

Analogical Process Performance

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Abstract

Analogy is one of the primary mechanisms of cognition, particularly in problem-solving and learning. However, people do not use analogies very effectively. I postulate seven separate processes for analogy that could be responsible for weak analogical reasoning and test those processes independently. The results suggest that performance on analysis of the problem and performance on confirmation of the appropriateness of the analogy both might be suspect in analogical deficits.

Various analyses of the component processes of analogy in problem-solving have been performed. Clement (1981, 1986) has investigated how subjects approached new problems by forming analogies to old ones and has derived process specifications from empirical observation. Sternberg (1977a, 1977b) has specified the steps in analogy for problems where the base domain is known. Holland, Holyoak, Nisbett, and Thagard (1986) have developed a model of induction that includes an account of analogical processes. Gentner (1989) has also outlined a theory of processes in analogy. In contrast to the psychological approaches, Hall (1989) has developed a synthesis with which to analyze the various artificial intelligence models of analogy. These specifications are summarized in Table 1.

Clement	Gentner	HHNT	Hall	Sternberg	Quinn
		Represent		Encode	Analysis
Generate	Access	Select	Recognize		Access
	Map	Map	Elaborate	Map	Map
Confirm	Soundness		Evaluate	Justify	Confirm
					Transfer
Predict				Apply	Solve
Transfer	Store	Transfer	Consolidate		Transfer

Table 1.

Comparison of these analyses of analogy indicates that none of the above specifications includes all the steps that can be involved in the use of analogies. Under Quinn in Table 1 is the analysis proposed for consideration here. This analysis includes an exhaustive list of the processes involved in analogical problem solving. These steps are:

1. *analyze* the target problem to be understood;
2. *access* a familiar base domain;
3. *map* relations between the base and the target;
4. *confirm* the analogy;
5. *transfer* the problem statement of the target to the base domain representation;
6. *solve* the problem for the base domain;
7. *transfer* the solution to the target problem.

¹Based on research performed while the author was at the University of California, San Diego

The first four steps may need to be repeated until a base analogy is successfully accessed and confirmed as being an appropriate model for the target. Some parts of the elaboration of the representations resulting from later processes may actually be accomplished by preceding processes, for instance the transfer of the problem from the target to the base domain may be accomplished as a result of the access and mapping processes. This still requires specification of all the processes, however, as no process can be assumed to be completely subsumed.

This model for analogy leads to predictions about performance. Prior research (Gick & Holyoak, 1980, 1983) has suggested, in a coarse analysis, that accessing an adequate analogy is less likely than successful exploitation of a provided analogy. Which of the cognitive processes of analogy are entailed in obtaining a relevant analogy and which in the subsequent use? Further, which of the processes involved in accessing an analogy might contribute to deficits in performance?

A fine-grained view of access should include the processes of analysis of the problem, access of a base domain, a mapping between the two domains, and confirmation of the analogy. Use of a given analogy, however, should incorporate the processes of mapping between the domains, transfer of the problem to the familiar base domain, solution of the problem in the base domain, and transfer to the target of the solution. Gick & Holyoak found that, given a hint to use a previous problem, subjects are quite adept at using the suggested analogy to generate an acceptable solution. This suggests that the processes involved in use of an analogy, mapping, transfer, and solution, should be adequate.

On the other hand, Gick and Holyoak found that subjects were unlikely to recall a recently presented analogical solution. Which processes might be inadequate in the access of an analogy? When presented with analogies, subjects correctly rate good analogies as better than poor ones (Gentner & Landers, 1985; Ratterman & Gentner, 1987). This would indicate that the subjects can confirm analogies adequately. Mapping has already been identified as a process that should be well practiced and effective. The problem then is to decide whether it is the analysis process or the access process that introduces the performance deficits. The analysis process yields a representation of the target problem that is then used as a basis for the selection of the base domain. The access process is determined by the representation of the target problem. Gentner (1982) has effectively argued that the access is "ballistic" in the sense that the base domain accessed is wholly determined by the representation and once the access process is launched it proceeds without possible intervention to produce a base domain representation. Given a surface representation of the target domain, the access process should return a base domain that matches on surface features. Similarly, if the analysis process results in a deep representation of the problem, the base accessed should return a useful deep analogy. This suggests that analysis is the culpable process. The expectation is that performance on analysis is inadequate. Other processes should have adequate performance.

Experiment: Component Process Performance

This experiment tested the processes independently to determine which processes were culpable in inefficient analogical performance. The processes tested were analysis, access, mapping, confirmation, transfer, and solution.

Method

The processes were tested by having the subject perform the appropriate subsequent process on a problem with the previous processes performed. For example, a subject might be instructed to perform the mapping between one domain, elaborated by the analysis process, and a new domain from the access process.

Each of the six processes was tested in six domains. Testing each process in order or in random order on the same or different domains could lead to contamination effects. For this reason the process factor had to be conducted between subjects. Each subject could perform the process in each of the six domains. This led to a two factor design with one between-subjects factor (task) and one within-subjects factor (domain).

Background knowledge could strongly influence performance on any of the analogical processes. Ideally, subjects would be presented with suitable artificial material so that all subjects share equal knowledge of the base domain and the target. A more practical answer may be to have a variety of analogies over a spectrum of domains, and to allow the subjects to self-evaluate their knowledge of the domain. However, a pilot study (Quinn, 1989) assessed and revealed no effect of self-rated domain knowledge on performance.

Materials. The materials consisted of a workbook containing the six problems. Since there were six different tasks that were administered between subjects, there were six different types of books. Each book consisted of six randomly-ordered problems, each problem in a different domain, all testing the performance of a single process.

I obtained or created six analogies, each with a paired target and base domain. These analogies are drawn from the literature, from my own experience, or were created for the experiment. They cover a broad range of likely experience, from some that require very specific knowledge to some that are likely to be familiar to most every subject.

Within each analogy, I created questions that addressed the specific processes required for analogy. For analysis, subjects were given the target problem and asked *not* to solve the problem, but, rather, merely to analyze the problem, performing all the steps necessary to solve the problem. If the subjects *thought* they had an answer, they were asked to perform the steps that justified their answer. In the access task, the subjects read a target problem and were asked to think of a similar problem. They were instructed that the specifics of the situation might be very similar or widely different. For the mapping task, subjects were given both a target and base domain, with the target domain elaborated, and asked to elaborate the base domain and to establish the correspondences between the two domains. Subjects were instructed to confirm an analogy between two given domains by rating the quality of the match and, more important, justifying their decision. In the transfer task, subjects were given both target and base domains and a particular situation in one domain. They were then asked to find the equivalent situation in the other domain. Transfer was examined as a single process since the cognitive processes operating on the two representations should be performed equivalently in either direction. The transfer process task was balanced between the two directions: transfer of the problem to the base domain and transfer of the solution back to the target domain. The final process tested was solution of a problem. Subjects were given a problem in the base domain and asked to find the solution.

Subjects. The subjects were 86 students in a cognitive psychology course. Participation in the experiment was voluntary. The topic of analogy was part of the course content, but was not presented before the administration of the experiment. These students were predominantly upper-division college students. While their generally high level of college experience *could* conceivably create a pattern of excellent performance on analogical processes, no explicit training is typically encountered in the curriculum and, in fact, their performance on some processes was less than perfect. Subjects with incomplete workbooks were eliminated from analysis. This eliminated 16 of the 86 subjects, leaving a total of 70 subjects for analysis: 11 in analysis, 8 access, 13 mapping, 13 confirmation, 12 transfer, and 13 solution.

Scoring. The data collected from this experiment consisted of six written answers for each subject. Each question was from a different domain. The subjects' answers differ in qualitative ways from the ideal answer. They can range from the subject having performed the wrong task or not having performed any task at all to an essentially perfect performance. Important distinctions between these two extremes are having performed the task but incompletely or poorly or having performed the task adequately but not exceptionally. These four distinctions were assigned a numerical score from one to four: a one (1) represented either no performance or performance of the wrong task, a two (2) was assigned for performing the correct task but not so as to allow the acceptable performance of subsequent processes, a three (3) was assessed for adequate performance of the task allowing subsequent processes to perform correctly, and a four (4) indicated performance of the task including extra performance that indicated an exceptional comprehension of the task.

This conceptual scoring system had to be interpreted differently for each task. While the criteria to determine whether the subject had performed either not at all or the wrong task were

clear, the other performance levels had to have requirements specific for each task. For analysis, to receive an adequate evaluation, subjects had to either re-represent the problem, specify the causal structure, or list the possible solutions. Adequate performance on access required the subjects to access a base domain that had a causal structure that matched the target domain. For acceptable mapping performance, subjects had to determine the corresponding elements in the base domain for all the elements that were elaborated from the target domain. Adequate confirmation was based on using the deep structure of the two domains to evaluate and justify the confirmation decision. Performing transfer to an acceptable level consisted of interpreting the equivalent perturbation in one domain given a modification to the other domain. Finally, a workable solution was required to determine the ability of the solution process. In all domains, performance less than this level resulted in a rating of a two (or a one if a different procedure was performed) while a four was assigned for elaboration on a task beyond the acceptable level.

Results

Coding. Two independent raters scored the data. One rater scored all the responses while a second rater performed a validity check. Several revisions of the rating process led to a procedure producing reliability greater than ninety percent.

Analysis. One of the original six domains was found inadequate because of an incomplete specification of the confirmation task and was eliminated. This left five domains for the six processes.

Process	n	Mean	SD
Analysis	55	2.2364	0.6657
Access	40	2.8500	0.8638
Map	65	3.0462	0.6233
Confirm	65	2.6923	0.7484
Transfer	60	3.4333	0.6475
Solve	65	3.4615	0.6393

Table 2.

A two factor mixed analysis of variance was performed, with six levels of the between subjects factor (process) and five levels of the within subjects factor (domain). There was a significant effect of process $F(5,65)=15.108$, $p<.001$ but no effect of domain $F(4,260)=.81$, $p=.519$.

Performance on analysis was the worst, followed by confirmation and then access. Mapping was adequate and both transfer and solution were performed quite well (see Figure 1).

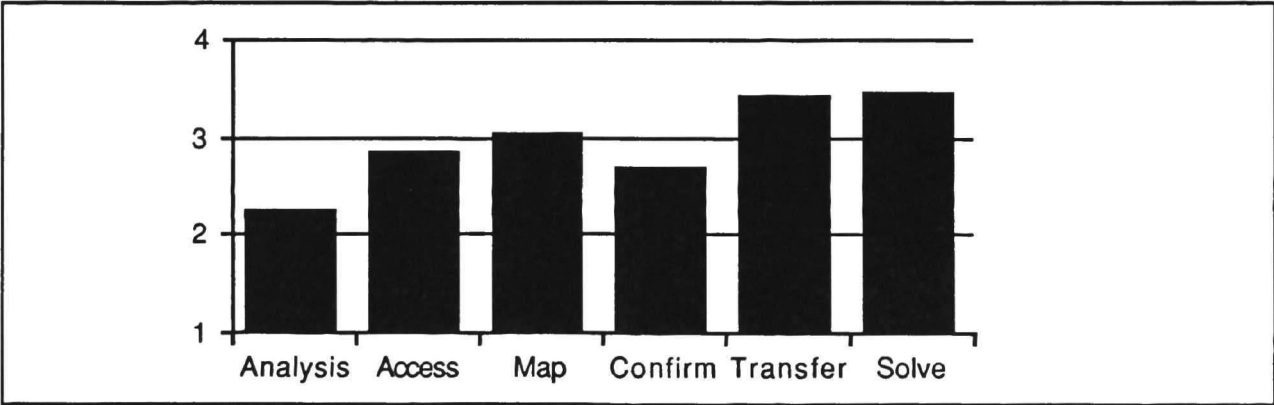


Figure 1.

The interaction between process and domain was significant $F(20,260)=3.779, p<.001$. This makes the main effect of process harder to interpret. However, as can be seen from Figure 3, there are a few isolated sources that constitute the majority of the interaction. Two of these sources are the good performance on analysis $t(53)=-2.317, p=.012$ and the weak performance on access $t(38)=2.894, p=.0031$ for the fifth pair of domains. Overall, patterns indicated by the means are maintained. The interaction can be seen in Figure 2.

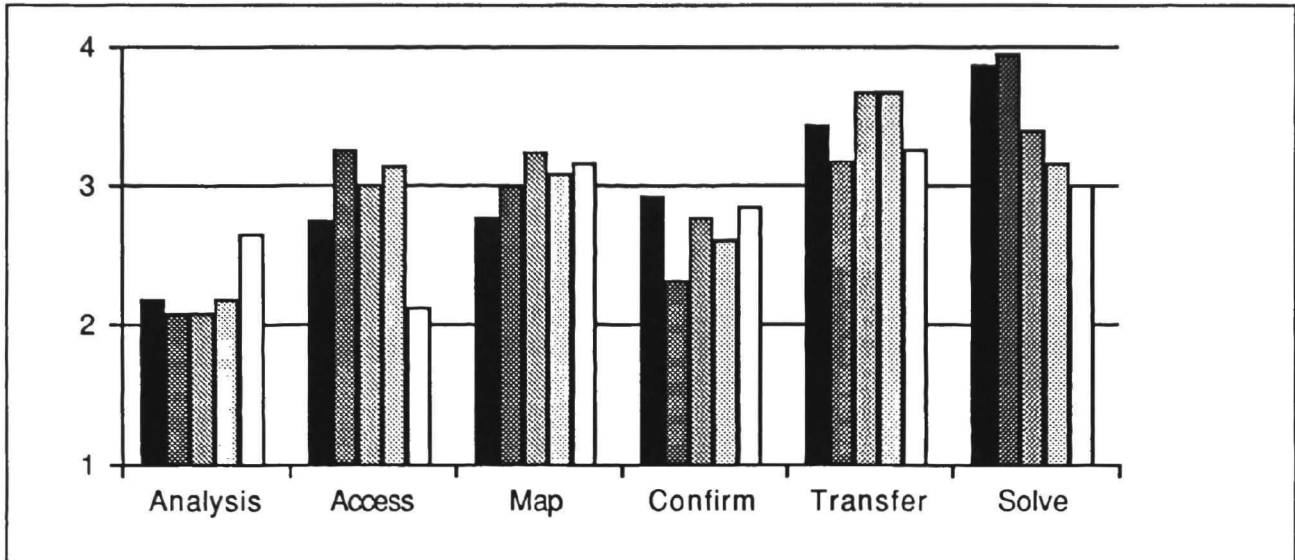


Figure 2.

Discussion

My original hypothesis was that performance on analysis should be inadequate, while performance on other processes should be adequate. These predictions were partially born out by the results of the experiment. Performance on analysis was less than adequate. Unexpectedly, the performances on access and confirmation were also less than adequate. This might be a result of one unusually low domain score for access, but it also might reflect a natural difficulty with access. Perhaps the specification of the analysis in the problems was not enough to ensure adequate access.

Performance on mapping was, on average, of a level sufficient to allow the subsequent processes to apply while performance on transfer and solution were above this level. Performance on solution was surprising, considering that problem-solving behavior has typically been considered weak. The answer may lie in the familiar domains that serve as the base problem for solution.

The result on confirmation is more surprising and harder to explain. Certainly, the task for confirmation here is different than in prior studies. In this study, subjects must explain their confirmation rating, and it is the explanation, not the rating, that receives evaluation. In the previous studies by Gentner (Gentner & Landers, 1985; Ratterman & Gentner, 1987), the subjects were evaluated on their judgement of the quality of the match. Justification may be a more complex and difficult task. Whether or not subjects actually understand the quality of the analogy, they may not be able to express that judgement well.

Another unanswered question about confirmation is whether subjects would use low-rated analogies. The experiments only determined how good the subjects thought the analogies were. One possibility is that subjects may ignore information on the quality of a match in their use of analogies, accepting inadequate base domains whether or not they have the ability to judge them. The cognitive overhead in evaluating the quality of a match, despite any ability to perform the evaluation, prevents this step from being accomplished. Another possibility is that the subjects simply use too low a threshold to confirm analogies. The subjects may have some evaluation of the analogies, and can recognize the relative quality of analogies, but accept the weak analogies.

Again, it might be that the processing load of returning to the analysis and access steps requires too much effort.

Despite the unanswered questions, the performance indications for the identified processes support both the existence of these processes as components of analogy and the utility of the process approach as a framework within which to view analogy. The use of the process approach succeeded in partially succeeded in predicting weak processes of analogy and serves as a guide within which to conduct more discussion about analogical performance deficits.

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