showed in their seminal research, few participants spontaneously transfer the solution of an isomorphic source problem (i.e., the *attack-dispersion problem*) to a target problem (i.e., Dunker's [17] *tumor-radiation problem*) even when the two problems are presented in succession. On the other hand, transfer increases substantially with the provision of a hint to use an analogous source problem as a guide [1].

Subsequent studies have revealed considerable increases in spontaneous transfer when the surface similarity between the source and target problems is augmented [18]. For instance, surface similarity influences performance on Duncker's [17] radiation problem and its isomorphs [18]. The more surface features the source and target problems have in common, the higher the rate of spontaneous transfer [19]. Apparently, similarity in surface features can influence analogical transfer as the source is retrieved [18], during the source-to-target mapping phase [20,21], and as the target is encoded [22].

Other studies have revealed substantial increases in spontaneous transfer when the underlying or structural features are either enhanced [23] or attended to (e.g., Novick, 1988). For instance, cognitive training studies haven shown that when an abstract relational structure of the goal, dilemma, and solution of a source is generated, spontaneous transfer occurs more frequently than when either gist about a source's main points or details about a source problem and solution are summarized [23]. Presumably, creating an abstract relational structure or schema of the source increases transfer because it emphasizes structural correspondences and de-emphasizes surface differences between the source and target

problems [2,23]. As well, research examining expertise differences in both domain general and domain specific transfer (e.g., chess, physics, snooker) suggests that, in comparison to less-successful problem solvers, successful problem solvers rely more on a source that shares many structural features with a target than a source that shares considerably fewer features [24-26]. Perhaps these expert-novice differences exist because when structural features are used to form an abstract mental representation of a source it becomes easier to notice correspondences between the source and target problems.

Although some analogical problem solving studies have focused on the general role that structural features play in the development of an abstract representation or *schema* of a source [2,5,23], while other studies have focused on the role that structural features play when developing a deeply connected relational structure or *structural alignment* between a source and target [10,27-29], much less is known about the importance and/or role that just the relationship between the source problem and its solution plays in spontaneous transfer. That is, *how important to spontaneous transfer is the relationship between the source problem and its solution?* Given that the ultimate goal of analogical problem solving is to transfer the solution from a source to a novel problem, certainly a lack of a relationship between the source problem and its solution might preempt transfer success. Indeed, as early as 1966, Hesse [30] proposed that the relationship between two parts of a single analog, like the source problem and its solution, is an important part of analogical problem solving that is separate or distinct from the relationship between the source and target problems.

To the best of our knowledge, no study has directly examined the extent that the relationship between the source problem and solution influences spontaneous transfer; although, there is some indirect evidence. For instance, Needham and Begg [31] showed that when participants received a detailed explanation about why a particular solution solved a source problem, these problem-orientated participants spontaneously transferred from source-to-target more so than participants who did not receive a detailed explanation. Although Needham and Begg [31] interpreted their findings as evidence for the benefits of problem-orientated training in spontaneous transfer, an alternative explanation is that perhaps a detailed explanation why the solution solved the problem ensured a well-formed relationship between the source problem and solution, and that it was this well-formed relationship, and not problem-oriented training that increased spontaneous transfer. Like Needham and Begg [31], Gick and McGarry [32] also observed that a manipulation, which may have influenced the relationship between the source problem and solution, increased spontaneous transfer. However, unlike Needham and Begg [31], Gick and McGarry's [32] study examined learning from mistakes. Specifically, when they induced failures to solve the source by supplying incorrect solutions prior to the correct one, spontaneous transfer of the correct source solution to the target was greater than when failures to solve the source were not induced. Although Gick and McGarry [32] attributed their findings as evidence for the importance of failed solutions in spontaneous transfer, again an alternative explanation is that perhaps processing failed solutions encouraged participants to be more attentive to the relationship between the source problem and its correct solution, and it was this relationship between the source problem and solution and not the processing of failed solutions that increased transfer of the source solution to the target.

Moreover, the idea of forming a strong relationship between the source problem and solution is also consistent with Kintsch's [33] postulation that a well-elaborated mental representation of a text, including gist and elaborations, can be useful in solving novel problems, whereas a mental representation consisting of only gist is not. According to Kintsch [33,34], three mental representations of a text can be created during comprehension: (1) a *surface representation* consisting of verbatim memory, (2) a *textbase representation* consisting of gist, and (3) a *situation model* consisting of both gist and elaborations. When readers form a textbase representation of a text but fail to form a situation model, they often recall the text quite well but are unable to use information from the text in new and productive ways [35]. On the other hand, when readers form a situation model of a text they can employ the information in a useful way, such as applying the new, acquired knowledge to a new text [33; see also 7].

The findings of Mandler and Orlich [23], Needham and Begg [31], and Gick and McGarry [32] also appear to support Kintsch's [33]

contrast between the utility of a situation model and a textbase representation. For instance, problem-orientated participants in Mandler and Orlich's study [23], who presumably formed situation models when they focused on the relations or abstract structure of key elements in the source problem and solution, outperformed participants, who presumably formed textbase representations when they summarized just the main points of the source problem and solution. In Needham and Begg's study [31], problem-orientated participants, who presumably formed situation models when they received detailed explanations about why a particular solution solved a source problem, outperformed memory-orientated participants, who presumably formed textbase representations when they were instructed to remember the source problem for future recall. Finally, in Gick and McGarry's study [32], participants who presumably formed situation models when they received a correct solution to the source problem after first receiving an incorrect solution, outperformed participants who presumably formed textbase representations when they received the source and just its correct solution.

Of course, one could argue that a situation model, consisting of both gist and elaborations, is not much different from what problem solving researchers call a schema, an abstract mental representation of a problem. In general, this argument is true because both schema and situation models involve creating mental representations of text. However, whereas problem solving researchers have largely defined schemas as abstract mental representations of the structural elements of a problem, consisting of little to no gist-level knowledge [2,5,23,36], a situation model consists of both gist-level knowledge and relationships or elaborations among crucial ideas in a text [33]. Moreover, situation models tend to specify the exact relations among the structural elements of problems. In the context of the present study, this specificity of relationships introduces the possibility of enhancing crucial relationships between key elements of a problem, such as the relationship between a source problem and its solution.

1.1 Overview of Our Experiments

The goal of the present study was to determine the components of the mental representations of the source and target problems that are crucial for spontaneous transfer. As in typical administrations of analogical problem solving tasks, participants encoded a source problem and solution and then read and generated solutions for a target problem. However, one unique feature of our study was the inclusion of a manipulation that specifically enhanced the strength of the relationship between the source problem and solution. Experiment 1A used *why* questions to strengthen this relationship and Experiments 1B and 2 used multiple-choice questions. Based on our interpretations of Needham and Begg's and Gick and McGarry's studies [31,32], the prediction was that spontaneous transfer in conditions that included this enhanced relationship would be greater than spontaneous transfer in a gist-source or gist-level condition.

A second feature that we considered was whether gist-level knowledge of the source and target problems might influence spontaneous transfer. This consideration was included because, even with a strengthened relationship between the source problem and solution, it is possible that spontaneous transfer will not occur unless there is adequate encoding of the gist of the source and target problems [37; also see 13,16; for exception see 7]. Indeed, Mumford, Baughman, Supinski, and Maher [38] observed that when participants spent time encoding pertinent information about insight problems their solutions were more original and of a higher quality than the solutions of participants who spent less time. Therefore, in some of the conditions in Experiment 1A, participants freely recalled facts from both the source and target problems. In Experiment 1B, they answered multiple-choice questions. In Experiment 2, we further tested the importance of gist-level knowledge of the source and target problems by comparing conditions that included gist-level multiple-choice questions to conditions that did not include these questions.

2. EXPERIMENT 1A

Experiment 1A examined whether enhancing the strength of the relationship between the source problem and solution plus ensuring gist-level knowledge of the target problem increased spontaneous transfer. Participants encoded and recalled a source problem and solution, such as the *climber problem* described in Table 1, and then read and generated solutions for a target problem, like the *pirate problem* described in Table 1. However, in two conditions, we also included two novel features. One feature was a detailed explanation about why the source

solution solved the source problem. Our thinking here was that perhaps an additional explanation about the relationship between the source problem and solution might strengthen the relationship between these two elements of the source and, as a result, spontaneous transfer of the solution from source to target might be greater then when this relationship is not strengthened. Such a finding would be consistent with Hannon and Daneman [39] who showed that when *why* questions were embedded in short passages in order to strengthen relationships between important elements, less-skilled readers were more likely to generate thematic inferences about the passages then when *why* questions were not embedded.

A second feature of Experiment 1A was that, in two conditions, participants freely recalled essential points from the target problem. Our thinking here was that perhaps additional processing might enhance the gist-level mental representations of the target. With the relationships between the source problems and solutions enhanced via *why* questions and representations of the targets enhanced to a gist-level, participants might then begin to draw parallels between the structures of the source and target which, in turn, may increase the frequency that they spontaneously transfer the source solution (e.g., the *climber problem*) to the target (e.g., the *pirate problem*).

Although the idea of enhancing mental representations has been examined previously by Antonietti [5], Antonietti [5] observed limited success [see 7,13,16 for other studies that have tried to enhance transfer). The present study improved upon his study in a number of ways. Whereas Antonietti enhanced mental representations of the source problem and solution by using various manipulations (i.e., literal memorization, stating an opinion about the solution, and schematizing the problem and solution), he also provided a hint that the source problem and solution might help with solving the target. As a result, Antonietti's manipulations cannot be construed as ones that increase s*pontaneous transfer*; rather, they increased *cued transfer*. In contrast, in the enhanced-source+gist-target condition, no hint was provided. Further, although one of Antonietti's manipulations [5], namely, stating an opinion, was presumably included to

Table 1. Example of source-target problem set used in Experiments 1A, 1B, and 2

Source Problem: Climber

A climber decided to take two pairs of expensive boots on a mountain climbing vacation. However, once the climber arrived at the base of the mountain he realized that he could only take minimal provisions with him if he was going to succeed climbing the mountain. So the climber decided to leave one pair of boots behind. At first he thought about taking the boots back to his jeep, but his jeep was 30 miles away and he didn't have enough time to complete the round trip to his jeep and climb the mountain. He also thought about leaving the boots at the base of the mountain, but the boots were expensive and he was sure that someone would steal the boots before he returned from his climb. So the climber decided to devise a different plan.
The climber decided to hide one boot under a rock near the mountain side. Then, a short distance further on, he decided to hide the other boot in the middle of a bush. He reasoned that, whereas one boot may be found, it was unlikely that the same person would find both boots, and since one boot would be of little or no value it would not be taken.

Target Problem: Pirate

A pirate found two pieces of a much-desired map that led to an extremely large treasure. However, once the pirate started developing his plan for collecting the treasure he realized that there were many tasks that needed to be done first and that while doing these tasks it was too dangerous for him to carry around the map. So the pirate decided that he had to do something about the map. He thought about memorizing the map but there were just too many important details that were far too easy to forget. He also thought about taping the map to his chest, but there were too many robbers in town and he knew that eventually one of them would steal the map while he was sleeping. So the pirate devised a different plan.

How was the pirate going to solve the problem?

Taken from Gick and Holyoak [1] and Reed [40]

enhance the source solution, it is quite possible that this manipulation simply elicited value judgments that were based on unrelated prior knowledge and opinion. Indeed, Antonietti's actual instructional phrase [5] was *"subsequently you will have to give your opinion about the solution."* (p. 251) In contrast, the why-question, used in our enhanced-source+gist-target condition, does not elicit an opinion but rather an explanation why the solution solves the source problem. By directing participants in this manner, presumably their responses will be based on connections between information provided in the source problem and solution rather than prior knowledge and opinions. Finally, whereas the target was simply read in Antonietti's study [5], in Experiment 1A the essential points of the target were extracted and summarized. To the best of our knowledge, this is the first time a study has actually attended to the gist-level quality of mental representations of a target. Because the enhanced-source portion of the manipulation required actively relating the source problem to its solution, which is consistent with our alternative interpretation of Needham and Begg's [31] and Gick and McGarry's [32] studies, the prediction was that spontaneous transfer would be greater in the enhanced-source+gist-target condition than in either a literal recall of the source (i.e., gist-source) or a baseline condition. What was unclear is whether transfer in the enhanced-source+gist-target condition would be lesser than, greater than, or equivalent to the gist-source+hint or the enhanced-source+gist-target+hint conditions.

2.1 Materials and Methods

2.1.1 Participants and design

The participants were 140 University of Texas at San Antonio Introductory to Psychology students who received course credit for their participation. All students were fluent English speakers and were tested in one session in groups of two to four. Participants were randomly assigned to one of five conditions: baseline, gist-source, gist-source+hint, enhanced-source+gist-target, or enhanced-source+gist-target+hint; with 28 participants completing each condition. (i.e., this was a between-subjects design). In each condition, participants solved one problem, like the pirate one depicted in Table 1. In the baseline condition, they simply solved the target problem. On the other hand, in the other four conditions, participants received a partner source problem before solving the target. See Table 1 for examples of the source and target problems.

2.1.2 Analogical problem solving task

Our analogical transfer task was a variant of Gick and Holyoak's task [1], which measured the transfer of a solution from a source (e.g., *climber problem*) to a target (e.g., *pirate problem*). The critical condition was the enhanced-source+gist-target condition, which included gist recall of the source problem, a why question for relating the source problem and solution, and gist recall of the target. However, we also included four other conditions for comparison purposes: baseline, gist-source, gist-source+hint, and enhanced-source+gist-target+hint. The baseline condition served as a measure of analogical problem solving ability without the possibility of transfer. The gist-source condition, which involved recalling the source prior to solving the target, served as a measure of analogical problem solving ability with the possibility of spontaneous transfer of a solution from source to target. The gist-source+hint condition, which included recalling the source and receiving a hint prior to solving the target problem, served as a measure of cued transfer. Finally, the enhanced-source+gist-target+hint condition served as a measure of the combination of our enhancements plus a hint. As noted earlier participants completed only one of these conditions.

2.1.2.1 Materials

The four pairs of problems were taken or adapted from analogical problem solving studies and logic books [1,40-42]. Although the structures of the problems within a pair were similar, the structures between the pairs were different. For example, the climber and pirate problems, shown in Table 1, have similar structures inasmuch as both problems focus on a specific object (i.e., *either a pair of expensive boots or two pieces of a treasure map*), both characters desire to retain the object (i.e., *expensive boots or a treasure map*), and so on. In contrast, the other pairs of problems have different structures. For example, the *balloon and lake problems* both require capacity estimations (i.e., *helium or water*) that do not require the division of an object. Rather, the balloon and lake problems require determining the concentration of chemicals to helium or water and then using this

information to make an estimate about the volume.

The criteria for selecting and/or developing the pairs of problems were: (1) the structures of problems within a pair were similar, (2) the structures between pairs were different, (3) each problem had a solution that consisted of a minimum of three points, and (4) there were 6 to 8 sentences within each problem. The four pairs of problems were counterbalanced such that all pairs appeared equally within the five conditions.

2.1.2.2 Procedure

As in Gick and Holyoak [1], participants in the *baseline condition* solved the target problem using an analogous problem as a guide. As Table 2 shows, they were given seven minutes to read the target (e.g., *pirate problem*) and to generate as many solutions as possible. In the *gist-source condition*, eight minutes eight minutes were allotted for reading and memorizing the source problem and solution (e.g., *climber problem*) and then five minutes for recalling the source problem and solution as close to its original form as possible. Next, participants were allotted seven minutes to read the target (e.g., *pirate problem*) and to generate as many solutions as possible. They were not allowed to refer visually to the source. In the *gist-source+hint condition*, participants were allotted eight minutes to learn the source problem and solution and five minutes to recall the source problem and solution as close to their original form as possible. Then, they received the target and were instructed to read and solve the problem. Prior to receiving the target, participants were told that "*You might find that the first problem that you read gives you some hints for the second problem, so you should try and use it if you can"* [1, p. 337]. They were allotted seven minutes to generate as many solutions as possible and were not allowed to refer visually to the source.

As Table 2 shows, in the *enhanced-source+gist-target condition* four minutes were allotted for reading and extracting the essential points from the source problem and then four minutes for outlining the essential points. Next, participants were given three minutes to read the source solution and to complete an evaluation form that was designed to relate the problem with its solution. Specifically, the question "*Why does this solution solve the problem?"* required participants to evaluate the solution with respect to the source problem. Immediately after completing the evaluation form, they were allotted four minutes to read and extract the essential points from the target ad then four minutes to outline the essential points.

Table 2. Steps used in the baseline, gist-source, gist-source+hint, enhanced-source+enhanced-target, and enhanced-source+enhanced-target+hint conditions in Experiment 1A

Condition	Source problem	Target problem
Baseline	Not applicable	1. Read problem and solve (7 min)
Gist-source	1. Read and memorize problem and solution (8 min) 2. Recall (5 min)	3. Read problem and solve (7 min)
Gist-source+hint	1. Read and memorize problem and solution (8 min) 2. Recall (5 min)	3. Hint before instructions 4. Read problem and solve (7 min)
Enhanced-soruce+gist-target	1 a. Read problem only (4 min) b. Outline main points (4 min) 2. Read solution only and complete evaluation (3 min)	3 a. Read problem only (4 min) b. Outline main points (4 min) 4. Read problem and solve (7 min)
Enhanced-source+gist-target+hint	1 a. Read problem only (4 min) b. Outline main points (4 min) 2. Read solution only and complete evaluation (3 min)	3 a. Read problem only (4 min) b. Outlie main points (4 min) 4. Hint before instructions 5. Read problem and solve (7 min)

Finally, participants were given seven minutes to read the target again and to generate as many solutions as possible. They were not allowed to refer visually to the source. Like the enhanced-source+gist-target condition, in the *enhanced-source+gist-target+hint condition* participants learned and recalled the source problem, evaluated the relationship between the source problem and solution, and then learned and recalled the target. However, unlike the enhanced-source+gist-target condition, prior to reading and solving the target, they were given a hint that was identical to the one used in the gist-source+hint condition. Participants then generated as many solutions as possible and again, they were not permitted to refer visually to the source.

2.2 Results and Discussion

In all three experiments, the data for the problems were scored by one independent rater, who was unaware of the conditions and the overall experimental hypothesis. The magnitude of each significant effect was indicated by eta-squared (i.e., η^2) and Cohen's *f.* It is important to note, that according to Cohen [43] a large effect has a Cohen's $f = .40$, a medium effect has a Cohen's $f = .25$, and a small effect has a Cohen's $f = .10$, and that effects with Cohen's $f's > .50$ are rare in the behavioural sciences (See also Howell [44] for a discussion of effect sizes). Analysis of the target problem consisted of solution complexity (i.e., how complex were the solutions for the target problem?) and frequency of transfer (i.e., how frequently was a high-quality complex solution transferred?). In general, the results showed that both solution complexity and transfer frequency for the enhanced-source+gist-target were equivalent to performance in the two conditions that included hints.

2.2.1 Target problem performance: Solution complexity

A quantitative measure of solution complexity was calculated for each participant by summing the number of critical components in their best solution. For example, the three critical solution components for the *pirate problem* were: (1) dividing the map into two pieces because one piece of the map would be of little to no value, (2) hiding one piece of the map in a secure location, and (3) hiding the other piece of the map in another secure location. See Antonietti [4] and Gick and Holyoak [1] for a similar scoring method. Because each participant completed one problem and each solution had three critical components, a score ranged from 0-3. A solution complexity score of three meant that the solution included all three critical components; for example, a three-point solution for the pirate problem would include the three components detailed above. A solution complexity score of zero meant that no critical components were included in a solution. Partial credit was awarded for partial answers; for example, a score of two was awarded if two of the three components were included in a solution.

To determine whether enhancing the relationship between the source problem and its solution as well as including gist-level recall of the target influenced solution complexity, a one-way analysis of variance (ANOVA) was performed with condition as the between-subjects factor (i.e., baseline, gist-source, gist-source+hint, enhanced-source+gist-target, and enhanced-source+gist-target+ hint). As Table 3 shows, solution complexity appears to be equivalent among the enhanced-source+gist-target, gist-source+hint, and the enhanced-source+gist-target+hint conditions, F (*4*, 135) = 9.09, MSE = 8.35, $P < .001$, $\eta^2 = .212$, Cohen's $f = .52$. Subsequent t-tests confirmed this observation. Whereas complexity of solutions in the baseline and gist-source conditions was significantly lower than those in the enhanced-source+gist-target, gist-source+hint, and the enhanced-source+gist-target+hint conditions (i.e., 18.75% and 21.13% versus 49.70%, 58.93%, and 48.21% respectively), *min t* (54) = 3.14, $P = .003$, there were no differences in solution complexity among the latter three conditions, *max t* (54) = 1.15, $P = .26$. Taken together these findings suggest that strengthening the relationship between the source problem and solution as well as ensuring gist-level knowledge of the target increases the complexity of a solution to a level that is equivalent to providing a hint.

2.2.2 Target problem performance: Frequency of transfer

Besides determining whether the complexity of answers in the enhanced-source+gist-target condition were equivalent to those observed in a gist-source+hint condition, we also examined whether the frequency of complex solutions generated in the enhanced-source+gist-target condition was equivalent to the frequency of complex solutions generated in the gist-source+hint or the enhanced-source+gist-target+hint conditions. In order to make these

comparisons, we converted each solution complexity score into either a zero or a one and then performed chi-squared tests on the frequency scores. A score of zero indicated that a solution complexity score was less than the mean of the gist-source+hint condition, whereas a score of one indicated that it was equivalent to, or greater than the mean of the gist-source+hint condition. The mean of the gist-source+hint condition was chosen as the threshold for transfer because it allowed direct comparisons between frequency of cued transfer and frequency of spontaneous transfer.

As Table 4 shows, frequency of transfer varied as a function of condition, χ^2 (4) = 20.16, $P < .001$. Whereas transfer frequency in the enhanced-source+gist-target, gist-source+hint, and enhanced-source+gist-target+hint conditions were equivalent, χ^2 (2) = .38, $P = .83$, and transfer frequency in the baseline and gist-source conditions were also equivalent, χ^2 (1) = .16, $P = .69$, transfer frequency in the former three conditions (i.e., the enhanced-source+gist-target, gist-source+hint, and enhanced-source+gist-target+hint) was significantly greater than transfer frequency in the latter two conditions (i.e., baseline and gist-source), *min* χ^2 (1) = 6.84, $P = .009$.

In summary, the results of the ANOVA and chi-squared tests are quite positive inasmuch as they suggest that both increasing the strength of the relationship between the source problem and solution and including gist-level recall of the target problem increases spontaneous transfer to a level that is equivalent to cued transfer. Further, the results suggest that the addition of a hint over and above our enhancements, as in the enhanced-source+gist-target+hint condition, does not increase complexity of a solution any greater than just providing either a hint or enhancements. However, these results are not without their limitations. For instance, there is some question about whether they can be replicated using a different manipulation.

Table 3. Solution complexity as a function of condition in Experiments 1A, 1B, and 2

Condition	Experiment 1A	Experiment 1B	Experiment 2
Baseline	18.75 (4.73)	15.28 (5.46)	20.24 (4.97)
Source+target			38.10 (4.55)
Gist-source	21.13 (5.47)		43.75 (6.60)
Relationship-source			44.05 (5.75)
Enhanced-source			46.73 (6.28)
Gist-target			43.75 (4.77)
Hint		50.35 (6.98)	54.75 (4.75)
Gist-source+hint	58.93 (6.46)	42.08 (7.53)	
Relationship-source+ gist-target			39.60 (5.47)
Enhanced-source+gist-target	49.70 (6.62)	46.67 (7.72)	52.68 (5.64)
Enhanced-source+gist-target+hint	48.21 (6.68)	50.00 (6.86)	

Note. Reported in percentages. Standard errors are in brackets

Table 4. Frequency of solution transfer as a function of condition in Experiments 1A, 1B, and 2

Condition	Experiment 1A	Experiment 1B	Experiment 2
Baseline	10.71	12.50	14.29
Source+target			21.43
Gist-source	14.29		46.43
Relationship-soruce			39.29
Enhanced-source			39.29
Gist-target			39.29
Hint	53.57	62.50	60.71
Gist-source+hint		41.67	
Relationship-source+gist-target			39.29
Enhanced-source+gist-target	46.43	50.00	46.43
Enhanced-source+gist-target+hint	46.43	50.00	

Note. Frequency of transfer reported in percentages

As well, the processing times for the source and target varied among the conditions, which leaves one to wonder whether the results are a consequence of our enhancements or simply varying processing times. Finally, there is some question whether all the enhancements are truly necessary for spontaneous transfer to be equivalent to cued transfer. That is, are the two unique enhancements we included, enhancing the gist-level of the target problem and enhancing the relationship between the source problem and solution, enough for spontaneous transfer to be equivalent to cued transfer, or must we also enhance the gist-level of the source; an enhancement that is typically found in administrations of an analogical problem solving tasks, like the one we used in Experiment 1A? In order to address the first two limitations, in Experiments 1B and 2 we substituted the free recall and why-question with multiple-choice questions and we equated processing times for the source and target problems among the conditions. In order to address the third limitation, in Experiment 2 we tested whether one, two, or all three enhancements were necessary for spontaneous transfer to be equivalent to cued transfer.

3. EXPERIMENT 1B

Experiment 1B served three purposes. First, we were interested in replicating the findings of Experiment 1A with a different manipulation; and so, in Experiment 1B, the *why* question and free recall were substituted with multiple-choice questions. But even more importantly, we wished to eliminate some of the differences in time allotments among the conditions used in Experiment 1A. For instance, as illustrated in Table 2, more time was spent processing the source problem and solution in the gist-source and gist-source+hint conditions than in either the enhanced-source+gist-target or enhanced-source+gist-target+hint conditions (i.e., 13 versus 11 min). As well, in the former two conditions, less time was spent processing the target problem than in the latter two conditions (i.e., 7 versus 15 min). In order to eliminate these differences, in Experiment 1B, time allotments for processing the source and target were made as consistent as possible. The final times that are reported in Table 2 were based on integrating the times used by previous researchers [1] plus the practical experience we gained from Experiment 1A (i.e., was the amount of time excessive, just right, too little).

As well, we sought more control on the degree to which participants related the source problem to its solution because, although a *why* question encourages relating the problem to its solution, the extent that the problem is related to its solution can potentially vary from participant to participant. Similarly, we sought more control on gist-level encoding of the source and target problems because the extent that facts from these two problems are encoded may also vary from participant to participant. Therefore, in Experiment 1B, we substituted the *why* question and free recall with multiple-choice questions that either enhanced the relationship between the source problem and solution or gist-level knowledge of the source and/or target problem.

The multiple-choice questions that enhanced the relationship between the source problem and solution were designed to ensure that participants acknowledged a relationship between the problem and solution without exerting a particularly heavy memory load. Consider, for instance, the following question:

By concealing one boot under a boulder and the other boot in a shrub

a. *The climber could abandon a pair of boots*
b. *The cyclist could abandon a pair of socks*
c. *The climber could throw away a pair of boots*

This question is quite easy to answer if two basic facts about the *climber* problem are remembered, namely that the character in the story is a *climber* and not a *cyclist* and that the object to be abandoned but not *thrown away* is *a pair of boots* and not a *pair of socks.* Because most participants should remember that the problem is about a climber and a pair of boots, it is highly likely that they will correctly connect the question stem, which is part of the solution, with the appropriate answer, which is part of the problem. When this outcome occurs, presumably, participants will form a relationship between the source solution and problem.

The multiple-choice questions that enhanced gist-level knowledge of the source and target problems were similar to those used for enhancing the relationship between the source problem and solution inasmuch as they were not particularly mentally taxing. However, unlike the latter questions, the gist-level questions re-enforced basic facts about the source or target. For example, the gist-level source question,

The climber chose to:

a. *Abandon a pair of socks.*
b. *Abandon a pair of tennis shoes.*
c. *Abandon a pair of boots.*

Re-enforces the fact that the object is a *pair of boots* and not a *pair of socks* or *a pair of tennis shoes.* Similarly, the gist-level target question,

The pirate resolved to:

a. *Do something about the portrait.*
b. *Do something about the picture.*
c. *Do something about the map.*

Re-enforces the fact that the object is a *map* and not a *portrait* or *a picture.* See Table 5 for other examples of questions.

Because the multiple-choice questions in Experiment 1B were designed to perform the same functions as the *why* question and free recall in Experiment 1A, and because Experiment 1A showed that enhancing the relationship between the source problem and its solution plus gist-level encoding of the target increased spontaneous transfer to a level that was equivalent to cued transfer, we predicted that performance in the enhanced-source+gist-target condition would be equivalent to performance in both a gist-source+hint and an enhanced-source+gist-target+hint condition. Further, we predicted that performance in the enhanced-source+gist-target condition would be greater than performance in the baseline condition.

Table 5. Examples of different types of questions for climber-pirate problem set

Source problem: Gist-level

The climber considered abandoning the boots near the bottom of the mountain, but they were

a. *costly and he was confident that somebody would take the socks before he came back.*
b. *cheap and he was confident that somebody would borrow the tennis shoes before he came back.*
c. *costly and he was confident that somebody would take the boots before he came back.*

Source solution: Gist-level

The climber decided to conceal

a. *one boot beneath a boulder near the mountain.*
b. *one sock beneath a boulder near the main road.*
c. *one tennis shoe beneath a boulder near the main road.*

Source problem and solution: Relationship

By thinking that it was unlikely the same person would discover both boots if they were concealed separately,

a. *the cyclist solves the problem that someone might take his socks.*
b. *the cyclist solves the problem that someone might take his tennis shoes.*
c. *the climber solves the problem that someone might take his boots.*

Target problem: Gist-level

A pirate discovered

a. *two pieces of a coveted map that led to a significantly sizeable treasure.*
b. *two pieces of a coveted portrait that led to a significantly sizeable ship.*
c. *two pieces of a coveted picture that led to a significantly sizeable ship.*

When the pirate began developing his strategy for gathering the treasure he recognized that there were errands that needed to be made and

a. *it was too risky to take the portrait.*
b. *it was too risky to take the map.*
c. *it was too precautious to take the map.*

3.1 Materials and Methods

3.1.1 Participants and design

The participants were 120 University of Texas at San Antonio Introductory Psychology student who received course credit for their participation. All students were fluent English speakers and were tested in one session in groups of one to three. Participants were randomly assigned to one of five conditions: baseline, hint, enhanced-source+gist-target, enhanced-source+gist-target+ hint, or a second hint condition that included gist-level encoding of the source problem (i.e., gist-source+hint); with 24 participants completing each condition (i.e., this was a between-subjects design). In each condition, participants solved one problem, like the pirate problem depicted in Table 1. In the baseline condition, they simply solved the target problem. In the other four conditions, they received a partner source problem before solving the target problem.

3.1.2 Analogical problem solving task

As in Experiment 1A, Experiment 1B included the critical enhanced-source+ gist-target condition, as well as baseline and enhanced-source+gist-target+hint conditions to serve as control conditions. However, Experiment 1B also included two hint conditions. One hint condition—the gist-source+hint--was similar to the hint condition that is typically administered in analogical problem solving studies [1] and the one used in Experiment 1A inasmuch as participants encoded the source problem and solution and then completed a memory test (i.e., recognition instead of free recall) to ensure encoding of the source. But, one limitation of this type of hint condition is that it also includes gist-level encoding of the source; a limitation that makes it somewhat ambiguous to ascertain whether solution transfer occurred because of (i) a hint, or because of (ii) the gist-level encoding of the source AND a hint. Therefore, Experiment 1B included a gist-source+hint condition for comparison purposes but it also included a second hint condition that did not require gist-level encoding of the source (i.e., hint). See Table 6 for more details about the differences between these two hint conditions. As noted earlier participants completed only one of these conditions.

3.1.2.1 Materials

The stimuli consisted of three pairs of problems that were used in Experiment 1A, namely the *climber-pirate*, the *balloon-lake*, and the *attack-tumor* problems. Experiment 1B also included multiple-choice questions that either: (i) enhanced the relationship between the source problem and its solution, (ii) enhanced gist-level encoding of the source, or (iii) enhanced gist-level encoding of the target. The *jealous wife-suspicious girlfriend* problems were eliminated because of time constraints for creating the multiple-choice questions.

Table 6. Steps used in the baseline, hint, gist-source+hint, enhanced-source+gist-target, and enhanced-source+gist-target+hint conditions in Experiment 1B.

Condition	Source problem	Target problem
Baseline	Not applicable	1. Read problem and solve (7 min)
Hint	1. Learn problem and solution (7 min)	2. Learn target problem (4 min) 3. Hint before solving 4. Read problem and solve (7 min)
Gist-source+hint	1. Learn problem and solution (7 min) 2. Complete gist-level questions	3. Learn target problem (4 min) 4. Hint before solving 5. Read problem and solve (7 min)
Enhanced-source+gist-target	1. Learn problem and solution (7 min) 2. Complete gist-level and relationship questions	3. Learn target problem (4 min) 4. Complete gist-level questions 5. Read problem and solve (7 min)
Enhanced-source+gist-target+hint	1. Learn problem and solution (7 min) 2. Complete gist-level and relationship questions	3. Learn target problem (4 min) 4. Complete gist-level questions 5. Hint before solving 6. Read problem and solve (7 min)

The three pairs of problems were represented equally in the conditions. However, because the number of sentences varied from problem to problem so did the number of multiple-choice questions. For instance, there were four questions for enhancing the relationship between the source problem and solution; there were eight to eleven questions for ensuring gist-level encoding of the source problem and solution, and there were five to seven questions for ensuring gist-level encoding of the target. See Table 5 for examples of questions.

A number of criteria were used for developing the multiple-choice questions. Consider, for instance, the following question that was designed to enhance the relationship between the source problem and solution:

By concealing one boot under a boulder and the other boot in a shrub

a. The climber could abandon a pair of boots.
b. The cyclist could abandon a pair of socks.
c. The climber could throw away a pair of boots.

The question stem conveys the same meaning as the actual sentences it is adapted from (i.e., *The climber decided to hide one boot under a rock near the mountain side. Then, a short distance further on, he decided to hide the other boot in the middle of a bush*.); although, verbs like *hide* are exchanged with verbs like *conceal*. As well, the false choices (i.e., *b. the cyclist could abandon a pair of socks* and *c. the climber could throw away a pair of boots*) are nearly identical to the correct choice (i.e., *a. the climber could abandon a pair of boots*), except critical nouns, like *climber* and *boots*, were exchanged with erroneous ones, like *cyclist* and *socks* and critical verbs, like *abandon*, were exchanged with erroneous ones, like *throw away*.

Similarly, the question stem and correct choice for the gist-level questions convey the same meaning as the actual sentence they were adapted from. For instance, the question

The climber chose to:

a. Abandon a pair of socks.
b. Abandon a pair of tennis shoes.
c. Abandon a pair of boots.

Includes a question stem (i.e., *The climber decided to:* and a correct answer (i.e., c. *abandon one pair of boots*) that convey the same meaning as the sentence they were adapted from (i.e., *So the climber decided to leave one pair of boots behind.*) As well, the false choices (i.e., *a. abandon a pair of socks* and *b. abandon a pair of tennis shoes*) are nearly identical to the correct choice (i.e., *c. abandon one pair of boots*), except critical nouns, like *boots*, were exchanged with erroneous ones, like *socks* and *tennis shoes*.

Each question included three choices: one correct choice and two erroneous choices and the option number for the correct answers was counterbalanced among the questions. The questions were randomly presented, one at a time, in the middle of a computer screen and remained there until a participant selected an answer. Once a participant selected an answer, the question disappeared and the next question appeared.

3.1.2.2 Procedure

Table 6 outlines the steps completed in each condition as well as the time allotted to each step. As Table 6 shows, the sequence of steps were highly similar to those executed in Experiment 1A, except the times allotments for learning the source and target problems were much more consistent across conditions. Further, as in Experiment 1A, participants were not allowed to refer visually to the source problem and solution as they generated solutions for the target. Finally, the *hint*, which was used in the hint, gist-source+hint, and enhanced-source+gist-target+hint conditions, was identical to the one used in Experiment 1A.

3.2 Results and Discussion

Analysis of the source problem consisted of a check of our manipulation(s). Analysis of the target problem consisted of solution complexity (i.e., how complex were the solutions for the target?) and frequency of transfer (i.e., how frequently was a high-quality complex solution transferred?). In general, the results were similar to those of Experiment 1A inasmuch as solution complexity and transfer frequency for the enhanced-source+gist-target was equivalent to the two conditions that included hints.

3.2.1 Source problem performance

Our first goal was to verify that participants found the multiple-choice questions easy to answer. Overall, performance was high as the percentages for correct responses were 99%,

97.3%, and 94% for the source problem and solution relationship, gist-source, and gist-target questions respectively; a finding that confirms that participants did indeed find the questions easy to answer.

3.2.2 Target problem performance: Solution complexity

To determine whether we replicated the findings of Experiment 1A, solution complexity scores were calculated, using the same procedure detailed in Experiment 1A, and then submitted to a one-way ANOVA with condition as the between-subjects factor (i.e., baseline, hint, gist-source+ hint, enhanced-source+gist-target, enhanced-source+gist-target+hint). As Table 3 shows, solution complexity appears to be equivalent in the enhanced-source+gist-target, hint, gist-source+hint, and the enhanced-source+gist-target+hint conditions and solution complexity for these latter four conditions appears to be greater than that in the baseline condition, F (*4*, 115) = 4.46, MSE = 4.67, P = .003, η^2 = .134, Cohen's f = .39. Subsequent t-tests confirmed this observation. Whereas, solution complexity in the baseline condition was significantly lower than those in the enhanced-source+gist-target, hint, gist-source+hint, and the enhanced-source+gist-target+hint conditions (i.e., 15.27% versus 46.67%, 50.33%, 42.08%, and 50.00% respectively), *min* t (46) = 2.88, P = .009, there were no significant differences in solution complexity among the enhanced-source+gist-target, hint, gist-source+hint, and enhanced-source-gist-target+hint conditions, *all t's* < 1.0. These findings support those of Experiment 1A inasmuch as strengthening the relationship between the source problem and solution as well as the gist-level of the target increases the complexity of a solution to a level that is equivalent a condition that includes a hint. However, once again, the results revealed that including a hint over and above our enhancements (i.e., the enhanced-source+gist-target+hint condition) did not increase the complexity of a solution.

3.2.2.1 Target problem performance: Transfer frequency

We also were interested in examining whether the frequency that participants generated complex solutions was equivalent to, less than, or greater than the hint conditions. To accomplish this goal, we converted each solution complexity score into either a zero or one, using the procedure detailed in Experiment 1A, and then performed chi-squared tests on these frequency scores. As Table 4 shows, frequency varied as a function of condition, χ^2 (4) = 13.78, P = .009. Whereas frequency of transfer in the enhanced-source+gist-target, hint, gist-source+hint, and enhanced-source+gist-target+hint conditions were equivalent, χ^2 (3) = 2.13, P = .54, transfer frequency in these four conditions was significantly greater than transfer frequency in the baseline condition, *min* χ^2 (1) = 5.17, P = .025. This finding supports the results of the ANOVA as well as those of Experiment 1A inasmuch as increasing the strength of the relationship between the source problem and solution and ensuring gist-level encoding of the source and target problems increases spontaneous transfer to a level that is equivalent to cued transfer.

4. EXPERIMENT 2

The findings of Experiments 1A and 1B suggest that enhancing the relationship between the source problem and solution plus ensuring gist-level knowledge of the source and target problems elevates spontaneous transfer to a level that is equivalent to cued transfer. Of course, these findings are based on three enhancements—the relationship between the source problem and solution, gist-level knowledge of the source problem, and gist-level knowledge of the target problem—and so, one might wonder whether all three enhancements are necessary for spontaneous transfer to be equivalent to cued transfer. For instance, perhaps just enhancing the relationship between the source problem and solution increases spontaneous transfer to a level equivalent to cued transfer. Or, perhaps, enhancing the relationship between the source problem and solution as well as enhancing gist-level knowledge of the source problem are necessary in order to make spontaneous transfer equivalent to cued transfer. In order to test these and other possibilities, Experiment 2 included a number of combinations of enhancements that were designed to isolate the locus of spontaneous transfer. For example, there were conditions with an enhancement for just the gist of the source (i.e., *gist-source*) or gist of the target (i.e., *gist-target*) and there was a condition with enhancements for both the gist of the source and the relationship between the source problem and solution (i.e., *enhanced-source*). Finally, there was a condition that included the source and target problems with no enhancements (i.e., *source+target*).

4.1 Materials and Methods

4.1.1 Participants and design

The participants were 252 University of Texas at San Antonio Introductory Psychology student who received course credit for their participation. All students were fluent English speakers and were tested in one session in groups of one to three. Each student completed one problem in one of the nine randomized conditions of the analogical problem solving task: Baseline, source+ target, relationship-source, gist-source, enhanced-source, gist-target, relationship-source+gist-target, enhanced-source+gist-target, or hint; with 28 students completing each condition (i.e., this was a between-subjects design). In the baseline condition, they simply solved the target problem. On the other hand, in the other eight conditions, they received a partner source problem before solving the target problem.

4.1.2 Analogical problem solving task

As in Experiment 1B, Experiment 2 included the critical condition, the enhanced-source+ gist-target, as well as baseline and hint conditions for making comparisons. However, Experiment 2 included six other conditions in order to isolate the locus of spontaneous transfer. The *source+target* condition served as a measure of analogical problem solving with the possibility of transfer without enhancements. The *gist-source* condition, which included gist questions about the source and solution, the *relationship-source* condition, which included questions that enhanced the relationship between the source and solution, and the *enhanced-source* condition, which included both gist and relational questions about the source problem and solution, served as measures for the potential benefits of different types of source enhancements. On the other hand, the *gist-target* condition served as a measure for the potential benefits of a gist-level target enhancement. Finally, the *relationship-source+gist-target* condition served as a measure of the combined benefits of relating the source problem and solution plus enhancing the gist-level of the target problem. See Table 7 for more detail about the differences among the nine conditions. As noted earlier participants completed only one of these conditions.

Table 7. Steps used in the baseline, hint, source+target, relationship-source, gist-source, enhanced-source, gist-retrieval, relationship-source+gist-target, enhanced-source+gist-target, and hint conditions in Experiment 2

Condition	Source problem	Target problem
Baseline	Same as Experiment 1B	Same as Experiment 1B
Source+target	1. Learn problem and solution (7 min)	2. Learn target problem (4 min) 3. Read problem and solve (7 min)
Relationship-source	1. Learn problem and solution (7 min) 2. Complete relationship questions	3. Learn target problem (4 min) 4. Read problem and solve (7 min)
Gist-source	1. Learn problem and solution (7 min) 2. Complete gist-level questions	3. Learn target problem (4 min) 4. Read problem and solve (7 min)
Enhanced-source	1. Learn problem and solution (7 min) 2. Complete gist-level and relationship questions	3. Learn target problem (4 min) 4. Read problem and solve (7 min)
Gist-retrieval	1. Learn problem and solution (7 min)	2. Learn target problem (4 min) 3. Complete gist-level questions 4. Read problem and solve (7 min)
Relationship-source+gist-target	1. Learn problem and solution 2. complete relationship questions	3. Learn target problem (4 min) 4. Complete gist-level questions 5. Read problem and solve (7 min)
Enhanced-source+gist-target	Same as Experiment 1B	Same as Experiment 1B
Hint	Same as Experiment 1B	Same as Experiment 1B

4.1.2.1 Materials

The stimuli consisted of the *climber-pirate* and *attack-tumor* problems as well as multiple-choice questions that either: (i) enhanced the relationship between the source problem and solution, (ii) ensured gist-level encoding of the source, or (iii) ensured gist-level encoding of the target. The *balloon-lake* problems were eliminated in order to make administration of the nine conditions easier. The remaining two problem pairs were counterbalanced among the conditions.

The multiple-choice questions were identical to those used in Experiment 1B but, of course, the types of questions varied from condition to condition. For example, the *gist-source condition* included gist-level questions about the source problem and solution, while the *enhanced-source condition* included questions that enhanced the relationship between the source problem and solution as well as gist-level knowledge about the source problem and solution.

4.1.2.2 Procedure

Table 7 outlines the steps that were completed in each condition as well as the times allotted. As Table 7 shows, the general procedure was highly similar to the one used in Experiments 1A and 1B. As in previous experiments, participants were not allowed to refer visually to the source as they generated solutions for the target. As well, the *hint*, used in the hint condition, was identical to the one used in previous experiments.

4.2 Results and Discussion

4.2.1 Source problem performance

As in Experiment 1B, performance on the multiple-choice questions was high. Specifically, the percentages for correct responses were 99.1%, 96%, and 94.8% for the source problem and solution relationship, the gist-source, and the gist-target questions respectively. As in Experiment 1B, this finding suggests that participants found the questions easy to answer.

4.2.2 Target problem performance: Solution complexity

As in previous experiments, we computed a quantitative measure of solution complexity for each participant and then performed a one-way ANOVA with condition as a between-subjects factor (i.e., baseline, source+target, relationship-source, gist-source, enhanced-source, gist-target, relationship-source+gist-target, enhanced-source+gist-target, and hint). As Table 3 shows, solution complexity varied as a function of condition, F (8, 243) = 3.36, MSE = 2.52, P < .001, η^2 =.10, Cohen's f = .33. Subsequent post-hoc tests revealed significant differences in solution complexity between the baseline and the other eight conditions (i.e., source+target, relationship-source, gist-source, enhanced-source, gist-target, relationship-source+gist-target, enhanced-source+gist-target, and hint), $min\ t$ (54) = 2.65, P = .01; a finding which suggests that providing a source problem and solution prior to the target increases the quality of correct solutions for the target more so than when a source problem and solution are absent. As well, solution complexities in the enhanced-source+gist-target and hint conditions were equivalent (i.e., 52.68% and 54.76% respectively), t < 1.0; a finding which suggests that enhancing key elements of the source and target increases the complexity of solutions to a level that is equivalent to providing a hint. However, only solution complexities in the enhanced-source+gist-target and hint conditions were significantly greater than solution complexity in the source+target condition (i.e., 52.68% and 54.76% versus 38.10% respectively), $min\ t$ (54) = 2.01, P = .05; the solution complexities for the relationship-source+gist-target, relationship-source, gist-source, enhanced-source, and the gist-target conditions were not (i.e., 39.60%, 44.05%, 43.75%, 46.73%, 43.75% versus 38.10% respectively), $max\ t$ (54) = 1.11, P = .27. Because only solution complexities for the enhanced-source+gist-target and hint conditions were greater than the solution complexity for the source+target condition, a condition with no enhancements, it appears that all three enhancements—ensuring a relationship between the source problem and solution, ensuring gist-level knowledge of the source problem, and ensuring gist-level knowledge of the target problem—are necessary for complexity of solutions in an enhanced condition to be equivalent to those of a hint condition.

4.2.3 Target problem performance: Transfer frequency

Our final goal was to assess frequency of solution transfer by converting solution complexity scores into either a one or zero, using

the same procedure detailed in Experiment 1A. As Table 4 shows, frequency varied as a function of condition, χ^2 (8) = 17.73, *P* = .03. Subsequent tests revealed that frequency in the gist-source, relationship-source, enhanced-source, gist-target, relationship-source+gist-target, enhanced-source+gist-target, and hint conditions, was greater than frequency in the baseline condition, *min* χ^2 (1) = 4.46, *P* = .03, whereas frequency in the baseline and source+target conditions was equivalent, χ^2 < 1.0. This finding suggests that, regardless of the type of enhancement that we introduced, any enhancement increases the frequency of quality solutions. Moreover, transfer frequency in the enhanced-source+gist-target and hint conditions was greater than transfer frequency in the source+target condition, χ^2 (1) = 3.90, *P* = .04, while transfer frequency in the relationship-source+gist-target, relationship-source, enhanced-source, and gist-target, was not, *max* χ^2 (1) = 2.11, *P* = .15. This finding suggests that enhancing the relationship between the source problem and solution as well as the gist-level of the source and target problems increases frequency of transfer of high quality solutions more so than when many of the enhancements are presented individually. However, one unusual finding was that transfer frequency for the gist-source condition was also greater than that for the source+target condition, χ^2 (1) = 3.90, *P* = .04; a finding which suggests that enhancing the gist-level knowledge of the source problem increases the frequency of quality solutions more so than when no enhancements are present. Finally, there were no differences in frequency of transfer among the hint, enhanced-source+gist-target, relationship-source+gist-target, enhanced-source, relationship-source, gist-source, and gist-target conditions, χ^2 (5) = 3.94, *P* = .55.

In summary, the results of the ANOVA and chi-squared tests suggest that, for the most part, all three enhancements--ensuring a relationship between the source problem and solution, ensuring gist-level knowledge of the source problem, and ensuring gist-level knowledge of the target problem—are necessary for spontaneous transfer to be equivalent to cued transfer. The only exception was that enhancing the gist of the source increases the frequency of transfer of very high-quality solutions to a level equivalent to a hint condition. However, because the results of the ANOVA suggest that solution complexity in the gist-source condition was no greater than that for the source+target condition, a condition with no enhancements, it appears that although increasing the gist-level of the source may increase frequency of transfer, increasing the gist-level of the source does not consistently produce, complex solutions that are better than a condition with no enhancements (i.e., source+target). Rather, only by ensuring a relationship between the source problem and solution, ensuring gist-level knowledge of the source problem, and ensuring gist-level knowledge of the target problem can spontaneous transfer to be equivalent to cued transfer both in solution complexity and frequency of transfer.

5. CONCLUSIONS

In general, the present experiments support the idea that enhancing both the gist-level of the source and target problems as well as the relationship between the source problem and solution increases spontaneous transfer to a level equivalent to cued transfer. Below we discuss our major findings, discuss their relation to other work, and suggest their implications for theories of analogical problem solving and future research.

5.1 Influences of Enhancements on Spontaneous Transfer

The results of Experiment 1A revealed increases in both complexity of correct solutions for the target problem and frequency of solution transfer from source to target after participants answered a question about why the source solution solved the source problem and freely recalled the source and target. Further, solution complexity and frequency of transfer were equivalent to conditions that included a hint or a hint plus enhancements (i.e., enhanced-source+gist-target+hint). The facilitative influences of the enhancements persisted when the gist-level recall of the source and target problems and the *why-question* (Experiment 1A) were exchanged with multiple-choice questions (Experiments 1B and 2). Finally, the results of Experiment 2 suggested that in order for both complexity of correct solutions for the target problem and frequency of solution transfer to be both equivalent to a hint condition and greater than a condition absent of enhancements (i.e., source+target), all three enhancements--ensuring a relationship between a source problem and solution, ensuring gist-level knowledge of a source, and ensuring gist-level knowledge of a target—are probably necessary.

But, why might enhancing the relationship between the source problem and solution as well as the gist-level of the source and target problems increase spontaneous transfer to a level equivalent to cued transfer? One plausible explanation is that, perhaps, the presence of multiple-choice questions after both the source and target problems cued participants to the nature of our study. The general idea here is that participants realized a relationship between the source and target problems because multiple-choice questions followed each of these problems. If this explanation were true, then it would not be that surprising to observe equivalent performance in the enhanced-source+gist-target and hint conditions because it would simply mean that an indirect cue or hint (i.e., the two sets of multiple-choice questions) had the same influence as an explicit hint. However, if this explanation were true then one would also expect similar performance in all conditions that had questions following the source and target. Yet, performance in the relationship-source+gist-target condition, which also included questions after the source and target, was substantially different from that of the enhanced-source+gist-target and hint conditions. Indeed, whereas solution complexity and transfer frequency in both the enhanced-source+gist-target and hint conditions were significantly greater than those of the source+target condition, a condition without enhancements, solution complexity and transfer frequency in the relationship-source+gist-target and source+target conditions were equivalent. Thus, it seems that the presence of questions following both the source and target is an inadequate explanation for our results.

A second explanation is that, perhaps, our manipulations did indeed enhance key elements in the source and target problems. These additional enhancements may have facilitated retrieval of the source solution when participants were searching their memories for solutions for the target problem. According to this explanation, the source solution would be selected as a potential answer for the target over other potential answers from long-term memory because the source problem and solution had a greater activation level than the other solutions. However, if this explanation were true then one would expect other conditions with source enhancements to also show increases in spontaneous transfer. Yet, the results of Experiment 2 suggest that other conditions with source enhancements, like the enhanced-source, relationship-source, and gist-source conditions, had, at best, small increases in spontaneous transfer; a finding that suggests that increased activation of the source problem and solution cannot be the sole explanation for our results.

An alternative and perhaps better explanation is that the enhancements facilitated both horizontal mapping between the source and target problems and vertical mapping between the source problem and solution (See Hess [30] for more on horizontal and vertical mapping). The general idea here is that the gist-level enhancements increased the activation levels of key elements in the source and target, which facilitated comparisons between the structures of the source and target problems (i.e., horizontal mapping), while the relationship enhancement increased the strength of the relationship between the source problem and solution (i.e., vertical mapping). With both types of mappings enhanced, participants could easily create a relational structure or *structural alignment* between the source and target problems and then easily retrieve the source solution because of its strengthened relationship with the source problem.

5.2 Relation of Present Findings to Other Work

Although the designs of our manipulations were based on findings and interpretations of existing analogical problem solving research, we also introduced the idea of what Kintsch [34] calls a situation model. To re-iterate, in Kintsch's construction-integration model of comprehension there are three types of mental representations: (1) a *surface representation* consisting of verbatim memory, (2) a *textbase representation* consisting of gist, and (3) a *situation model* consisting of both gist and elaborations. Because the relationship manipulation encouraged participants to draw inferences between the source problem and solution and because inferences are more situation-based rather than surface or textbase, it is quite possible that our participants developed a situation model of the source problem and solution. If this speculation were true then one criterion for spontaneous analogical problem solving may be that the mental representation of the source problem must be more elaborate like a situation model. Indeed, such a possibility is consistent with Ripoll, Brude, and Coulon [45], who argue that representations, like situation models, may play an important role in analogical transfer, as well

as the findings of Mandler and Orlich [23], who showed that generation of an abstract relational structure of the goal, dilemma, and solution of a source increases frequency of spontaneous transfer.

In addition, the idea that spontaneous transfer occurs more frequently when the source is a situation model, rather than a textbase representation, closely parallels Adams and colleagues [46] work on insight. In their study, participants viewed insight problems, such as:

> *The Reverend Sol Loony announced that, on a certain day, at a certain time, he would perform a great miracle. He would walk for 20 minutes on the surface of the Hudson River without sinking into the water. A big crowd gathered to witness the event. The Reverend Loony did exactly what he said he would do. How did he manage to walk on the surface of the river without sinking? [46].*

Prior to solving the problems, solutions were presented in one of two ways. Factual statements conveyed a fact, such as *A person can walk on frozen water.* In contrast, problem-orientated statements, such as *A person can walk on water if it is frozen.*, were conditional and therefore, required more processing. Adams and colleagues observed that problem-orientated statements elicited more correct solutions than factual ones. Within Kintsch's [34] theoretical framework, this finding makes sense because each problem-orientated statement required relating its subject and predicate together and then verifying the truth of this relationship with prior knowledge. Thus, participants would need to form situation models of these statements in order to verify their truth. On the other hand, because each factual statement required only verification with prior knowledge, participants need only form textbase representations of these statements.

On a similar note, the idea that people often fail to establish important relationships when processing problems closely parallels findings in the comprehension literature. For instance, Hannon and Daneman [47] showed that bridging inferences, which are necessary for text coherence, are not routinely executed by poor readers (see also [48]). Similarly, Long, Oppy, and Seely [49] showed that poor readers often fail to make thematic inferences when processing text. Findings, such as these and those observed in the present study, suggest that many people tend to adopt a *minimalist* approach towards elaborations when processing and comprehending text [50] and thus, potentially limit the future value of their learning.

5.3 Relation of Present Findings to Everyday Practical Problems

Our finding that spontaneous transfer can be equivalent to cued transfer with the addition of source and target enhancements also has some important implications for everyday practical problems. Most students, for instance, find math problems to be one of the most, if not the most, difficult task to complete in a school context. Given the findings of the present study it is quite possible that if students were given a "example" or source math problem with its accompanying answer and were asked to process this source math problem and the to-be-solved analogous target problem in the same way as our students did in the present study then quite possibly students might spontaneous use or transfer the strategy for solving the first math problem to solving the second math problem. See Richland, Stigler, and Holyoak, [51] for other suggestions for how to generate transfer with math problems and Holyoak and Richland [52] for how to use transfer for cognitive readiness.

5.4 Implications for Theories of Analogical Problem Solving and Suggestions for Future Research

Most models of analogical problem solving propose a number of phases [45], and one or all of these phases might be the locus of difficulty in spontaneous transfer: (1) encoding the source, (2) encoding the target, (3) retrieving a source analogue from memory, (4) finding a mapping between the source and target, and (5) drawing inferences from the mapping. Although some researchers suggest that mapping (i.e., phase four) is the most crucial phase (see [45] for a discussion of this point), the results of the present study suggest that other phases, such as encoding the source (i.e., phase 1) and encoding the target (i.e., phase 2) might be equally important. Further, as the results of Experiment 1A showed, simply encoding the source problem and solution is not enough. Rather, it seems that people frequently fail to relate the source problem and solution adequately. In order to account for this finding, models of problem solving should consider including *relating the source problem and solution* as a separate

phase, which follows phase one, or re-word phase one to include strengthening the relationship between the source problem and solution.

In addition, one interesting direction for future research might be to examine the degree to which earlier phases of analogical problem solving influence subsequent phases. As we mentioned in the introduction, the ultimate goal of analogical problem solving is to transfer the solution from a source to a target problem, and a lack of an adequately formed relationship between the source problem and its solution might preempt transfer success. However, this is not to say that other phases, such as mapping (i.e., phase 4) are not equally important. Indeed, the results of the present study were far from perfect even with the inclusion of our enhancements; a finding that certainly suggests other causes of difficulty during analogical transfer. Moreover, one has to wonder what the influences of our enhancements might be when multiple source problems are presented prior to the target problem. Such a situation might downplay the importance of encoding the source and target problems and increase the importance of other phases such as retrieval (i.e., phase 3), mapping (i.e., phase 4), or inferences (i.e., phase 5).

A second avenue for future research might be to examine the influences of varying lengths of delays between presentations of a source and target. Delays between the source and target are particularly interesting because Kintsch, Welsch, Schmalhofer and Zimny [53] showed that whereas the strengths of textbase representations fade as the lengths of a delay increase between learning and retrieving, the strengths of situation models remain relatively stable. In the context of analogical transfer such a finding suggests that if a mental representation of a source includes elaborations, like the relationship between the source problem and solution, spontaneous transfer will remain fairly constant with increases in length of a delay. On the other hand, if mental representations of a source do not include elaborations, spontaneous transfer will decline as the length of a delay increases.

6. CONCLUSION

In summary, we believe that the results of the present study are encouraging in that they extend the traditional focus of solely examining the role of the source to a focus of examining the roles of both the source and target problems. Moreover, the present study also introduces the idea of enhancing key elements of the source and target in order to increase spontaneous transfer across different domains of knowledge. Clearly the results of our study are positive inasmuch as we observed that spontaneous transfer can be equivalent to cued transfer, with the addition of source and target enhancements.

CONSENT

The authors declare that written informed consent was obtained from all participants.

ETHICAL APPROVAL

All authors hereby declare that this study have been examined and approved by UTSA Institutional Review Board for research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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