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ABSTRACT

This paper examines whether an experimental treatment that encourages generativity and meaningful encoding can facilitate spontaneous analogical thinking, measuring the spontaneous generation of a relevant analog in solving a problem rather than the amount of factual material learned. Sixty-eight undergraduate students participated by reading the Attack-Dispersion Story (M. L. Gick and K. J. Holyoak, 1980) and writing a summary of each paragraph or the whole story or an analogy for each paragraph or the story. As predicted, cognitively processing the story in parts (paragraphs) rather than as a whole or merely rereading it facilitated solution of the test problem. The pattern of scores was in the expected direction (analogizing and summarizing greater than reading), but a main effect for mode of processing was not determinable from the data. It seems likely that subjects were not adequately skilled in analogizing and summarizing. Implications for instruction are discussed. Instructional strategies that engage the learner in generating summaries and analogies of subcomponents rather than just main ideas tend to facilitate far transfer problem solving. An appendix contains the story and test directions. (Contains 22 references.) (SLD)

Title:

Facilitating the Spontaneous Generation of Analogies in Problem Solving

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The shift from the behaviorist paradigm to the cognitive paradigm has led researchers to turn their attention to cognitive processes. Although the research has been impressive, it sometimes fails to translate clearly into instructional practice. Perhaps no place is this more apparent than in the study of analogies. Basic research has provided insight into the nature and mechanism of analogies (e.g., Gentner, 1983; Rumelhart & Norman, 1981; Sternberg, 1977a, 1977b), shown that analogical reasoning ability is a poor predictor of "the ability to infer from analogies" (Yacci, 1990), and demonstrated that learners can be taught to generate analogies (e.g., Lowenthal & Pons, 1987). Another line of research has focused on instructional applications, usually instruction-provided analogies. These applications have typically been in math and science with lower-level learning outcomes (e.g., Zeitoun, 1984). Instructional analogies have been found beneficial for learners from fifth grade (Simons, 1984) through college (Newby & Stepich, 1991). Occasionally researchers have investigated the role of analogies in facilitating higher-order outcomes. For example, Gick and Holyoak (1980, 1983) found that providing multiple analogs (i.e., cases or stories analogous to the target problem) can facilitate problem solving, although single analogs were generally effective only 40% of the time unless subjects were *prompted* to apply the analog.

While instruction-provided analogies require more instructional/learning time, performance gains generally offset the additional time required (Newby & Stepich, 1991; Simons, 1984). Nevertheless, the cognitive paradigm and growing interest in constructivism suggest a different perspective: Must analogies remain primarily time-consuming instruction-provided strategies, or can learners be empowered to spontaneously generate analogies to facilitate higher-order learning, and, if so, how?

Several lines of research guided our investigation into these questions. First, Gick and Holyoak (1980, 1983) showed that reading two relevant story analogs immediately before being asked to solve a problem facilitates the generation of a successful solution. However, since many of their subjects could also generate the appropriate solution from a single-story analog after they were prompted to use it in solving the problem, other cognitive processes might underlie the spontaneous generation of analogies to solve problems. Could subjects be taught to apply more effective cognitive strategies on single analogs rather than having to study multiple analogs? The former would potentially be a more efficient use of time and be available for wider transfer.

The importance of a broad knowledge base is supported by another line of research (e.g., Brown, Campione, & Day, 1981) which suggests that efforts to develop spontaneous analogical thinking may depend both on developing general knowledge ("world knowledge") and domain-independent strategies. Instructional strategies to develop spontaneous analogical reasoning are consistent with this view since they teach students to process information deeply by engaging in meaningful elaboration.

In the series of experiments by Gick and Holyoak (1980, 1983) subjects read one or two story analogs; subjects were usually told that they would be tested on the story. Various orienting tasks were required, most of which required little cognitive processing (e.g., single-sentence oral summaries of the whole story). Before they were tested on the story, subjects were asked to solve Duncker's (1945) cancer-radiation problem which was usually introduced as a tangential task. This case posed the problem of how to irradiate a tumor at sufficiently high doses, while avoiding damage to surrounding cells. The key solution to the problem was to simultaneously irradiate the tumor at low doses from different angles, resulting in a high cumulative dose at the tumor site. An analogous solution is suggested by The Attack-Dispersion Story (see Appendix), presented earlier to subjects, wherein armies avoided tripping land mines by dispersing troops along several different roads into a city.

The present study made use of Gick and Holyoak's content, and drew from Wittrock and Alesandrini's (1990) research method. All subjects in our study received The Attack-Dispersion Story. Depending on their assigned treatment, subjects were asked to process the story in different ways:

Summarize:	**Each paragraph of the story**	**The whole story**
Develop an analogy for:	**Each paragraph of the story**	**The whole story**

A fifth group was asked to simply record the time of completion for each paragraph, resulting in a 2 x 2 factorial design with an additional control group.

Our experiment differed from the Gick and Holyoak studies in significant ways, particularly relating to the generative model of learning (Wittrock, 1974). First, the Gick and Holyoak studies required little cognitive processing of the content; our experiment compared the effect of having to cognitively process each paragraph or the whole story (by summarizing or by generating an analogy) on the ability to solve the radiation problem. Second, the Gick and Holyoak studies did not direct the subjects to express the summaries totally in their own words, a requirement which is expected to facilitate more meaningful encoding (Wittrock & Alesandrini, 1990). Since conceptual analogies facilitate creative transfer of knowledge, while comprehensive analogies facilitate storing information (Stepich & Newby, 1988; Simons [1984] calls these respectively "unconnected" and "connected" analogies), we hypothesized that having to generate summaries or analogies for each *part* of the story, rather than just for the whole, would make the individual elements of the story analog more accessible and facilitate creative application (far transfer). This hypothesis also seems to be supported by Mayer's (1980) theory of assimilative encoding: "The assimilative encoding process results in a broader cognitive structure, which supports transfer to creative problem situations" (p. 109).

The present study examined whether an experimental treatment such as the one used by Wittrock and Alesandrini (1990), which encourages generativity and meaningful encoding, can facilitate spontaneous analogical thinking. Our study differs from that study in that it is measuring spontaneous generation of a relevant analog in solving a problem rather than the amount of factual material learned. Because of the limited access to students for testing, we did not examine relationships between verbal ability, analytic ability, and ability to solve the problem successfully.

Method

Hypotheses

We hypothesized that (a) generating summaries or analogies for an analog story, described in the procedure section, would facilitate subjects' abilities to generate the analogical dispersion solution to the radiation problem and (b) generating summaries or analogies for each part of the analog story would further facilitate subjects' abilities to generate the dispersion solution to the radiation problem.

Subjects

Seventy-one students enrolled in five courses in the graduate school of education at a public, urban university participated voluntarily in this study. We focused on graduate students because we believed that they would already know how to generate summaries and analogies. Three subjects were eliminated because they were already familiar with the criterion problem.

Materials

The Attack-Dispersion Story (Gick and Holyoak, 1980) served as the story analog (see Appendix). The story was divided into 4 paragraphs, rather than 2, to break the story into more salient parts and to allow for more summaries and analogies according depending on the treatment. All instructions were included in the test packets. Subjects in the summary groups were instructed to write a summary (of each paragraph or of the whole story). Subjects in the analogy group were instructed to write an analogy (of each paragraph or the whole story) and received the following example:

> Each analogy should consist of one or two sentences and should clearly relate the new ideas to familiar things. For example,
> _______ reminds me of _______; or
> _______ is like _______ .

Subjects were presented with the story prior to the Radiation Problem (Duncker, 1945; see Appendix), which served as the test problem.

Procedure

Subjects were told the purpose was to "study how people learn from written material. . . .You will be asked to study a very short story. Then we will give you a written test to find out what you learned from the passage. The information we obtain in this way may be of help in improving students' learning strategies." In three of the classes, the professors allowed class time for those who wished to participate; in the other two classes, the experiment was administered immediately after or before class (the students' choice). Students in each class were randomly assigned to five groups in a 2 x 2 design (4 treatments plus a control group): encoding task (generate summary, generate analogy) and level of processing (each paragraph, whole story).

Separate booklets were prepared for each treatment, and included the instructions, the analog story (The Attack-Dispersion Story), the radiation problem, and a questionnaire to collect demographic data (prior knowledge of the radiation problem, degrees, majors, how many graduate credits they have completed, age, and sex). Subjects in each treatment read The Attack-Dispersion Story and generated summaries or analogies; subjects in the control group read each paragraph of the story twice, recording the time after each reading. After they had finished the treatment, the radiation problem was presented as an extraneous problem so that subjects would not be prompted to connect the story to the problem. They were instructed to write all the solutions they could think of.

Evaluation. The summaries and analogies subjects generated during the treatment were evaluated using a procedure derived from Wittrock and Alesandrini (1990) to measure the extent to which subjects followed the directions and the extent to which the treatments induced the intended effects upon generation of the analog solution.

Subjects in the **summary treatments** received separate scores for following directions and for including salient content. Subjects in the paragraph-summary treatment received 2 points per paragraph if they wrote a correct summary, 1 point if they relied on words from the story, and 0 points if they wrote nothing (8 points maximum). They received 1 point per paragraph for salient content: (a) routes radiating from fortress; (b) full force required for the attack; (c) total force impossible from one route without producing unwanted harm; (d) dividing into small groups, using different routes, and converging simultaneously (4 points maximum). Subjects in the whole-summaries treatment were evaluated similarly, with 2 points maximum for following directions and 4 points maximum for content.

Subjects in the **analogy treatments** received a single score focusing on following the directions (responses were often so loosely worded that it was impossible to rate the correspondence between the story and the experience the subject was recalling). Subjects in the paragraph-analogy treatment received 3 points per paragraph for generating real analogies, 2 points for generating loose analogies, 1 point for writing something else, and 0 points for writing nothing (there were 12 points maximum). Whole-analogies were scored similarly (3 points maximum).

The responses to the test problem were evaluated for quantity (each solution received 1 point) and quality. The quality of the target solution was evaluated as follows: 2 points for radiation from different directions; 1 point for low-intensity; 1 point for simultaneity (or converging).

We each independently evaluated responses based on pre-determined criteria. Overall, there were 11 differences in scoring of the test; 5 were readily reconciled as errors or oversights. Pearson product-moment correlations between ratings were then calculated to estimate interrater reliability for the number of solutions ($r = .983$) and for the score on the test ($r = .987$).

Results

We focused our analysis on the average quality of the solutions to the radiation problem (maximum = 4). Because our design had only one level in the control group, we performed two analyses of variance: (a) a one-way 5-group ANOVA, and (b) a two-way ANOVA. Hypothesis 1—that generating summaries or analogies for an analog story would facilitate subjects' abilities to generate the analogical dispersion solution to the radiation problem—was not supported. Hypothesis 2—that generating summaries or analogies for each part of the analog story would further facilitate subjects' abilities to generate the dispersion solution to the radiation problem—was partially supported. Table 1 shows the mean scores of the solutions.

Table 1. Mean Scores of Solutions *

	Analogy	Summary	Reading (control)	
Paragraph	2.11 (n = 14)	1.75 (n = 12)		1.94 (n = 26)
Whole	.89 (n = 14)	.68 (n = 14)		.79 (n = 28)
	1.50 (n = 28)	1.17 (n = 26)		
	1.343 (n = 54)		.79 (n= 14)	1.22 (n = 68)

* maximum score = 4

The one-way ANOVA indicated that the differences between the means of the five groups (Table 1) approached significance ($p = .069$). Because the difference approached significance, we decided to compare the groups as we had initially planned. A Fisher PSLD *post hoc* test revealed statistically significant differences ($p < .05$) between the paragraph-analogy group and (a) the whole-analogy group, (b) the whole-summary group, and (c) the reading group. A two-factor ANOVA, with the control group data omitted, further clarified the effects of the treatments. It revealed a main effect for frequency of processing (Table 1, Paragraph and Whole); that is, subjects who responded to each paragraph with an analogy or a summary had a statistically higher mean score ($p = .013$) than subjects who responded at the end of the whole story. Although the analogizers scored higher than the summarizers (1.5 vs. 1.17), there was no main effect for the mode of processing. Thus, there was a clear value in responding to the story paragraph by paragraph, and, from the one-way ANOVA, possible value in analogizing rather than summarizing.

Other factors. In their answers to the test problem, 7 subjects, who were distributed in a nonsignificant pattern across treatments, referred to the analog story. Six of those subjects (85.7%) scored at least 3 on the test. An analysis of variance revealed a statistically significant difference ($p = .0001$) between the average test scores of those 7 subjects and the scores of the 61 subjects who did not refer to the analog story (3.5 vs. .967).

Quality of Processing

Surprisingly, the quality of summaries and analogies was not significantly related to solution of the radiation problem. Quality accounted for only 3 - 23% of the variance in all treatments, even though the quality of subjects' summaries and analogies varied greatly.

For example, the subject who wrote the following good summary scored 0 on the problem:

- A clever military leader succeeds in overthrowing a ruthless despot. His troops evade destruction and entrapment by attacking the central fortress from diverse directions.

The range in the quality of analogies was even wider than for summaries. Probably the poorest analogy was the following, written by a subject who scored 0 on the problem:

- The general is great leader to make dicision quickly.

Occasionally, analogies were very general comparisons, sometimes so broad as to seem useless. For example:

- Dictator is like many kings of medieval times. Dictator reminds me of Russian czars. The great general is like Stalin.
- Capturing the fortress is like solving a problem.
- This reminds me of two things—the Alamo and the Ho Chi Min trail.

Yet even subjects who drew direct analogies, sometimes paragraph by paragraph, to Desert Storm did not necessarily get the correct solution to the problem (the Gulf War ended a few months before the study was conducted). For example:

(1) Kuwait fell to Saddam Hussein, he ruled from Iraq-Kuwait.
(2) UN forces gathered in surrounding countries—Scud missiles threatened & mines [were] planted.
(3) Waiting period of UN troops prior to attacking.
(4) UN troops attack from different directions with few casualties & Kuwait reclaimed.

Discussion

As predicted, cognitively processing the story in parts (paragraphs) rather than as a whole, or merely rereading it, facilitated solution of the test problem. This finding is consonant with the theory of deep processing (Craik & Lockhart, 1972), as well as with the generative model of learning (Wittrock, 1974) and the theory of assimilative encoding (Mayer, 1980).

Although the pattern of scores was in the expected direction (analogizing and summarizing greater than reading), the precise reason for the failure to find a main effect for mode of processing cannot be determined from the data. However, it seems likely that the subjects were not adequately skilled in analogizing and summarizing. We generally assumed that graduate students would possess adequate skills for both; yet their responses clearly indicated a wide range of skill levels, particularly in analogizing. This variability in skill levels hurt the internal validity and control of the study, but at the same time served to strengthen the study's external validity. Clearly university-level instruction must meet the needs of students with widely varying skills.

Another reason for the failure to find a main effect for the task (i.e., mode of processing) might be lack of adequate incentive. Hicken, Sullivan, and Klein (1992) found that incentive is a significant factor in subjects' performance in research studies. Future studies should provide improved incentives for solving the problem.

Although the paragraph-analogy treatment produced the best results, the potential effect might have been inhibited not only by an inadequate incentive but also by other factors. For example, some subjects in the paragraph-analogy treatment actually created partially or fully "connected" analogies (as in the whole-analogy treatment) rather than "unconnected" analogies (Simons, 1984) and may thus have inhibited the hypothesized creative transfer of knowledge. Seven subjects (50%) in this treatment drew at least one analogy to Desert Storm, particularly to Saddam Hussein and General Schwartzkopf; only 1 of the 4 who drew more than 1 comparison to Desert Storm got the correct solution. It is possible that subjects using Desert Storm as a "connected" analogy strongly coded the story simply as a "war story," thus making transfer to another problem less likely. As noted above, "unconnected" analogies facilitate creative transfer of knowledge, while "connected" analogies facilitate storing information (Stepich & Newby, 1988).

The ability to identify The Attack-Dispersion Story as an analog to the problem clearly facilitated solving the problem. But the data in the study provide no insight into why some subjects were able to make the connection. The 6 who referred to the story and scored at least 3 were dispersed across treatments; and they varied in age (34-52), sex (3 female, 3 male), undergraduate major (art, English, electrical engineering, education, economics). It is possible that others were aware of the connection but just did not mention in their solutions. Future studies should include debriefing of subjects to determine if they were aware of the connection.

In spite of the limitations of the study, the groups which processed parts rather than the whole scored higher on average than the other groups, with the paragraph-analogy group scoring higher than the paragraph-summary group. Theory does suggest an explanation for these differences. The first explanation derives directly from schema theory's explanation of semantic networks. These networks

> represent [the] knowledge structures which enable learners to combine ideas, infer, extrapolate or otherwise reason from them. Learning consists of building new structures by constructing new nodes and interrelating them with existing nodes and with each other. The more links that the learner can form between existing knowledge and new knowledge, the better the learner will comprehend the information and the easier learning will be. (Jonassen, Cole, & Bamford, 1992, p. 395)

It is assumed that analogizing and summarizing engage our semantic networks more than passive reading does. But this assumption does not explain why the whole-analogy and whole-summary treatments performed essentially the same as the re-read group.

We believe one explanation lies in the fact that paragraph-level processing tends to result not only in more discrete processing, but also in less "packaged" processing. That is, the "unconnected" analogies and summaries make the knowledge more accessible for far transfer than do "connected" analogies and summaries. This explanation is consonant with cognitive flexibility theory (e.g., Spiro et al. 1988) and it extends explanations of "unconnected" (conceptual) versus "connected" (comprehensive) analogies (e.g., Simons, 1984; Stepich & Newby, 1988) to summaries .

A final question is why the "unconnected" analogies tended to produce better performance than the "unconnected" summaries. Since both treatments were intended to produce meaningful encoding, this difference is not readily explainable. One explanation seems particularly plausible. Because analogizing is a less familiar study strategy it may have caused the learners to attend to details more carefully and thus made them more accessible during the test. However, this explanation as well as others must be explored in future research.

Implications for Instruction

The most important implications relate to focus and types of processing: Instructional strategies that engage the learner in generating summaries and analogies in the learner's own words of subcomponents rather than just main ideas tend to facilitate far transfer problem solving, at least in immediate situations. This finding is consonant with Wittrock and Alesandrini's (1990) findings and with the generative model of learning in general (Wittrock, 1974). It is also consonant with theories of conceptual versus comprehensive analogies (e.g., Stepich & Newby, 1988), and with cognitive flexibility theory (e.g., Spiro et al., 1988), which argues for the use of multiple analogies in instruction. Whether these findings apply to other domains, to delayed transfer, and to the study of longer text, and whether there are any aptitude-strategy interactions remain to be investigated.

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Appendix

The Story

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

2 A great general arose who raised a large army at the border and vowed to capture the fortress and free the country and the dictator. The general knew that if his entire army could attack the fortress at once it could be captured. His troops were poised at the head of one of the roads leading to the fortress, ready to attack. However, a spy brought the general a disturbing report. The ruthless dictator had planted mines on each of the roads.

3 The mines were set so that small bodies of men could pass over them safely, since the dictator needed to be able to move troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road and render it impassable, but the dictator would then destroy many villages in retaliation. A full-scale direct attack on the fortress therefore appeared impossible.

4 The general, however, was undaunted. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal, and each group charged down a different road. All of the small groups passed safely over the mines, and the army then attacked the fortress in full strength. In this way the general was able to capture the fortress and overthrow the dictator.

Test Directions

Before you take a test to see what you learned from the story, we would like you to try to solve the following problem:

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is possible to operate on the patient, but unless the tumor is destroyed the patient will die.

There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either.

Without cutting the patient, what type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

In the space below, write down as many procedures as you can think of. If you need extra space, you may write on the back.