

Reinvestigating the Effects of Surface and Structural Features on Analogical Access

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Abstract

Competing theories of analogical reasoning have disagreed on the relative contributions of surface and structural features to the access of analogs. The present experiment attempted to systematically assess how access is affected by the number of surface and structural matches between a currently-read story and one that is presumably in memory. The results suggest that both surface and structural features affected access about equally.

Introduction

An issue of major interest in the field of analogical reasoning has been the relative roles of surface and structural features of stories on the likelihood of a learner being reminded of a prior story while reading a current one. Surface features are features that, when changed, do not affect the solution procedure for a problem or do not affect relationships in a story. Structural features are those that, if changed, do affect the solution procedure or relationships.

For instance, consider a story about a hunter that shoots an arrow at a hawk but misses because the arrow does not have any feathers on it to help stabilize its flight. The hawk then gives the hunter some of its feathers and the hunter is so pleased he promises not to hunt hawks anymore. Consider a second story about an aggressive country that attacks its neighbor with missiles; the missiles fail to do any damage because they were poorly guided and missed their targets. The neighbor, which makes supercomputers, offers to sell some to the aggressive country. The aggressive country is so appreciative that it pledges never to attack its neighbor again.

These two stories share a similar structure but differ in terms of surface features. Now consider a revision of the second story. A nervous country offers to sell some computers to its aggressive neighbor in order to obtain a promise that the aggressive country will not attack it. The aggressive country then equips its missiles with the computers it had purchased and proceeds to attack the country that sold them the computers. The attack succeeds because of the computers. Like the first story about the countries, this story has about the same minimal degree of surface overlap with the hawk story. However, the degree of structural overlap has also been reduced.

Finally, consider a fourth story about an eagle that offers to provide tailfeathers to a sportsman who uses a crossbow

on his outings. The eagle wishes to extract a promise from the sportsman that the eagle will not be attacked. After giving the sportsman the tailfeathers, the eagle is later shot by the hunter and the arrow that did the damage had the eagle's tailfeathers to help its flight. This story has a number of surface similarities to the hawk story, but as with the second country story, the structural feature overlap has been reduced relative to the first country story.

If a person were to read a large number of "base" stories and then, perhaps after a week's delay, were to read a large number of "cue" stories, a question of interest is which base story(ies) the reader would be reminded of when reading a particular cue story. Would the reminding be driven by surface feature overlap between a particular base and cue or would it be affected also, or instead, by structural feature overlap? More concretely, if the hawk story were one of the base stories, would the first country story be as good a cue as the story about the eagle?

Recent research has been equivocal on this issue. Gentner, Rattermann, and Forbus (1993) found that reminding in such a situation tended to be driven largely by surface feature overlap. In a typical experiment from their study, participants would read a collection of base stories and then a week later would read a collection of cue stories. A given cue story would have a matched base story where the match could be at several levels. A first-order relation, or FOR, match would be one in which certain low-level predicates would be present in both stories (e.g., X shoots Y) but there would be minimal surface feature overlap (e.g., hawk vs. country). A surface feature, or SS, match would be one in which the stories would share FORs as well as some entities (e.g., hunter vs sportsman; hawk vs. eagle). A higher-order relation, or HOR, match would be one in which both stories share FORs (but not surface features) as well as sharing a higher-order structure that relates the FORs (e.g., an attack is made but fails; this causes the entity being attacked to offer to provide an item to the attacker to help the attacker; this offer causes the attacker to be grateful and to promise not to attack again). See Gentner (1989) for a more complete discussion of these types of matches.

Gentner et al. (1993) found that a cue story that shared surface features with a base would be more likely to lead a person to recall that base compared to a cue that shared only first-order relations with the base. In addition, Gentner et al. found that a cue that shared a higher-order relation with a base would be more likely to lead to a reminding compared

to a cue that shared only lower-order relations. However, the effect due to higher-order relation overlap was much smaller than the effect due to surface feature overlap. Taken together, the results suggest that surface features play a large role in affecting access while the contribution of structural features is relatively minor.

However, other results indicate that structural features might play a larger role in access than suggested by Gentner et al.'s (1993) findings. Wharton, Holyoak, Downing, Lange, Wickens, & Melz (1994) suggested that a difficulty in the design used by Gentner et al. (1993) was that for any given cue story, there was at most only one base story that had a strong semantic similarity to the cue (i.e., in the surface similarity condition). In this case, the likelihood of accessing the base story might be fairly high regardless of the addition of structural similarity since there would be relatively little competition.

Wharton et al. (1994) argued that a more sensitive way to determine whether structural features would have significant impact on access would be to provide readers with two base stories that match a particular cue story in terms of surface features, but differ in the degree of structural overlap. In this situation, if the base story with greater structural overlap with the cue tends to be the one that is accessed by a person when reading the cue, this would suggest that structural features play a larger role in access than had previously been believed. Wharton et al. obtained such a result.

It is difficult to compare the results of Gentner et al. (1993) and Wharton et al. (1994) because the methodologies and materials differed. Gentner et al. used stories of about 75-110 words in length while Wharton et al. mostly used stories consisting of two sentences and a cue of one sentence (although in one experiment they used materials closer in length to those used by Gentner et al.) Participants in Gentner et al.'s study read the cue stories a week after reading the base stories; participants in Wharton et al. typically read the cue stories during the same experimental session with an interpolated task between the base and cue stories. There was only one base story that matched a given cue story in Gentner et al. while in Wharton et al. there were two base stories that matched a particular cue. The researchers also used different terminology in describing the relationships among the base and cue stories.

Besides the differences in methodologies making it difficult to compare the results of Gentner et al. (1993) and Wharton et al. (1994), there is a question about whether their manipulations provided a sufficiently systematic test of relative effects on access of surface and structural features. In both sets of studies, the manipulations were more of a "kind" than a "degree" (see also Seifert & Gray, 1990). For instance, consider a base story from Gentner et al. (1993) that had first-order relations overlap with a cue story. In a typical experiment such a story was recalled about 25% of the time when a participant read the relevant cue. Suppose the cue story is now changed to include some surface feature overlap between the base and cue while keeping the first order relations the same. Now access jumps to 70%. This kind of result is taken as evidence for the importance of surface features in access. However, another approach would be to manipulate the *number* of matches of a particular type

and examine whether an increase in matches leads to increased access. The present study takes this approach by manipulating the number of surface feature (entity) and first-order relation matches between a particular base story and a particular cue story.

Experiment

Method

Participants. Participants were 120 students at the Georgia Institute of Technology who participated in the experiment for course credit.

Materials. Sixteen base stories and 16 cue stories were used in the study. Fifteen of the base and cue stories were taken from Gentner et al. (1993) and were used as fillers. The base story of interest was a story about a doctor treating a patient with a tumor and was adapted from Gick and Holyoak (1983) and provided with an ending (see Table 1).

The cue story of interest was a story about a dentist. There were four versions of the dentist story produced by crossing the number of surface and FOR matches that a cue story would have with the base story of interest (see Table 2). Care was taken to make sure that various "content" words that appeared in the base story did not also appear in the various versions of the cue story (e.g., "simultaneously" is used in the base story while "at the same time" is used in the cue story).

The entity and FOR matches between the doctor story and the different versions of the dentist story are listed in Table 3. Note that a "match" does not have to be exact (e.g., "ray" matches with "laser," SEND matches with DIRECT). If the number of entities and FORs that are shared by the base story and the possible cue stories are counted, one will see that the range for each goes from one to three.

Figure 1 attempts to graphically illustrate the central higher-order structure of each story that connects the first-order relations using a notation consistent with that used by Gentner and her colleagues (e.g., Gentner, 1989). The higher-order relation (CAUSE) was held constant across the base story and the different versions of the cue story. This relation could be thought of roughly as: the desire to not affect something near a target causes simultaneous low-strength forces to be sent towards the target.

Procedure. During Phase 1 participants read 16 base stories and were told to try to remember the stories since they would be coming back the following week to read more stories. In addition, after reading each base story they rated it for imaginability and plausibility (each on a scale from 1 to 10 each time) in order to increase the depth of processing of the stories and also because this type of rating task was used by Wharton et al. (1994). During Phase 2, which occurred one week after Phase 1, participants performed an unrelated task for approximately 20 minutes and then read 16 cue stories. After reading a cue story participants were asked to write down any stories from the prior week of which they were reminded. They were asked to write a brief summary

that they felt would be sufficient to allow another person to unambiguously determine to which story they were referring.

Since 15 of the base and cue stories were chosen essentially randomly from those used by Gentner et al. (1993), little attention was paid to the reminders reported to those cue stories. Rather, the focus was on the likelihood

of a participant reporting being reminded of the doctor story as a function of which version of the dentist cue story was read.

Participants were randomly assigned to one of four conditions (30 participants per condition) defined by the relationship of the cue story to the base story.

Table 1: Base Story (The Doctor).

A tumor developed in Mr. Johnson's stomach and had to be removed. The doctor had available a kind of ray that could be used to destroy the tumor. If the rays reached the tumor at a sufficiently high intensity, the tumor would be destroyed. Unfortunately, at this intensity the healthy tissue that the ray passed through on the way to the tumor would also be destroyed. The doctor decided to use multiple ray machines to send low-intensity rays at the tumor simultaneously from different directions. In this way the rays would add up to a sufficient intensity to destroy the tumor without hurting the surrounding tissue.

Table 2: Versions of Cue Story (The Dentist).

3 entity matches, 3 FOR matches

The dentist needed to extract a small cyst from the gums of his patient. He was going to use a laser device that would cause the cyst to shrink. However, if the laser was used at the appropriate level, it would damage the area of the gums near the cyst besides shrinking the cyst itself. The dentist chose to use several laser devices each at a reduced setting and direct them at the cyst from a few positions all at the same time. The combined lasers hitting the cyst would be able to shrink it while the area near the cyst would not be affected since only a reduced level would be passing through any particular part of the gums.

1 entity match, 3 FOR matches

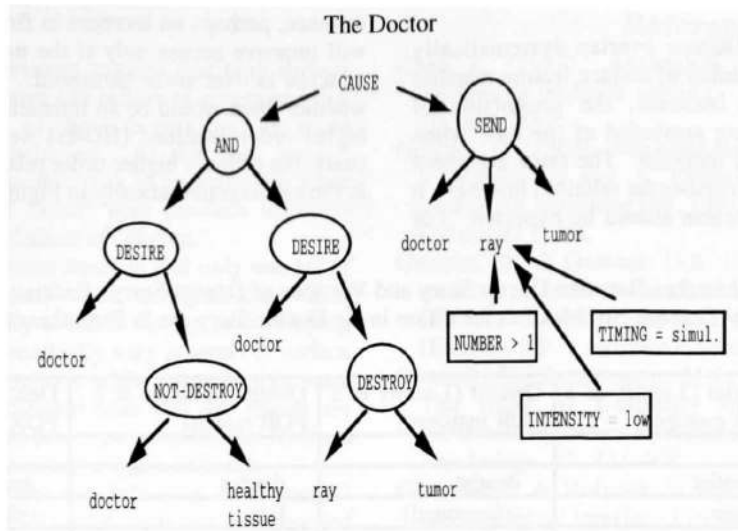
The dentist needed extract a tooth from his patient. He was going to use a device that sent out ultrasound that caused the tooth to fracture and then could be painlessly pulled. However, if the ultrasound was used at the appropriate level, it would damage the area of the gums near the tooth besides fracturing the tooth. The dentist chose to use several ultrasound devices each at a reduced setting and direct the ultrasound at the tooth from a few positions all at the same time. The combined ultrasound hitting the tooth would be sufficient to fracture it while the gums would not be affected since only a reduced level would be passing through any particular part of the gums.

3 entity matches, 1 FOR match

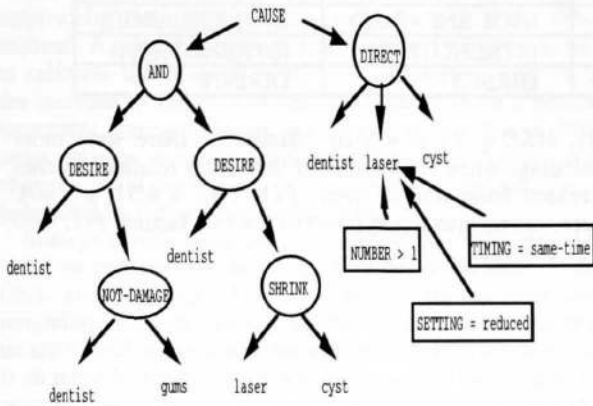
The dentist wanted to ensure a long life for his patient's false tooth. He was going to use a laser device that would strengthen the tooth. However, if the laser was used at the appropriate level, it would enlarge a cyst on the area of the gums near the tooth besides strengthening the tooth. The dentist chose to use several laser devices each at a reduced setting and direct them at the tooth from a few positions all at the same time. The combined lasers hitting the tooth would be sufficient to strengthen the tooth while the cyst would not be enlarged since only a reduced level would be passing through the cyst.

1 entity match, 1 FOR match

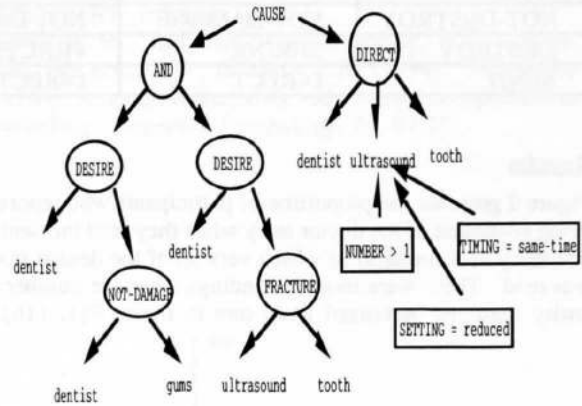
The dentist wanted to ensure a long life for his patient's false tooth. He was going to use a device that sent out ultrasound that would strengthen the tooth. However, if the ultrasound was used at the appropriate level, it would enlarge the area of the gums near the tooth besides strengthening the tooth. The dentist chose to use several ultrasound devices each at a reduced setting and direct them at the tooth from a few positions all at the same time. The combined ultrasound hitting the tooth would be sufficient to strengthen the tooth while the gums would not be enlarged since only a reduced level would be passing through any particular part of the gums.



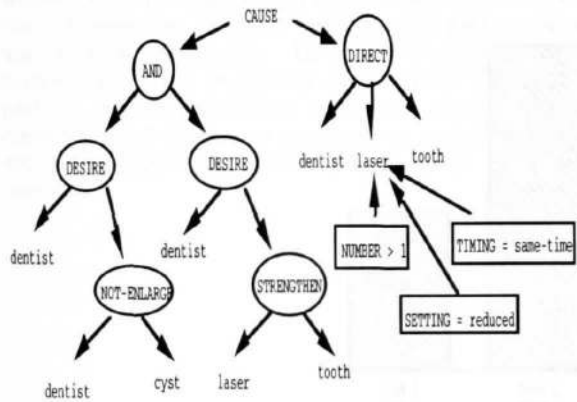
Dentist (3 entity matches, 3 FOR matches)



Dentist (1 entity match, 3 FOR matches)



Dentist (3 entity matches, 1 FOR match)



Dentist (1 entity match, 1 FOR match)

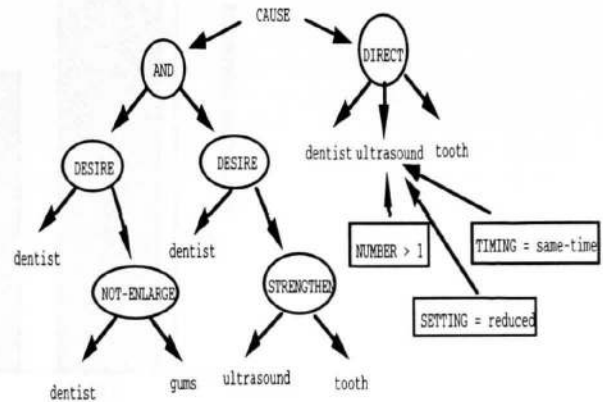


Figure 1: Graphical Illustration of Central Entities, FORs, and HOR for Each Story. Terms that are Circled Represent First-Order Relations. Terms that are in Boxes Represent Functions (Number, Timing, Intensity/Setting -- Not Discussed in this Paper, But Held Constant Across Stories). The HOR Shared by All Stories is CAUSE. Entities are in Lower Case.

Predictions. If surface feature overlap systematically affects access, then as the number of surface feature matches between a base and cue increase, the proportion of participants who report being reminded of the base when reading the cue story should increase. The same argument applies for structural feature (first-order relation) matches. It is unclear whether an interaction should be expected. For

instance, perhaps an increase in first-order relation matches will improve access only if the number of surface feature matches is over some threshold. In addition, it is unclear whether there would be an interaction based on whether the higher-order relations (HORs) were manipulated. In this study, the primary higher-order relation was held constant as is shown diagrammatically in Figure 1.

Table 3: Entity and FOR Matches Between Doctor Story and Versions of Dentist Story. Entities and FORs in a Dentist Story That are Not Matches for Those in the Doctor Story are in Parentheseses.

Doctor	Dentist (3 entity & 3 FOR matches)	Dentist (1 entity & 3 FOR matches)	Dentist (3 entity & 1 FOR match)	Dentist (1 entity & 1 FOR match)
Entities				
doctor	dentist	dentist	dentist	dentist
ray	laser	(ultrasound)	laser	(ultrasound)
tumor	cyst	(tooth)	cyst	(tooth)
FORs				
NOT-DESTROY	NOT-DAMAGE	NOT-DAMAGE	(NOT-ENLARGE)	(NOT-ENLARGE)
DESTROY	SHRINK	FRACTURE	(STRENGTHEN)	(STRENGTHEN)
SEND	DIRECT	DIRECT	DIRECT	DIRECT

Results

Figure 2 presents the proportion of participants who reported being reminded of the doctor story when they read the dentist cue story as a function of which version of the dentist story was read. There were more reminders when the number of entity matches increased from one to three, $F(1, 116) =$

6.01, $MSE = .23$, $p = .016$. Similarly, there were more reminders when the number of first-order relation matches increased from one to three, $F(1, 116) = 4.31$, $p = .04$. There was no interaction between the two factors, $F(1, 116) = .04$, $p = .85$.

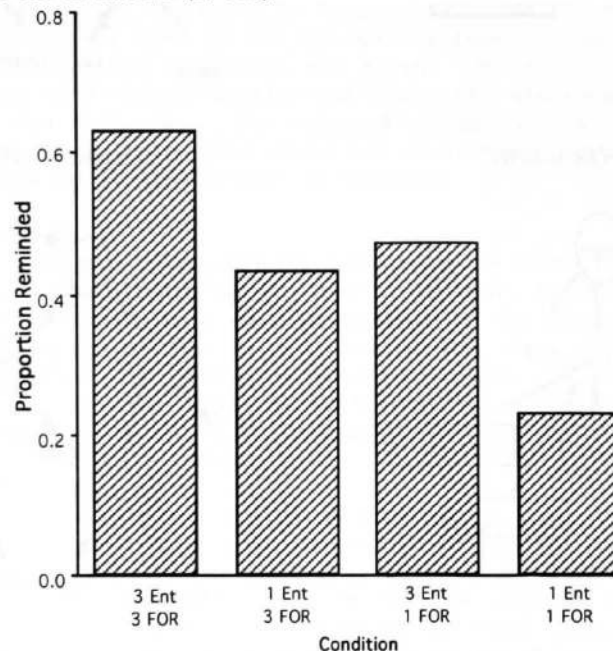


Figure 2: Proportion of Participants Reporting Being Reminded of Base Story as a Function of the Number of Entity (Ent) and First-Order Relation (FOR) Matches with Cue Story.

Discussion

The results from this experiment suggest that both surface features and structural features can influence access and that the relative contributions of these factors may be more similar than previously believed. At the very least it suggests that methodologies that seek to examine this issue through manipulations of "kind" may produce different results compared to manipulations of "degree."

One limitation of the current study is that only one set of stories (doctor and dentist) were manipulated. This limitation was due primarily to the difficulty in developing cue stories that could systematically vary in terms of surface features and first-order relations while other factors were controlled. However, additional base and cue stories are being developed in order to determine whether the findings obtained in the present experiment are generalizable.

A second limitation is that the definition of a "match" either between entities or first-order relations was decided intuitively by the experimenter. For instance, it was assumed that "tumor" matches "cyst" but does not match "tooth" (see Table 3). Such assumptions need to be tested empirically through similarity judgments or some other method. A related concern is that there was no obvious way to calibrate the strength of the manipulations. That is, is the increase in entity matches from one to three a similar increment compared to an increase in the number of first-order relation matches from one to three? Again, such changes could potentially be measured through similarity judgments by independent participants.

Analogical reasoning research in the early 1980's tended to focus on problem solving (e.g., Gentner & Gentner, 1983; Gick and Holyoak, 1983). One of the reasons that reminding measures have been the recent focus in research on analogical reasoning is that problem solving performance is an imperfect measure of whether a person has accessed a prior analog. For instance, a person could be reminded of a prior story or problem when working on a current problem, but then dismiss the prior story/problem as not being helpful for solving the current problem or fail to adapt solution from the prior story/problem (see Chen, 1995). In such a situation, problem solving performance would underestimate reminding. However, if problem solving studies can be run in parallel with "access" studies, then perhaps the results can be compared and the separate contributions of access and adaptation on analogical problem solving performance can be more accurately and reliably assessed.

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