The Effect of Alternative Representations of Relational Structure on Analogical Access

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Abstract

Retrieval of an appropriate analogy from memory is often difficult because the structure common to two analogous domains is embedded in specific contexts that differ at the surface level. The present study examines an aspect of domain representations that may affect the access of analogs in memory. Subjects were asked to identify analogies between new and previously learned passages. Passages varied in the manner in which analogous relations were described. In all passages the relations were embedded in a particular context that was dissimilar at the surface level between analogs. However, the expression of relations within a passage varied in level of abstraction. In "abstract" passages relations were lexicalized with relatively abstract terms and were described with little domain specific detail. In "specific" passages more specific terms were used and extensive domain specific detail was given about how relations were instantiated within the domain. In "mixed" passages both abstract and specific descriptions of relations were given. Subjects reading abstract passages were best at identifying analogies. The present results suggest that even though analogous relations are embedded in dissimilar contexts, the way in which those relations themselves are represented can affect analogical access. Subjects are relatively successful at analogical access when the relations are represented in a relatively general and sparse form.

The flexibility of the cognitive system is displayed when analogies are drawn between disparate domains, for example, when we transfer our knowledge about a hydraulic system to an electric circuit. But how do we make these connections? What leads us to notice that electricity and water flow can be compared?

Many investigators have found that recognizing analogical similarity between events, passages, or problems from disparate domains is often difficult. Subjects often fail to apply a previously learned task when presented with an analogous task (Reed, Ernst, & Banerji, 1974; Gick and Holyoak, 1980; 1983; Gentner and Landers, 1986; Ross, 1987). The difficulty seems to lie in the access process, that is, in spontaneously noticing the analogical similarity between a current task and a prior task represented in long term memory. Once subjects are presented with the two tasks for comparison, they have relatively little difficulty mapping their similarities.

The difficulty of analogical access is not surprising when we consider the features of an analogy between disparate domains. First, in an analogy the two domains being compared are not similar in terms of salient contextual or "surface features" such as concrete object attributes (Gentner, 1983). For example, electricity does not share "wetness" with water. Rather the two domains are only similar in terms of underlying structural relationships. Second, an analogy draws a correspondence between two specific domains rather than between an explicit, general principle or schema and the target domain. In an explicit principle, objects or arguments have become variables, and the relations are no longer embedded in a specific context (Gentner, 1983). Often we rely on analogies when such general principles or schemas are unavailable. A schema is induced only after an analogy has been discovered and used (Gentner, 1989).

Investigators have found that access of prior tasks represented in memory is strongly influenced by surface features shared with a target situation, (e.g. Ross, 1984, 1987; Lewis and Anderson, 1985; Gentner and Landers, 1986; Rattermann and Gentner, 1987; Holyoak and Koh, 1987). When only relational features are shared, prior tasks are often not easily retrieved. However, subjects can access relational structures when these structures are no longer embedded in specific contexts. Gick and Holyoak (1983) found that subjects could transfer a solution schema from base analogs to a target problem that shared few surface similarities with the analogs. However, transfer was found only when subjects had been given two base domains and had abstracted an explicit schema (characterizing the analogous structure) from the two domains. Chen

and Daehler (1989) and Clement (1987) found similar results. Thus access of explicit schemas, independent of the specific analogs, is easier than retrieval of specific cases in which the schemas are implicit. Bassok and Holyoak (1989) present a related finding that transfer of structures from mathematics to physics was easier than transfer of structures from physics to mathematics. Mathematics appears to allow essentially domain independent representations of structures, whereas in physics the structures are linked to particular contexts.

Thus, analogical access is difficult because the structure common to two analogous domains is embedded in specific contexts that differ at the surface level. Yet successful access of analogs can occur. Presumably when successful access occurs, the specific domains are represented in a manner that highlights the relevant relational similarities, and subjects are easily able to disregard surface dissimilarities (Novick, 1988; Faries & Reiser, 1989; Gick and Holyoak, 1983; Gentner,1989; Seifert, McKoon, Abelson, & Ratcliff, 1986). This does not imply that access requires the induction of an explicit domain-independent schema. Schema induction may be the last stage of analogical processing (Gentner, 1989). How can we account for access of analogs when subjects have not yet developed domain-independent schemas that characterize the analogous domains?

A key factor in analogical access may be the manner in which the analogous relations are represented within a domain. Even though analogous relations are linked to a particular context, their representation within that context can vary. For example, the relations may be represented in more or less domain specific format. Often analogous relations may only appear similar between domains when they are translated from relatively domain-specific terms to more general terms. For spontaneous access, it may be necessary that the analogous relations be already represented in a form that allows relatively direct detection of their similarity.

There are several ways in which the relations within analogous domains can be represented in a more or less compatible way. For example, if the relations are lexicalized with verbs, these verbs can be relatively specific or abstract. If they are specific, the general components must be differentiated from domain-specific components (such as the manner or instrument entailed by the verb) before cross-domain similarities can be detected. This may require viewing the verb as an instance of a more abstract concept, or decomposing the verb until a common core component is found (Gentner, 1989). As an example of the contrast between relatively abstract or domain-specific relational verbs, imagine a creature that "gathers" food. Either a general term like "gathers" can represent the relation, or a more specific term can be used that specifies how the gathering occurs, e.g. "sucks". If the creature is analogous to something else that gathers but does not suck, the more general term will allow easier detection of the analogy.

The representation of a relation may include a more or less detailed account of how the relation is instantiated within a domain. Again in order to recognize cross-domain similarities, these relations may have to be re-represented. They may either be lexicalized with a relatively abstract term, or a sparser, more general description may be substituted. This may require synthesizing detail to arrive at a higher level of description, or deleting detail to isolate a relevant general idea. For example, suppose a creature tests the food supply in his habitat. Detail about how this testing proceeds could be given, and it could be left for the reasoner to integrate the information and conceptualize it as "testing". In contrast, the relation could be lexicalized directly with the term "test".

In the present research the descriptions of relations in analogous domains was manipulated to make the similarity between domains more apparent. Domain descriptions were either abstract or specific. Although the basic content was the same, the abstract descriptions used more abstract words to convey key relations. Also, the abstract descriptions contained less domain-specific detail about how relations were instantiated. It should be made clear that the abstract descriptions were not domain-independent schemas. The relations were still linked to particular contexts. A third condition was also included in which both abstract and specific expressions of relations were included in a domain description.

This manipulation of the level of abstraction of analogous relations should affect how easily subjects can detect a structural similarity between analogous domains. If access processes rely on

the relatively direct detection of similarity, subjects with the abstract domain descriptions should be more likely to access a base domain in the presence of a target than subjects with specific domain descriptions.

Method

Design

Adult subjects learned base passages during a Learning Session. Two days later, during an Analogy Session, subjects had to match the base passages to target passages. We assessed subjects' ability to both access the correct base for a given target passage, and to work out the mapping between an identified analogous pair. Base and target passages differed for three groups: (a) For the Specific Group (n=28) all base and target passages received were "specific". (b) For the Abstract Group (n=28) all base and target passages received were "abstract". (c) For the Mixed Group (n=28) all base and target passages were "mixed" -- they included both abstract and specific descriptions of relations.

Materials

Analogies. Five analogies were developed each consisting of a base and target passage. Each passage was one paragraph in length and described the activity of a fictional creature or object. Table 1 outlines the common relations in an example analogy between two domains called "The Tams" and "The Satellites".

Table 1
Analogous Relations in *The Tams* and *The Satellites*

Gathering:
Tams: Creatures called Tams eat minerals from rocks.
Satellites: Satellites take photographs of planets.

Relocation:
Tams: When the minerals are gone from one place, the Tams move on.
Satellites: When an orbit is complete, (no more new photographs to be taken) the Satellite moves to a new path.

Testing Supplies:
Tams: At a new spot the Tam sees if minerals are plentiful.
Satellites: At a new path, the Satellite determines whether new pictures can be taken.

Staying or Moving on:
Tams: If the minerals are plentiful, the Tam stays and eats. Otherwise it moves on.
Satellites: If the pictures are fresh, the Satellite stays and takes pictures. Otherwise it moves on.

Tables 2 and 3 illustrate the actual wording used to describe some of the relations in the abstract and specific versions of the Tams and Satellites passages. Notice that more or less abstract verbs are used to describe relations, and that more or less detail is given about how relations are instantiated in the domain. The mixed version simply combined the content of the abstract and specific versions. For each analogy, which passage served as the base (given during the Learning Session), and which served as the target (given during the Analogy Session) was varied within each group.

Surface matches. Each passage was designed to share a salient surface similarity to one other passage to which it was not analogous. This surface match included a similarity in object type, object attribute and/or simple relation. For example, a passage not analogous to the Tams was similar to the Tams in that the central characters were also "fierce" and also lived among rocks. No other information in the two passages was similar. These surface matches were present in each condition-Abstract, Specific and Mixed.

Table 2
Examples of the Instantiation of Analogous Relations in the Abstract and Specific Versions of *The Tams.*

Gathering

Abstract *Tams are fierce little creatures that gather and consume a mineral called feldspar found in rocks. A Tam uses its underbelly to gather and bring in the feldspar.*

Specific *Tams are fierce little creatures that voraciously eat a mineral called feldspar found in rocks. A Tam has an abrasive underbelly that hurriedly wriggles back and forth to loosen minerals from a rock. The belly then slurps in loosened feldspar.*

Testing Supplies (after moving to a new location)

Abstract *As soon as the Tam reaches a new spot, it tests the available mineral supply.*

Specific *As soon as the Tam discovers a new spot, it sees how much feldspar can be loosened with a few quick wriggles of its underbelly.*

Table 3
Examples of the Instantiation of Analogous Relations in the Abstract and Specific Versions of The Satellites.

Gathering

Abstract *A special satellite is used to collect data about planets. This satellite collects pictures with highly sensitive cameras. The satellite follows a path around a planet taking pictures at frequent intervals.*

Specific *A special satellite is used to provide data about planets. The satellite slowly spins a path around a planet, snapping pictures at frequent intervals with highly sensitive cameras. Every few seconds, a camera eye opens and new film is exposed.*

Testing Supplies (after moving to a new location)

Abstract *Sometimes the second path is too close to the first path, and the pictures taken are duplicates. Therefore, whenever the satellite begins a new path, it evaluates whether or not it is collecting fresh pictures.*

Specific *Sometimes the satellite's second path is too close to the first path, and the pictures snapped are duplicates. Therefore, whenever it begins a new path, the satellite compares pictures being snapped on this path with old pictures. The satellite scans its store of old pictures and looks for a match with pictures being snapped.*

Validation of materials. To verify that the specific and abstract versions of each passage embodied the same relational structure, the two versions were given to two groups of subjects (n=14,14) not involved in the main experiment. Half of each group received one passage from each analogy. Subjects were also given abstract statements, some of which characterized the relational structure common to the base and target of each analogy. Other statements served as distractors.

These subjects' task was to identify which abstract statement belonged to which passage. Following this, subjects were given the intended match and they rated how well the abstract structure applied to the passage. As expected there was no difference between groups in the mean number of correct matches made (the means were 4.57 and 4.43 for the specific and abstract passages respectively). Also, there was no difference in the ratings (the mean rating was 6.2 in each group). These results suggest that the specific and abstract passages did not differ in how well they expressed the relational structure common to analogous pairs.

Procedure

Learning session. For each of five base passages, subjects: (a) studied the passage for three minutes, (b) tried to recall the passage in writing; subjects were asked to recall a passage "verbatim, exactly as it was written", and (c) corrected their recall by checking it against the passage. Subjects were asked to recall the passages verbatim to increase the likelihood that their representation of the passages would correspond to the particular type of passage read (abstract or specific).

Analogy session. Two days after the learning session subjects received six new passages, five of which were analogous to the five base passages.

1. Subjects first received an Access Task. Subjects were allowed three minutes to read each new passage and name an analogous passage from the Learning Session. (An analogy was defined for subjects as a partial similarity, and two examples of analogies with relational similarities were given.) Subjects were allowed to think of more than one analog for a given target.

2. Next, in a Recall Task subjects were asked to describe from memory each of the five base passages they learned during the Learning Session. The purpose of this task was to provide evidence that the specific, abstract and mixed passages were comparable in terms of how well they were retained.

3. Finally, in a Mapping Task subjects were told which passages formed an analogous pair. For each pair they were to describe how the passages were analogous.

Results

Access Task

Subjects were scored for the number of correct base- target matches made during the Access Task (possible scores were 0 to 5). Figure 1 shows the mean number of correct matches made in each group. The Abstract group made significantly more correct matches than the Specific group. ($F1,52 = 13.1$, $p < .001$). Performance of the Mixed group is intermediate and does not differ significantly from either that of the Abstract or Specific groups.

Figure 2 shows the proportion of subjects in each group making the correct match for the individual analogies. For four of the five analogies, significantly more subjects made correct matches in the Abstract group than in the Specific group (Fisher exact tests, $p <.001,.001,.01, .05$).

Analyses of errors revealed that subjects in the Specific group were more likely than subjects in the Abstract or Mixed groups to match passages on the basis of surface similarities. For example, they more frequently paired the Tams with the other passage concerning fierce creatures. The mean number of surface matches in the Specific, Abstract and Mixed groups respectively is 2.00, 1.29 and 1.36. The difference between the Specific and Abstract group is significant ($F_{1,52} = 4.02$, $p < .05$).

Recall Task

Subjects' recall of each base passage was scored for the presence of components of the analogous relational structure. Overall there was no significant difference between groups (the mean proportion of components present is .50, .43 , and .43 in the Abstract, Specific and Mixed groups respectively). However, the Abstract group did show significantly better recall than the Specific group for two of the passages, and significantly better recall than the Mixed group for one passage. These results raise the possibility that poor retention of the base passages among Specific subjects may have influenced the difference between groups in the Access Task. On the other hand, carry-over effects from success on the Access Task may have improved the recall scores of Abstract subjects. This issue is addressed in a follow-up experiment.

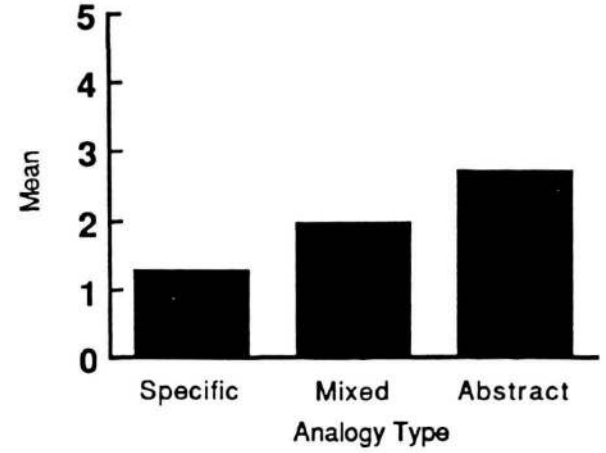

Figure 1 Access Task: Mean Number of Correct Matches in each Group

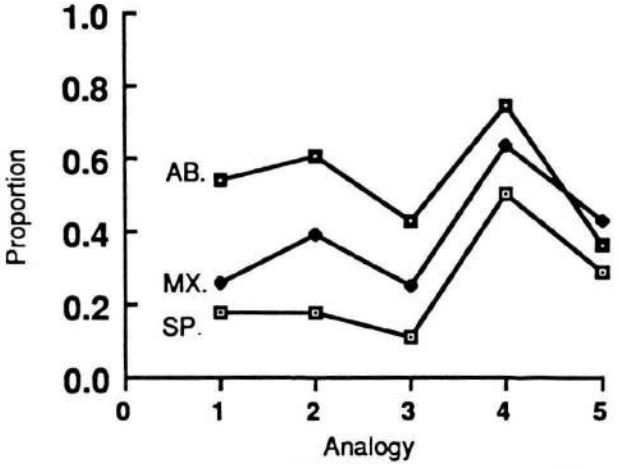

Figure 2 Access Task: Proportion of Subjects in each Group Making the Correct Match for each Analogy

Mapping Task

Subjects' descriptions of the similarity between base and target passages were scored for the presence of components of the analogous relational structure. The mean proportion of components mapped across the five analogies did not significantly differ between groups (M= .5, .42 and .43 for the Abstract, Specific and Mixed groups respectively). When the individual analogies are considered, the Abstract group showed significantly better mapping than the Specific group for one analogy only. No other differences are significant. Thus, although the abstract materials allowed better access of a base domain in the presence of the target, they did not have a strong effect on

mapping the structure of a base and target presented for comparison.

Follow-up Experiment

A follow-up experiment was conducted to examine the possibility that the abstract passages were easier to retain in memory than the specific or mixed passages. Three groups of subjects (n=17,16,17) received either abstract, specific, or mixed passages in a Learning Session identical to the Learning Session used in the main experiment. Subjects returned for a second session after two days. During the second session subjects recalled in writing the passages they had learned.

Responses were scored for the presence of components of the relational structure embodied in the passages. There was no evidence that the different types of passages were more or less easy to retain. The mean proportion of components recalled was .47, .51 and .46 in the Abstract, Specific and Mixed groups respectively. Also, when individual passages are examined, no differences between groups are found. These results suggest that the group differences in access of analogs found in Experiment 1 cannot be attributed to differences in retention of the different types of passages.

General Discussion

Analogical transfer between disparate domains is often difficult because the structural similarities between domains are difficult to detect. The common relational structure is embedded in information which is dissimilar at the surface level. Thus, recognizing analogical similarity often requires transforming domain representations into a more compatible form. For example analogous relations may have to be generalized to a higher level of abstraction or decomposed until a common component is found. The present research attempted to provide domain representations for subjects that should make structural similarity more directly detectable. Specifically, within a domain the analogous relations were expressed in either a relatively domain-specific or domain-general form. The relations were always embedded in a particular context, but the relations themselves were expressed with more or less abstract terms, and more or less detail was given about how the relations were instantiated. These manipulations should affect whether relations in one domain are characterized in a manner compatible with a different domain. This aspect of domain representations appeared to affect analogical access. Abstract subjects were better than Specific subjects at accessing a base domain in the presence of the target. Specific subjects often failed to notice an analogical match, and unlike the Abstract subjects, they tended to make matches based on surface rather than structural similarities.

The locus of the difficulty for the Specific Group may have been (a) the absence of more general or higher-level terms to characterize relations, or (b) interference from the domain-specific detail. The intermediate performance of the Mixed group provides some evidence that both factors were important. For this group, the abstract descriptions may have helped, but the specific detail interfered with recognition of analogies. These subjects may have been poor relative to Abstract subjects because the detail may have dominated the representations and made the abstract concepts less salient.

The variation in domain descriptions affected access of analogs more than mapping information between already identified analogs. Both access and mapping require arriving at a compatible representation of analogs. However, because access requires search of LTM, factors that affect the efficiency at arriving at this representation may be more important for access. Subjects in the Specific group may have been relatively inefficient at detecting relational similarities. Mapping between domains already in working memory may demand less efficiency. Thus even with relatively specific domain representations, subjects could often eventually work out a compatible representation.

Different levels of generality of a knowledge structure may be appropriate for different uses. For literal categorization, relatively specific knowledge structures may be the most effective. For example, to improve recognition of instances of a concept, explanation based learning systems (e.g. Mitchell, Keller, & Kedar-Cabelli, 1986) translate a highly abstract concept representation into a

more specific one. This facilitates identification of cases that instantiate the concept in similar ways. Unlike literal categorization, analogy requires a disregard of the particular way structures are instantiated. However, this does not entail that the detection of analogs requires the induction of an explicit, domain-independent schema. Induction of a schema is often seen as the last stage of analogical processing (e.g. Gentner, 1989). One way to understand how analogical access may occur is to consider that even though analogous relations are linked to a particular context, their representation within that context may be relatively abstract. The present research suggests that representations that are relatively sparse and abstract may permit access of analogs from disparate domains.

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