Competition in Analogical Transfer: When Does a Lightbulb Outshine an Army?

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Abstract

This study investigated competition in analogical transfer to a problem solution. In two experiments, subjects read two stories, then attempted to solve Duncker's (1945) radiation problem, which has both a convergence and an open-passage solution. Stories were constructed that suggested each of these solutions; a third story was irrelevant. Subjects in the competitive conditions read both solution-suggesting stories, and subjects in the two noncompetitive conditions read one of these and the irrelevant story. In Experiment 1, the noncompetitive conditions convergence solutions and open-passage solutions were produced at comparable rates, but in the competitive condition, convergence solutions overwhelmed open-passage solutions. This asymmetry is too large to be explained by unidimensional models of retrieval and reflects the multidimensional nature of retrievability. In Experiment 2, the source stories suggesting each solution type were reversed, and the open-passage solution rate was higher than the convergence solution rate in all three conditions. In both experiments, subjects were able to successfully apply both source stories once cued to do so, indicating that the competition is at the retrieval stage of transfer, not at the mapping stage. Computational models of analogical transfer (e.g., ARCS and MAC/FAC) predict some competition but may have difficulty explaining the extreme nature of these results.

Analogical transfer occurs when a person draws upon knowledge about a familiar situation to make inferences about a new, less familiar, situation. Two situations are analogous when they contain parallel sets of causal relationships. Often, novel solutions to problems are initially generated based on analogies, which makes an understanding of this process critical to a theory of problem solving.

The experimental procedure used to study analogical transfer in problem solving is for subjects to first read a text passage, or *source story* in which a problem is described and solved. Later, subjects are asked to solve a new *target problem.* The basic transfer effect is that subjects are more likely to solve the target problem when the situation in the source story is analogous to the situation in the target problem than when it is not (e.g., Gick & Holyoak, 1980).

The degree of transfer between analogous problem solutions (i.e., problems with identical causal structure) depends on relationships among the analogous problems and conditions of analog presentation. Similarity between source analog and target is a crucial determinant of transfer in several major models of analogical transfer (Gentner, 1983; Holyoak, 1985; Hintzman, 1986; Ross, 1984). The higher the similarity, the more transfer is observed, whether that similarity is on the surface or at a deeper structural level (Holyoak & Koh, 1987; Gentner, 1989). However, different types of similarity play different roles in transfer. *Surface similarity*, similarity in noncausal aspects of story such as related semantic content, appears to have its primary role in analog retrieval, that is, in the identification of the source as a potential analog; *Structural similarity*, similarity in causal structure, appears to have its primary role in analog mapping, that is, in the way that the individual elements of the analogs are linked to each other (Holyoak & Koh, 1987; Gentner, 1989). Some theories of analogy suggest that surface similarity is the first feature used in accessing an appropriate analogy, and structural similarity only comes into the retrieval process when a system chooses among analogies of comparable surface similarity or when no good surface match is found (Gentner, Ratterman, & Forbus, 1993; Reed, Ackinclose, & Voss, 1990).

The number of presented analogs also affects the likelihood of transfer. The rate of transfer is higher when subjects learn several source analogs, each illustrating a common solution to the target problem, than when they learn only one source analog (Catrambone & Holyoak, 1989; Gick & Holyoak, 1980).

Some problems can be solved in more than one way, in which case the approach taken depends on what analogous situation is retrieved from memory. Gick and Holyoak (1980) showed that the type of solution produced in response to a target problem depended on the approach of a previously learned source analog. When a problem solver has learned more than one kind of source analog, it is not clear how the memory system chooses between them.

Numerous studies in the memory literature, going back more than 50 years, have shown that, in general, retrieval of information from memory is competitive (McGeoch, 1932; Melton & Irwin, 1940). One method used to demonstrate this competition has been to show that within-subjects designs or mixed-list presentations yield more dramatic strength effects than between-subjects designs or pure-list presentations. The differences reported are not just in statistical sensitivity (due to reduced within-subject variability); the absolute magnitude of the differences changes substantially. For example, the magnitude of transfer-appropriate processing effects has been shown to be larger for mixed-condition lists than for pure lists (e.g., in picture and word naming, Brown, et al., 1991).

Wharton (1993; Wharton, et al., 1994) investigated competition in analogical reminding. After reading a series of stories, subjects were asked to tell which stories they were reminded of when presented with either related sentences (Experiment 1) or related new stories (Experiment 3). He demonstrated that while effects of structural consistency were minimal in noncompetitive reminding conditions (those in which only one related story had been presented), a marked advantage for consistent over inconsistent analogies was repeatedly observed when those two types of analogies were put in competition with each other.

Analogical transfer differs from other memory tests (and from the analogical reminding paradigm) in two important ways. First, subjects are not specifically cued to recall items from the previously-learned set. Second, the memory is applied to a new situation instead of being reproduced in its original form. A convenient feature of this paradigm is that it allows examination of competition in both spontaneous and directed transfer.

Competition in transfer of source analogs for problem solving is a little-tested prediction of some models of analogical retrieval. For example the ARCS (Analogical Retrieval by Constraint Satisfaction, Thagard, et al., 1990) model uses inhibitory links to pressure one-to-one mapping between analogies. Whichever analogy is most highly activated (i.e., matches the target situation the best) suppresses activation of other candidate analogies. Thus, this model discourages retrieval of multiple analogies and predicts retrieval competition. In MAC/FAC (Many Are Called but Few Are Chosen; Forbus, Gentner, & Law, 1995), the set of potential source analogs with the highest similarity to the target are activated in the first stage, MAC; The second stage, FAC, always retrieves the best structural match out of that set. Thus, this model also predicts retrieval competition, but without inhibitory mechanisms. (In MAC/FAC, the better match outshines its competitors. In ARCS, the better match not only outshines, but obscures its competitors.)

By analogy to the other memory effects, when there are several analogs (items) in memory, any differences between them that tend to make one more salient than another should have greater effects in this competitive situation than when there is only one source analog. The present study investigates what will happen when multiple analogous solution types are simultaneously available in memory. Do they cooperate, or do they compete?

Experiment 1

The first experiment examined competition in transfer of analogous problem solutions using a procedure in which subjects read two stories and then solved a problem. The two stories were either (1) both analogous to the target problem but suggestive of different solution methods or (2) one analogous story and one irrelevant story.

Method

Materials. The target problem in this experiment was Duncker's (1945) Ray problem, in which the subject is asked as a doctor to find a way to use rays to destroy a patient's stomach tumor without harming the surrounding healthy tissue. Two analogies that each suggested a different solution to this problem were selected from previous studies. The first analogy was a version of the Lightbulb story (ultrasound version, Holyoak & Koh, 1987), which suggested a *convergence* solution to the Ray problem (i.e., using several low-intensity rays coming from different directions simultaneously). The second analogy was a version of the General story (open supply-route version, Gick & Holyoak, 1980), which suggested an *open-passage* solution to the Ray problem (i.e., finding an open passage such as the esophagus through which to send high-intensity rays directly to the tumor). A third story that was not analogous to the Ray problem, the Wine Merchants (Gick & Holyoak, 1980), was used as a filler story in the non-competitive conditions.

Procedure. Sixty-eight students from an introductory psychology class at UCLA participated for course credit. Two other subjects were disqualified because they had prior experience with the Ray problem. Participants were tested individually or in small groups. In the first phase of the experiment, two source stories were presented. Subjects had 3 minutes to read and 5 minutes to summarize each of these stories. Between the first and second experimental phases, subjects were given 5 minutes to complete a two-page questionnaire about their language-learning experiences.

In the second phase of the experiment, participants were given four opportunities to write a solution to the target problem. First, subjects were told that they would have 5 minutes to write possible solutions to the problem; no instructions were given to refer back to either source story. Next, a non-specific hint was given by saying that others had found it helpful to consider one of the stories they read earlier. The particular story that might be helpful was left open. They were given 4 more minutes to write a solution. On the third and fourth opportunities, subjects were to write the solutions suggested by the first and second source stories, respectively.

Design. The crucial manipulation was the combination of source stories. There were 3 story combinations. In the two noncompetitive conditions, one of the analogous stories (the Lightbulb or the General) was presented in combination with the nonanalogous story (the Wine Merchants). In the competitive conditions, both of the analogous source stories were presented. Approximately half of the participants were assigned to a competitive condition, and half were assigned to one of the noncompetitive conditions, distributing subjects as evenly as possible across specific forms. The order of source-story presentation was counterbalanced.

Results

Each problem-solving response was coded as a *convergence* solution, an *open passage* solution, or neither of the target solution types, using a lenient coding system. Convergence solutions required aiming low-intensity rays from different directions, but did not require simultaneity. Open-passage solutions required the use of high-intensity rays that did not come into contact with healthy tissue, but the open passage could either be a pre-existing one (e.g., the esophagus) or a newly created one (e.g., an incision or tube). Nontarget solutions were put in an *other* category. Several subjects gave *both* the convergence and open-passage solutions and were so coded. Coding of before-hint and nonspecific-hint solutions was blind to the source story condition. Because specific-hint solutions usually included the title of the corresponding source story, coding was only blind to the identity of the other story presented. Two independent raters coded each response (82% agreement, Cohen's $k = .70$), and consensus was reached on all discrepancies. Subjects who had given target solutions on the first attempt often gave less complete answers on their second attempt (with the nonspecific hint). Accordingly, categories of solutions given before the hint and after the nonspecific hint were combined to form the coding category for the *total* solution for each participant, as in the analysis of Holyoak & Koh (1987).

No presentation order effects were observed, so data from the two orders of each story combination were pooled. Table 1 shows the solution classifications for the before-hint and nonspecific-hint solutions. As is obvious from the table, the rows are not homogeneous either before the hint ($\chi^2(6) = 33.77$, $p < .001$) or after the nonspecific hint ($\chi^2(6) = 47.91$, $p < .001$). Before the hint, in the noncompetitive conditions, the convergence solution rate (77%, *convergence* and *both* categories, combined) in the Lightbulb story condition only had a slight advantage over the open-passage solution rate (59%, *open-passage* and *both* categories, combined) in the General story condition. However, in the competitive condition, convergence solutions (68%) outnumbered convergence solutions (9%) over 7 to 1. In fact, open-passage solutions were no more frequent in the competitive situation than when the open-passage analogy was not presented. The pattern was similar for the total (before hint + nonspecific hint) solution rates.

The low use of the open-passage solution in the competitive condition is not because subjects were unable to map the General story onto the Ray problem and construct an open-passage solution. When subjects were given a hint specifically identifying the source story suggesting that solution type, the advantage for convergence solutions (85%) over open-passage solutions (68%) in the competitive conditions was similar to that in the noncompetitive conditions (100% and 82% for convergence and open-passage solutions, respectively). The effect is clearly at the retrieval stage rather than the mapping stage of transfer (see Holyoak & Koh, 1987). For the same reason, the low rate of open-passage solutions cannot be attributed to failure to properly encode the General story and its solution.

Discussion

The most striking finding in this study is that the noncompetitive solution rates are fairly balanced for the two analogies, but are strongly asymmetric in the competitive condition. Models of choice that depend on a single strength parameter [e.g., a relative ratio model; more generally, models with simple scalability (Luce & Suppes, 1965)] cannot be used to explain these results. These models cannot explain simultaneously the large asymmetry in convergence and open passage solutions in the competitive condition and the more equivalent use of these solutions in the noncompetitive conditions. Either a multidimensional representation or a staged model [e.g., akin to Tversky's (1972) elimination by attributes model] is needed.

Source Story Condition	Solution Type: Conv.	Both	O.P.	Other	n
Before Hint					
Noncompetitive					
Lightbulb - Conv.	.59	.18	.06	.18	17
General - O.P.	.06	.00	.59	.35	17
Competitive	.65	.03	.06	.26	34
After Hint (Total)					
Noncompetitive					
Lightbulb - Conv.	.76	.24	.00	.00	17
General - O.P.	.00	.18	.65	.18	17
Competitive	.62	.26	.00	.12	34

Table 1: Proportions of subjects giving each solution type in Experiment 1
Conv. = convergence; O.P. = open-passage

Experiment 2

The high frequency of convergence solutions in Experiment 1 occurred in conditions in which it was analogous to the Lightbulb story. The effectiveness of this analog could be due to either the presence of the convergence solution per se or to the surface similarity of the Lightbulb story. The second experiment reversed the solution types suggested by each context to disentangle these possibilities. Thus, a convergence version of the General story and an open-passage version of the Lightbulb story were used.

Method

Materials. Two major changes were made from Experiment 1. First, the Lightbulb story was rewritten so as to suggest an open-passage solution (See Appendix A). Second, a convergence version of the General story (Gick & Holyoak, 1980) was used. The target problem was the same as in Experiment 1.

Design and Procedure. The design and procedure were identical to those of Experiment 1. Fifty-one students from an introductory psychology class at UCLA participated for course credit. Three other subjects were disqualified, because they had prior experience with the Ray problem.

Results

The coding criteria were also the same as in Experiment 1. Again, no order effects were observed, so data from the two orders of each story combination were pooled. Table 2 shows the solution classifications for the before-hint and nonspecific-hint solutions. The pattern is very different from that of Experiment 1. No inhomogeneity of the rows can be identified before the hint ($\underline{X}^2(6) = 4.73$, $\underline{p} > .50$) but one is present after the nonspecific hint ($\underline{X}^2(6) = 16.53$, $\underline{p} < .05$). In contrast to Experiment 1, the before-hint pattern was almost completely dominated by the solution type, with open-passage solutions much more likely in every condition. In the noncompetitive conditions, the open passage solution rate in the Lightbulb condition (53%) had a huge advantage over the convergence solution rate in the General condition (6%) before the hint. In the competitive condition, open-passage solutions (65%) outnumbered convergence solutions (24%) by a smaller margin. The convergent General source analog was unable to attract convergence solutions in the way that the convergent Lightbulb source analog in Experiment 1 did.

After the nonspecific hint, the noncompetitive condition advantage for open-passage over convergence solution rates (82% and 41%, respectively) was still greater than the competitive condition advantage (open-passage and convergence rates of 83% and 65%, respectively). Many subjects can construct a convergence solution after the nonspecific hint, but in this context they do so only after producing the open passage solution. In this respect, the present experiment differs markedly from Experiment 1.

Although open-passage solutions predominate in Table 2, subjects were nevertheless able to map the General story onto the Ray problem by constructing a convergence solution. When subjects in the competitive condition were told to use a specific story, both the percentage of convergence solutions derived from the General story and the percentage of open-passage solutions derived from the Lightbulb story were 88%. Similarly, in the noncompetitive conditions, there was no advantage for open-passage solutions (65% open passage, 76% convergence).

	Solution Type				
Source Story Condition	Conv.	Both	O.P.	Other	n
Before Hint					
Noncompetitive					
Lightbulb - O.P.	.06	.06	.47	.41	17
General - Conv.	.06	.00	.41	.53	17
Competitive	.06	.18	.47	.29	17
After Hint (Total)					
Noncompetitive					
Lightbulb - O.P.	.00	.12	.70	.18	17
General - Conv.	.12	.29	.74	.35	17
Competitive	.06	.59	.24	.12	17

Table 2: Proportions of subjects giving each solution type in Experiment 2
Conv. = convergence; O.P. = open-passage

Discussion

The pattern of results in this study differs from that of Experiment 1. One solution type, the open-passage solution, dominated in both noncompetitive and competitive conditions, even when it was not presented in a source analog. The convergent form of the General story was not able to draw subjects away from the more-dominant open-passage solution. The clearest difference between the two source analogs is that the Lightbulb story, being in a scientific setting, is a better surface match or content match to the medical setting of the Ray problem than is the General story. It appears that to elicit retrieval of a less-dominant solution, it is necessary to have high surface similarity between source and target, such as that between the Lightbulb story and the Ray problem. The dominance of the open-passage solution could not be attributed to either failure to encode or failure to map the convergence solution, because the convergence analogy was successfully retrieved and mapped once a specific hint was given to use its source story.

General Discussion

As is clear from Experiment 2, the open-passage solution has a higher base rate than the convergence solution, consistent with past results (Gick & Holyoak, 1980).

Both experiments demonstrate that the Lightbulb story is more readily retrieved for analogical mapping than the General story, indicating that surface similarity of the source story is important in analogical retrieval. From Experiment 1 to Experiment 2, the solutions suggested by each source story were reversed. In the competitive conditions of both experiments, the solution suggested by the Lightbulb story was more dominant (the convergence solution in Experiment 1, and the open-passage solution in Experiment 2). This solution-type reversal pattern is significant ($\underline{X}^2(3) = 21.66$, $\underline{p} < .001$), whereas the pattern of source story used is not ($\underline{X}^2(3) = 3.76$, $\underline{p} > .25$). This pattern shows the importance of source-story similarity in retrieval. Specifically, the results could be explained by a multidimensional concept of similarity. Surface similarities and structural similarities play different roles in transfer. Both the Lightbulb story and the General story are good structural matches to the Ray problem.

Both experiments indicate that differences in spontaneous retrieval, not in encoding or mapping, make one source story or solution type dominant. In both experiments, subjects were able to successfully map both of the source stories when given specific instructions to do so. When appropriately cued, they could direct their retrieval toward relevant aspects of the source analog for mapping.

The present study complements the effects of analogical reminding found by Wharton (1993; Wharton et al., 1994). The results of Experiment 1 are similar to his, in that retrieval differences that were undetectable in the noncompetitive conditions were much larger in the competitive conditions. More broadly, the results demonstrate that competition in retrieval from long-term memory extends to situations in which the information is to be retrieved and applied in a new context rather than simply repeated. As it happened, the results of Experiment 2 do not bear on this issue, because the convergent General story was not used at a high rate even in the absence of a competing open-passage source analog.

This study shows that retrieval competition between different source analogies for transfer in problem solving can show an asymmetry that is at odds with the degree of noncompetitive transfer. Although the basic competition effects are consistent with predictions of theories such as ARCS and MAC/FAC, it is not clear how these models would handle the extreme magnitude of the competition that we observed. The pattern of results suggests an active suppression process in which stronger competitors suppress weaker ones, rather than a competition in which stronger competitors merely enjoy a relative advantage. The ARCS model does have active suppression of competitors, which suggests that it may be able to accommodate our findings, although we have not yet attempted to get it to match our particular pattern.

The results of Experiment 1, if reproducible, considerably constrain the class of possible models of analogical retrieval in problem solving. As we noted above, the asymmetry of competitive choice combined with the symmetry of noncompetitive choice is inconsistent with a unidimensional representation (i.e., one with simple scalability). Any model shown to have the property of simple scalability can be ruled out. In particular, these results preclude any model in which spontaneous retrievability of an item is independent of context.

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Appendix A

Lightbulb Story (open-passage version)

In a physics lab at a major university a very expensive lamp which would emit controlled quantities of light was being used in some experiments. The research assistant responsible for operating the sensitive equipment came into the lab one morning and found that the lightbulb no longer worked. The research assistant realized that it was probably because she had accidentally knocked it over the previous night. As a result, the wires connecting the lightbulb to its power source had fused together, but the place where the wires had fused together was inside the lamp casing. The surrounding casing was completely sealed, so there was no way to open it. The lamp could be repaired if a brief, high-intensity ultrasound wave could be used to jar apart the fused parts. Furthermore, the lab had the necessary equipment to do the job.

However, a high-intensity ultrasound wave would also break the fragile casing surrounding the lightbulb and wires. At lower intensities the ultrasound wave would not break the casing, but neither would it jar apart the fused parts. So it seemed that the lamp could not be repaired, and a costly replacement would be required.

The research assistant was about to give up when she had an idea. Although the casing could not be opened, she reasoned that because the lightbulb generated so much heat, the casing must have a vent to let the hot air out. So she took it down off of its stand, and sure enough, there was an opening on top. By carefully inserting a tube through the vent and aligning the ultrasound machine to go through the tube, she was able to send the ultrasound wave directly to the broken wires and jar them apart. Since no spot on the fragile casing was exposed to the wave, the glass was left intact. There was a great relief that the lamp was repaired, and it was possible to successfully complete the experiment.

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