

Source Processing Influences Analogical Problem Solving

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ABSTRACT. Four experimental conditions were devised to test the hypothesis that the solution of a target problem is affected by the way in which a source story structurally similar to that problem has been previously elaborated. In the literal recall condition, undergraduates were requested to memorize the source in detail. In the schematizing condition, they had to identify the essential features of the source. In the evaluation condition, they were asked to judge the adequacy of the source. In the control condition, they had to read and recall a story with no correspondence to the target. The highest frequencies of analogical solutions occurred in the schematizing and evaluation groups. Data suggest that a deep and abstract representation facilitates the use of the source in problem solving.

ANALOGICAL PROBLEM SOLVING occurs when a familiar situation (source) is retrieved to solve a new problem (target) (Dreistadt, 1969). Analogical problem solving is an aspect of reasoning by analogy that is considered a central component of human cognition; it has been argued that all intellectual acts involve analogical thinking (Spearman, 1923), that analogy is the substrate of cognitive abilities (Keane, 1988), and that analogical thinking is the hallmark of intelligence (Sternberg, 1982). Consistent with these claims, the history of science shows that many important discoveries were made using analogies (Dreistadt, 1968); further, various types of training in creative thinking are based on the process of searching and applying analogies (e.g., Gordon, 1961). It is worth noting that one of the goals of school instruction is to develop the ability to transfer knowledge from one domain to another, by stressing the similarities existing between them, to successfully cope with novel situations (Bransford, Franks, Vye, & Sherwood, 1989; Simons, 1984). Finally, analogical reasoning often occurs in ordinary thinking (Lakoff & Johnson, 1980; Spearman, 1923) and appears early in development (Goswami, 1992). Despite these acknowledgments, only recently has analogical problem solving become a prominent topic in the psychology of thinking.

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The experimental procedure usually used in investigating analogical problem solving consists of first presenting a source story that participants have to read and then presenting the target problem. Such methodology, however, fails to mimic real-life situations because it involves only a short exposure to the source, whereas when someone tries to solve a problem by recalling similar earlier instances, the analogical cues that are retrieved concern situations that have been processed previously in very different ways. However, in the field of analogical problem solving, little attention has been paid to the effect of the treatment of the source on transfer to the target.

An analysis of the process of analogical reasoning predicts that during the presentation of the source, participants derive an abstract "problem schema"; afterward, when confronting the target problem, they apply the schema to the new situation and use it as a solution plan (Gick & Holyoak, 1980; Novick & Holyoak, 1991). The purpose of the present study was to foster an abstract representation of the source by means of neither specific training (see Cheng & Daehler, 1989) nor ad hoc, direct instructions (see Bassok & Holyoak, 1989; Catrambone & Holyoak, 1989; Fong, Krantz, & Nisbett, 1986), nor questions (Brown, Kane, & Echols, 1986), but simply through the elaboration of the source. All participants were provided with a source that had the same content and then were requested to process it in different ways after reading it.

In the first condition (*literal recall*; LR) participants were asked for verbatim retrieval. In the second condition (*schematizing*; S) they were asked to identify the essential features of the source. In the third condition (*evaluation*; E) participants were asked to judge the adequacy of the solution strategy described in the source. A control (C) condition—in which participants received a neutral story with no correspondence to the target—served as a baseline.

Method

Participants

One hundred sixty undergraduates attending the Faculty of Modern Languages of a university in Milan, Italy, were recruited for the study by means of an advertisement asking for voluntary participation in an experiment concerning reasoning processes. The students ranged in age from 19 to 25 years. They received no pay or course credit.

Materials

Target problem. The target problem was Duncker's (1935) radiation problem. This problem describes a patient with a tumor in his stomach; high-intensity X-rays can destroy the tumor, but they also destroy the surrounding healthy tissue; low-intensity rays are harmless to the healthy tissue, but they fail to destroy the tumor. The participants were asked to find a procedure to destroy the tumor with

the X-rays without damaging the healthy tissue. According to the “dispersion” (Gick & Holyoak, 1980) or “concentration” (Gick & Holyoak, 1983) strategy, the solution of the problem is achieved by sending several weak rays from different directions toward the tumor, so that they produce no harm to the healthy tissue and, by simultaneously converging, produce a high-intensity effect that destroys the tumor. (See Appendix A for the text of the problem.)

Source. I designed the “artificial lake situation” to suggest to participants—in the LR, S, and E conditions—the concentration solution of the radiation problem. (See Appendix B for the text of the analogical source.) Two pictures, the first representing a lake fed by a single large canal, the second a lake fed by four narrow canals, were inserted in the text after the corresponding verbal descriptions. As I have described (Antonietti, 1991), the artificial lake situation shows close structural relations to the radiation problem and the concentration solution. For the C condition, I devised a neutral story concerning the construction of an artificial lake without correspondence to the target problem and the concentration solution. The neutral story had the same number of words as the analogical source; two pictures illustrating the lake were included in the text. These pictures were different from those used in the other conditions and had no relation to the target.

Procedure

Participants were randomly assigned to one of the four experimental conditions, to create four subsamples of 40 individuals each. The percentages of males in the subsamples were approximately the same (30%, 25%, 29%, and 27%): This circumvented the possibility of influences related to differences between the sexes (Antonietti & Gioletta, 1995). I excluded some protocols because of difficulties in interpreting them; therefore, the actual numbers in the subsamples were as follows: for LR, $n = 37$ students; for S, $n = 39$ students; for E, $n = 39$ students; for C, $n = 40$ students.

Participants were studied in groups of 15 to 20 during sessions of about $\frac{1}{2}$ hr. In every session, participants were assigned to each of the four conditions with approximately equal frequency.

I presented the source in written form to the participants individually. For the C and LR subsample, the instructions were “Read this story with attention and memorize carefully all information. Subsequently, you’ll have to recall the story as close to its original form as possible.” The S subsample had the following instructions: “Read the story and try to extract the essential points. Subsequently, you’ll have to write a short schema summarizing the story.” Participants in the E subsample were asked to “Read this story and pay attention to the quality of the solution that is described. Subsequently, you’ll have to give your opinion about the solution.” Participants were allowed 5 min to read the source. Then, the papers relating the analogical source story were collected.

Subsequently, participants had to complete the source treatment task. Participants in the C and LR conditions were asked to write down, as closely as possible to its original form, the exact content of the artificial lake story previously read. Participants in the S condition were asked to write a brief schematic description of the main points of the artificial lake story they had read. Participants in the E condition were asked to write down their personal opinions about the efficacy of the solution found by the engineer in the artificial lake story they had just read. After 10 min, the sheets on which participants had written their responses were collected.

Immediately after the source treatment task, the target was presented in written form to the participants individually. They were told that it was a multiple-solution problem and that in the previous story they might find some ideas useful to the solution.¹ Participants were asked to write down all responses that they had in mind. They were allowed 15 min to solve the target problem.

Results

Three independent judges, researchers in cognitive psychology, analyzed the protocols. They had been instructed and trained about the scoring criteria to be used but were unaware of the hypotheses of the experiment and were blind to the condition to which each protocol belonged. Criteria had been defined previously on the basis of studies carried out with the same material (Antonietti, 1991; Antonietti & Gioietta, 1995). Scorers gave the same classification in the 97% of the protocols concerning the target problem and in the 96% of the protocols of the elaboration task; the scorers discussed disagreements and always reached unanimous decisions.

Responses to the target problem were classified into three categories.

1. Analogical solutions, consisting of the concentration solution described above. This solution of the radiation problem included three components: substitution of the high-intensity ray with several low-intensity rays (*decomposition*); circular disposition of the weak rays (*many directions*); and summation of the

¹ The hint at using the source to solve the target was given at the beginning of the target problem-solving task—but not, as in some studies (e.g., Gick & Holyoak, 1980), after participants had tried to solve the target for some minutes without such a hint—because in pilot studies it was observed that without the hint, participants found solutions for the radiation problem other than the analogical one, and they were satisfied with those responses (i.e., they maintained that their responses were good solutions). Hence participants, when the hint was given, were not motivated to look for further solutions to the target, so the initial responses had inhibitory effects on analogical transfer. Besides, without a hint, the frequency of analogical transfer—as noticed by researchers who used the same experimental procedure (e.g., Gick & Holyoak, 1980, 1983)—was very low, so that floor effects occurred, not allowing them to draw conclusions about the effects of the independent variables (e.g., Catrambone & Holyoak, 1989, Experiment 2).

intensity of the rays in the central convergence point (*summation*). Participants were classified as analogical solvers if they mentioned all three components.

2. Other effective solutions, such as sending X-rays into the stomach through a tube to avoid contact with the surrounding healthy tissue, sensitizing the tumor to the action of weak rays, and immunizing the healthy tissue.

3. Ineffective solutions, that is, solutions that broke the constraints of the problem, would not produce the expected effects, or could not be implemented.

One-way analysis of variance (ANOVA) revealed a significant effect of the condition upon the mean number of total responses given in the target problem, $F(3, 151) = 4.17$, $MSE = 0.04$, $p < .01$ (see Table 1). A Newman-Keuls test revealed that participants in the C and LR conditions gave a significantly ($p < .01$) higher number of responses than those in the S condition. I found no significant differences between those in the E condition and the other three conditions.

The distribution of the frequencies of analogical solvers (see Table 1) revealed a significant effect of the source treatment, $\chi^2(3, N = 155) = 25.57$, $p < .001$.² A comparison of the proportions of analogical solvers between the C condition and the LR, S, and E conditions yielded one-tailed z values of -1.90 ($p < .05$) -4.21 ($p < .001$), and -4.40 ($p < .001$), respectively. The comparison between

TABLE 1
Data Concerning the Solution of the Target Problem, by Condition

Target problem	Condition			
	LR	S	E	C
Numbers of total responses				
<i>M</i>	2.70	1.92	2.44	2.67
<i>SD</i>	1.51	1.09	1.03	1.38
Percentages of analogical solvers	18.9	46.2	48.7	5.0
Percentages of analogical solutions	7.0	24.0	20.0	1.9
Numbers of other effective solutions				
<i>M</i>	0.89	0.44	0.95	1.25
<i>SD</i>	0.91	0.55	0.72	0.87
Numbers of ineffective solutions				
<i>M</i>	1.19	0.85	0.87	1.37
<i>SD</i>	0.81	0.87	1.10	0.93

Note. LR = literal recall. S = schematizing. E = evaluation. C = control.

² In the present experiment, percentages of analogical solutions in Duncker's problem were lower than in Gick and Holyoak's (1980) original study. The present results may be related to the more conservative criteria used to score such responses or to the different source story used.

the LR condition and the S and E conditions yielded z values of -2.53 and -2.74 ($p < .01$), respectively. The percentages of analogical responses of the total number of responses given under each condition (see Table 1) were significantly higher in the LR, S, and E conditions than in the C condition ($z = 1.81, p < .05$; $z = 4.70, p < .001$; and $z = 4.21, p < .001$, respectively). They were also higher in the S and E conditions than in the LR condition ($z = 3.18, p < .001$; $z = 2.67, p < .01$).

Mean numbers of effective responses other than the concentration solution were significantly different in the four conditions, $F(3, 151) = 5.89, MSE = 0.17, p < .001$: Participants in the C, LR, and E conditions produced higher numbers of such responses than in the S condition, $p < .05$ by Newman-Keuls test (see Table 1). I found no significant differences between the mean numbers of ineffective solutions in the C, LR, S, and E subsamples, $F(3, 151) = 1.63, MSE = 0.14$ (see Table 1).

Protocols concerning the source treatment task were analyzed, to determine how the participants had completed the task and to determine whether there were links between performances for the source treatment and the target problem. More precisely, judges checked protocols to record whether participants had reported—in recalling or schematizing the source, respectively—the constraints mentioned (that is, the impossibility of using a single large canal and the inadequacy of a single small canal), the components of the concentration solution (decomposition, many directions, summation), and the pictures in the text. Percentages of participants who reported such elements of the source are shown in Table 2. No significant difference between the LR and S conditions emerged.

For both the E and S conditions, analysis also showed a lack of significant association between the analogical or nonanalogical solution of the radiation problem and the quotation or nonquotation, in the elaboration task, of the first constraint [LR: $\chi^2(1, N = 37) = 0.12$; S: $\chi^2(1, N = 39) = 0.37$]; the second constraint [LR: $\chi^2(1, N = 37) = 0.12$; S: $\chi^2(1, N = 39) = 0.04$]; the decomposition component [LR: $\chi^2(1, N = 37) = 0.01$; S: $\chi^2(1, N = 39) = 0.52$]; the many direction component [LR: $\chi^2(1, N = 37) = 0.49$; S: $\chi^2(1, N = 39) = 0.01$]; the summation component [LR: $\chi^2(1, N = 37) = 0.08$; S: $\chi^2(1, N = 39) = 1.04$]; and the reproduction of the pictures [LR: $\chi^2(1, N = 37) = 0.54$; S: $\chi^2(1, N = 39) = 0.25$].

In the E task, 61.5% of the participants expressed some criticism of the four-canal project planned by the engineer in the source story. There was no significant relationship between the presence or absence of such criticisms and the analogical or nonanalogical solution of the target, $\chi^2(1, N = 39) = 0.73$. Four of these participants (22%) suggested alternative plans to solve the artificial lake situation and did not give the analogical response in Duncker's problem.

Discussion

In the present experiment, different modes of processing the source produced different amounts of analogical transfer to the solution of the target problem.

Schematizing and evaluating the information reported in the source resulted in a significantly higher rate of analogical transfer than memorizing it verbatim did.

Protocol analysis demonstrated that in the LR task most participants summarized the source according to the instructions they received, reporting accurately the information mentioned in the analogical story. The degree of adequacy of the LR had no significant relationship with the analogical transfer of the solution principle from the source to the radiation problem.

In the S condition, participants identified, in the source treatment task, the essential features of the source that are isomorphic to the target. The frequencies with which obstacles and solution components described in the artificial lake story were mentioned by participants did not differ significantly from those observed in the LR condition. As in the first condition of the experiment, the quotation of such obstacles and components was not associated with the analogical transfer to Duncker's problem.

In the E condition, most participants expressed some criticism of the strategy used by the engineer of the artificial lake situation to avoid the mishaps of the first plan described in the analogical story. However, the frequency with which they transferred the solution principle embedded in the source to the target problem was not substantially different from that of participants who expressed

TABLE 2
Data Mentioned by Participants Regarding the Elaboration Task,
for the LR and S Conditions

Source element	Condition		Comparison between the LR and the S conditions
	LR	S	
Constraints			
Large canal	81.1%	82.1%	$\chi^2(1, N = 76) = 0.01, ns$
Small canal	89.2%	82.1%	
Components			
Decomposition	73.0%	69.2%	$\chi^2(1, N = 76) = 0.01, ns$
Many direction	97.3%	94.4%	
Summation	59.5%	33.3%	$\chi^2(1, N = 76) = 3.31, ns$
Pictures	37.1%	23.1%	$\chi^2(1, N = 76) = 1.32, ns$
Number of constraints			
<i>M</i>	1.70	1.64	$t(74) = 0.40, ns$
<i>SD</i>	0.62	0.71	
Number of components			
<i>M</i>	2.32	2.03	$t(74) = 0.12, ns$
<i>SD</i>	0.82	0.84	

Note. LR = literal recall. S = schematizing.

approval of the plan; it seems that the critical attitude toward the source did not impair analogical transfer.

In short, I did find evidence that the way in which the source is handled influences the probability of transferring it subsequently to the target problem. Retrieval of the source in a schematic fashion produces an advantage, compared with its literal recall, and the evaluation of the source enhances its use in the target problem. In addition, these effects do not depend on the number of elements of the source, relevant to the target, that are retrieved in the source treatment task.

Differences between the analogical solutions to the target can give an account of why participants in the C and LR conditions produced the largest number of total responses in the radiation problem: Because the source failed to clearly suggest the analogical solution for the target, participants had to look for other solutions. Perhaps such solutions did not appear so convincing as the concentration strategy, and most participants, having doubts about the efficacy of their answers, tried to produce more adequate responses and, consequently, gave more than one solution.

Doubts may be raised about an interpretation of the results in terms of memorability or recallability effects. First, the source story was simple and short, so that it was not difficult to remember. Second, the memory of the source was unlikely to decay, because the source treatment and the target tasks occurred immediately after the presentation of the source. Third, as far as the retrieval of the elements of the concentration solution strategy is concerned, no differences were found between the LR and S conditions, and we can assume that a similar lack of difference regarding the memorization of the critical elements of the source was present in the E condition.

After the exclusion of some possible interpretations, an explanation of the overall picture of the results is needed. As mentioned previously, there is a consensus that analogical problem solving involves the induction of problem schemata. So, the first attempt should be to give an account of the findings of the experiment in terms of schema abstraction: The highest rates of analogical transfer should follow treatment tasks requiring a structural representation of the source. Such a response might be elicited when the elaboration of the source is aimed at producing an abstract representation of the source (see the S condition). But how can this explanation give a reason for the facilitating effects of the E condition, in which the instructions did not hint at the induction of a schema?

I believe that analogical transfer is enhanced by treatment of the source in which participants work out the critical aspects relevant to the solution of the target. Such was the case in the E condition as well as in the S condition. In both those conditions, in the treatment task participants were invited to process the concentration solution strategy described in the source. Various data indicate that when problem solvers are given help in focusing on the goal structure of the source, they are more likely to apply it to new problems (e.g., Catrambone & Holyoak, 1990; Cummins, 1992). Presumably, such conditions involve a deep processing of the source (Craick & Tulving, 1975). The deeper the representation

resulting from the elaboration of the source, the easier is its subsequent use in solving the target problem. It is possible to argue that a deep consideration of the source facilitates the process of analogical reasoning, because it produces abstract problem schemata. In contrast, less deep processing yields a representation of the source in which details that are not relevant are preserved, so structural schema remain hidden.

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APPENDIX A

Target Problem: Duncker's Radiation Problem

A doctor is faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. X-rays can be used to destroy the tumor. If an X-ray reaches it at sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the ray passes through on the way to the tumor will also be destroyed. At lower intensities the ray is harmless to healthy tissue, but it will not affect the tumor either. What type of procedure might be used to destroy the tumor with the X-rays and at the same time avoid destroying the healthy tissue?

APPENDIX B

Source: Artificial Lake Situation

An engineer plans the construction of an artificial lake to produce electrical energy. According to his first plan, a single wide canal collects water coming from a valley and conveys it into the lake. However, the engineer realizes that during the flood periods, the stream of water flowing along the canal may be too strong and may damage the surrounding areas. He also realizes that during the drought periods, a single stream of water may be insufficient to feed the lake. To avoid these mishaps, the engineer elaborates a second plan. According to this plan, the lake is fed by four small canals whose total flow is the same as the single wide canal previously planned. These small canals are placed around the lake so that they convey water coming from four different valleys. In this way, only small amounts of water can flow in each canal, and thus during flood periods, dangerous overflowing might not occur. At the same time, the lake is fed by water from various valleys, so it is sufficiently fed even during droughts.

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