Improving the Use of Analogies by Learning to Encode Their Causal Structure

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Abstract

We investigated whether training in how to encode the causal structure of problems would improve individual's use of analogies to previously encountered cases. Subjects were trained either in how to encode the causal structure of business cases or given a lecture of equal length on a variety of decision making procedures. They were then asked to study several business cases and their successful solution. One week later, when asked to solve new problems, subjects who were trained in causal analysis, compared to the control group, were more likely to use an appropriate analogy from the previously studied cases (positive transfer) and were less likely to use an inappropriate analogy (negative transfer). Further analyses showed that training in causal analysis increased subjects' ability to encode the causal structure of the problem and increased the likelihood of being reminded of the analogy. Thus, the ability to encode causal structure and use analogies appropriately is not responsive only to increasing domain knowledge, but can also be improved by general training in the identification and encoding of the central components of the causal structure of problems.

Introduction

We often solve new problems by using solutions to past problems. Central to such analogical reasoning is the extraction of the relational structure of the past problem and its application to the new problem (Gentner, 1983; Gick & Holyoak, 1983; Holyoak, 1985; Read, 1984).

Unfortunately, people often fail to use analogies appropriately. They do so in at least two ways. First, they may attempt to inappropriately apply a past situation to the present problem. For example, Jervis (1976) and May (1973) have persuasively argued that foreign policy decision makers often rely on inappropriate historical analogies in developing policies, and as a result can make highly questionable decisions. In such cases, the decision maker seems to have been seduced by salient features of the previous case and failed to carefully examine its causal structure.

Second, people may fail to notice or be reminded of relevant past situations. If decision makers have failed to properly encode the causal structure of past problems, they might often fail to notice that the past situation is relevant to the current situation.

This suggests that encoding of the causal structure of situations plays a central role in successful analogical reasoning. Consistent with this, several researchers (e.g., Carbonell, 1983; Gentner, 1983; Holyoak, 1985) have argued that encoding the causal structure is key to both appropriate retrieval and application of analogies. By being able to identify and understand the specific relational or causal features of an analogy, the problem solver can better understand why a particular outcome did or did not occur. As a result, they may be more likely to be reminded of an applicable analogy and, if they have remembered it, be better able to apply it.

This study examines whether people could be trained to use analogical reasoning more effectively by providing them with an explicit technique to analyze and encode the causal structure of problems. The training procedure instructed subjects in the use of Carbonell's (1983) Means-Ends Analysis (MEA) framework for analogical reasoning, based on Newell and Simon's (1973) approach to problem-solving. Although proposed as a framework for retrieval, the present study examined its impact on encoding and application of analogies, as well. This framework involves the identification of four aspects of the causal structure of the past and present problems and the subsequent attempt to match those aspects of the structure of the old problem to the new problem:

1. the existing or current states of the new and previously solved problems.
2. the goal states of the new and solved problems.
3. actions that can be taken to move the system from the existing to the goal state.
4. constraints for the new and solved problems, such as limitations on time and resources, that can affect the ability to carry out the actions.

This should provide people with a mechanism to encode the causal structure of past events and as a result influence the three general phases of analogical reasoning: (a) encoding of the base, (b) reminding of a past situation by the target, and (c) application of the analogy (including both mapping and transfer).

This study is also relevant to the interest in the relative role of surface and structural features in analogical reasoning. Many of the studies that have examined the use of analogies (e.g., Bassok & Holyoak, 1989; Gick & Holyoak, 1980, 1983; Gick, & McGarry, 1992; Holyoak & Koh, 1987; Novick, 1988; Reed, 1987; Ross, 1987, 1989) have focused on the role of surface and structural features of the base analog in its retrieval and application to a new, analogous target. Surface features should not effect the application of a base, as they are not part of its relational or causal structure. Structural features are the relational components that define the causal structure of the base and thus should affect whether it can be correctly mapped to the target.

As expected, retrieval is largely influenced by surface similarity, with structural similarity playing a minor role (for a review see Wharton et al., 1994; for an exception see Read and Cesa (1991)). In contrast, the applicability of analogies is almost entirely affected by structural similarity (Gentner & Landers, 1985; Reed, 1987; and Holyoak & Koh, 1987).

However, under some conditions surface similarities do influence application, particularly when structural mappings are unclear (Ross, 1987; and Johnson, 1988). Apparently, people use corresponding surface features to help identify corresponding structural relations. Unfortunately, when surface features are not correlated with structural relations this may lead to negative transfer of a base to a target that shares only surface similarities (Novick, 1988; Bassok & Holyoak, 1989).

Novick (1988) proposed a framework for conceptualizing the conflicting findings of the role that surface and structural features play in access and use of analogies. When she compared novices and experts, she found that when source and target problems shared structural features, experts exhibited more positive transfer than novices. In contrast, when source and target problems shared surface features, but not structural features, novices were much more likely than experts to show negative transfer, inappropriately applying a non-relevant analogy.

This suggests that surface similarities can influence mapping of an analogy when the causal structure has not been encoded, whereas structural similarities will influence mapping when the structure has been encoded. Both Novick (1988) and Ross (1987) implied that providing experience in analogical mapping should increase positive transfer and decrease negative transfer.

Consistent with this is Brown's (1989) work on the impact of age-related differences in children's knowledge of causal structure. Spontaneous transfer was more likely if children understood the causal structure of problems. However, Brown also argued that when children have not yet differentiated the causal structure, surface features are important in analogical transfer.

This implies that training in a technique for encoding and mapping the causal structure of a problem, such as Carbonell's MEA framework, should improve analogical reasoning. This should be exhibited as an increase in positive transfer, and a decrease in negative transfer.

To examine this possibility, half of the participants in the present study received training in applying MEA to the analysis of the causal structure of analogs, and half did not. Participants were exposed to scenarios that dealt with a variety of marketing and strategic business issues.

The nature of the similarity of base and target was varied so that the effectiveness of training could be assessed on analogies which were and were not appropriate matches for the target. One base was totally non-analogous to the target, sharing neither surface nor structural features. A second base was primarily similar on surface features to a target, but shared little structural similarity. Subjects who failed to encode its causal structure should inappropriately apply it to the target problem (negative transfer). The third base was similar to a target in underlying causal structure, but not in surface features. Subjects who had encoded its causal structure should be more likely to apply it to the target (positive transfer).

Thus, trained individuals were predicted to be less likely than the untrained to transfer a solution from a base that was similar only on surface features (less negative transfer). In contrast, trained individuals would be more likely than the untrained to transfer a solution from a base that shared all four structural components but no surface features (more positive transfer).

Method

Subjects

One hundred and twenty men and women participated. Fifty-seven were students participating to receive extra credit in introductory psychology at the University of Southern California. The remaining 63 were employees of a health care company in Southern California. Subjects from the two groups were equally distributed across the two training conditions. Trained and untrained subjects were run in separate sessions, with seven to ten subjects in a session.

Design and Procedure

The study was a 2 X 3 mixed design. The between subjects factor was the type of training received, either training in Means-Ends Analysis (MEA) or training in general problem solving. The within subjects factor was the nature of the similarity of a set of three base stories to three targets, either non analogous, surface similarity only, or structural similarity only.

Subjects were randomly assigned in equal numbers to the trained or the untrained group. Both groups received the same stimulus materials. The trained group was trained on Carbonell's MEA framework for problem solving by analogy. The untrained group received an informative presentation on problem-solving and decision making approaches that lasted the same amount of time as the experimental training, approximately one hour. However, no specific framework or tools for problem-solving were provided. The untrained session was designed to show that the impact of MEA training goes beyond simply focusing people on thinking about the problems.

Five sets of business problems were developed, based on "real life" marketing and business scenarios. The base stories presented a problem and a solution, whereas the targets only presented a problem. Two sets of scenarios were used as training examples. The other three sets of base-target pairs were used to manipulate the three within subjects similarity conditions. The three conditions were: (1) **Non-Analogous**. Subjects received a base-target pair in which the two stories were completely unrelated to one another, with neither surface nor structural similarity. (2) **Negative Transfer**. The base story had mainly surface similarities (such as a similar industry) to the target. Structural components such as the operators and constraints were unmatchable, whereas the existing states and goal states, were, for the most part, matchable. (3) **Positive Transfer**. The structure of the base story was directly mappable to the target, such that the existing states and goal states, operators, and constraints of the base were congruent with those of the target. However, surface characteristics (e.g., type of industry) differed between base and target. Thus, there were three possible bases for each target.

Trained Session. The trained subjects were first given two practice base problems, without their solutions, to read and solve. They were then asked to discuss their solutions. Then they received and read the predetermined solutions to the practice problems to see how they compared with their solutions.

Next, subjects received a detailed description of the MEA procedure, including definitions of the four components, instructions on how to recognize them, and how to match them from the base to the target. They then got the targets that were matched to the base problems they had read, and were given instructions, rehearsal, and feedback, as the group analyzed the base-target example using the MEA framework.

The first practice target, the structurally similar base-target pair, was used to exemplify positive transfer, by showing how structural features were conducive to mapping this base solution to the target problem. Subjects were walked through comparisons of each of the four structural components. The same procedure was used with the second practice problem, the surface similar base-target pair. This was used to illustrate how solely mapping surface similarities of the base to the target, without attending to the underlying structural components, may potentially lead to mapping an inappropriate analogy.

Untrained Session. The untrained group was also given the two practice problems to read, solve and discuss. They then received information on how the decision making and problem-solving environment is changing in business. This included a historical perspective beginning with a traditional problem-solving approach and ending with a summary of five different approaches (creative and analytical) and implications about the pros and cons of each. While analogical reasoning was alluded to, a description was not given.

Subjects then received the matched target to the base problems they had read, and were given instructions, rehearsal, and participation feedback as the group analyzed the base-target examples from the perspective of the problem-solving approaches discussed in the previous presentation. This session lasted the same amount of time as that for the trained group.

Encoding Exercise. Upon completion of the training, all subjects received a packet of three base problems and their solutions. One base was non-analogous to a later target, the second similar in surface attributes only (negative transfer condition), and the third had structural similarities (positive transfer condition). All subjects received the same 3 target stories.

Subjects were instructed to read carefully and remember the problems and their solutions, as they would be asked some questions about them at a later time. To ensure that scenarios were processed, they were also asked to write a brief summary of each problem and solution.

Subjects returned one week later and received a booklet of 3 target problems without solutions. Each was matched to one of the three base stories they received previously. Subjects were instructed to provide a clear and concise solution to the target problems. They were also asked to write down any other solution they could think of.

After suggesting solutions for all targets, subjects were instructed to refer back to the target stories and indicate if each story reminded them of anything they had read the week before. If so, they were to write down briefly which story and its solution they were reminded of.

Results

Scoring: Transfer Task

Subject's proposed solutions were scored from 0 to 2. A 0 indicated no similarity to the base solution (a solution that was completely made up or that included a combination of a negative and positive transfer solution). A 1 indicated a positive transfer solution. A 2 indicated negative transfer, a solution that was inappropriately transferred to the target problem from a base.

All data were coded by the second author. Inter-rater reliability was calculated by having a second person, blind to conditions and hypotheses, code the data from 10% of the subjects. Agreement was .85, using Cohen's Kappa (described in Bakeman & Gottman, 1986).

Impact of Training on Transfer

As expected, in the positive transfer condition, trained subjects were much more likely than untrained subjects to provide an appropriate solution (positive transfer) (see Table 1). Conversely, untrained subjects were more likely than trained to provide a made up solution. In the negative transfer condition, untrained subjects were quite likely to be led astray by the inappropriate analogy and exhibit negative transfer, whereas trained subjects almost never did. In the non-analogous condition, over 90% of the solutions for both trained and untrained subjects were made up.

Thus, these findings demonstrate that training strongly improved people's ability to provide the appropriate analogous solution and ignore an inappropriate one. A significant interaction would therefore be expected between Training (Trained versus Untrained), Analogy condition (Non-analogous, Negative Transfer, or Positive Transfer), and the type of Solution (Non-analogous/Made up, Negative Transfer or Positive Transfer). This was tested using a backwards elimination approach to log-linear modeling. One starts with the full model, including all main effects and interactions, and first removes the highest order interaction to see if it is necessary to account for the pattern of frequencies. If it is not, then one eliminates it and proceeds to systematically remove the lower order interactions.

	Positive Transfer Solution	Negative Transfer Solution	Made-up Solution
Non-analogous Condition			
Trained Group (N=60)	3%	3%	94%
Untrained Group (N=60)	3%	0%	97%
Negative Transfer Condition			
Trained Group	90%	3%	7%
Untrained Group	3%	70%	27%
Positive Transfer Condition			
Trained Group	90%	0%	10%
Untrained Group	58%	2%	40%

Table 1: Frequency of Subjects Giving Each of Three Types of Solution in the Non-analogous, Negative and Positive Transfer Conditions

With the backward elimination approach, the difference in X^2 between the model with all terms, and the model with one term removed, indicates whether that term significantly contributes to the fit of the model. Because the highest order interaction, the three way interaction among Training, Analogy condition, and Solution, was the key prediction of the study, the backward elimination approach was an efficient way to test this prediction. Removing this three way interaction from the full model, resulted in a significant reduction in goodness of fit, $X^2(4)$ diff = 23.6, $p < .01$. Thus, this interaction was needed and the central prediction of the study was supported, making it unnecessary to test lower order terms.

To better understand this interaction, we did two follow-up comparisons, one comparing the performance of the trained with the untrained groups in the positive transfer condition and the other comparing the performance of the two groups in the negative transfer condition. As predicted, in the positive transfer condition, the trained group was far more likely to give the positive transfer solution than was the untrained group, $X^2(2) = 15.856$, $p < .01$. And in the negative transfer condition, the trained group was far less likely to give the negative transfer solution than was the untrained group, $X^2(2) = 91.84$, $p < .01$. Unexpectedly, trained subjects frequently gave the positive transfer solution in the negative transfer condition. In hindsight, the negative transfer problems always presented two different solutions that had been considered. The solution that was actually used was an inappropriate solution for the target. However, the untried alternative was appropriate for the target. In essence, when trained subjects determined that the previous solution was inappropriate for the target, the base provided them with an alternative solution that was appropriate for the new target.

Impact of Training on encoding and reminding

Subjects' summaries of the bases provided further evidence that training increased encoding of the causal structure. In the positive transfer condition all 60 trained subjects encoded the problem, as indicated by giving a clear summary of the key aspects of the problem, whereas only 36 of the 60 untrained subjects did so. In the negative transfer condition, almost all of the trained subjects (58 out of 60) encoded the problem, whereas only 40 out of 60 untrained subjects did.

Further, training increased reminding of previous bases. In the positive transfer condition, 39 out of 60 trained subjects were reminded of the similar base, whereas only 20 out of the 60 untrained were reminded. Results were comparable in the negative transfer condition, with 36 out of 60 trained subjects being reminded, but only 21 out of the 60 untrained.

Discussion and Conclusions

Although the ability to encode the causal structure of a problem has been argued to be key to the retrieval and appropriate application of analogies (Carbonell, 1983; Holyoak, 1985; and Brown, 1989), the present study is the first direct test of whether the ability to do so can be improved by training. This study demonstrates that training in causal analysis can dramatically improve people's ability to encode the causal structure of an analogy and, as a result, increase the likelihood that subjects' use of analogies will be sensitive to the underlying relational structure of the base and target. Thus, subjects who were trained in causal analysis were more likely to apply a potential base to a new situation when the causal structure matched (i.e., exhibit positive transfer), but were less likely to apply a potential base to a new situation when it failed to match on important causal features (i.e., exhibit less negative transfer.) Further, training in causal encoding also increased the likelihood of being reminded of similar situations. Finally, in the absence of such training, surface similarities strongly influenced transfer of inappropriate analogies.

Thus, increases in the ability to encode causal structure and use analogies appropriately are not responsive only to increasing domain knowledge, as the work of Novick (1988) and Brown (1989) might seem to suggest. Analogical reasoning can also be improved by general training in the identification and encoding of the central components of the causal structure of problems.

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