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Leaping across the mental canyon: Analogical retrieval across disparate task domains

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Abstract

The present study provides evidence for *far analogical retrieval*, i.e., analogical retrieval across disparate task domains, as a result of analogical comparison. Participants read source stories, which were then retrieved after a filled delay through abstract letter-string cues that matched the relational form of key parts of stories. They then generated responses to an ambiguous letter-string analogy problem. Evidence was found for far analogical retrieval of higher-order relations because 1. comparison of letter-string analogies cued source stories specific to the relations showed in the letter-strings, and then 2. those same relations formed the basis for how subjects solved novel letter-string problems. The experiment offers support for the schema induction account of analogical retrieval, and suggests that people are more sensitive to relational structures than was previously thought.

Keywords: analogy; memory; reasoning; analogical retrieval; letter-string analogies

Introduction

Analogical retrieval leads to many important insights in science and design. It appears that these insights often emerge as a result of analogical retrieval from vastly different domains to one's present situation. Despite this, studies of schema induction in analogical thinking have primarily focused on the relatively narrow domain of semantic differences between stimuli, and cross-domain effects have been rare. The *schema induction account* of analogical retrieval (Gentner et al., 2009) suggests that cross-domain analogical retrieval should be facilitated by a comparison of analogues, by promoting a structural alignment of common relations. A more general principle, or *schema*, is then assumed to be available as a memory probe for future mapping in analogous situations. Evidence for the schema induction account was established through a comparison of target analogues, i.e., *late analogical abstraction*. This effect has been demonstrated in both studies of cued-retrieval (Gentner et al., 2009) and problem solving (Kurtz & Loewenstein, 2007).

The effect was demonstrated in the domain of negotiation with a controlled memory set (Experiment 4; Gentner et al., 2009). Undergraduates read seven negotiation scenarios, with only one containing the target negotiation principle. After 30 minutes of a filled delay, half of the participants were given two example cases of a certain negotiation principle and were explicitly asked to compare them, noting the key parallels. The other half were given the two cases to read separately. They were subsequently asked to recall a source case that best matched the two target comparison cases. Participants that explicitly compared target cases were significantly more likely to retrieve the source cases than participants that read the target cases separately. It appeared the explicit comparison made the abstract schema directly available as a retrieval cue to the original story.

The main limitation to this literature is that most studies have only varied what Barnett and Ceci (2002) call the *knowledge* domain of the analogues, despite the possibility for retrieval across different *task* domains. Inherent to the schema induction account is the assumption that analogical comparison highlights relational structure regardless of surface features. That is, it allows a *cross-domain* mapping. However, as information is often relevant across different tasks, it is important to understand whether and how cross-task retrieval can occur. This is an important hole to fill in the literature.

In addition to investigating whether we can elicit remindings across task domains, we can further investigate whether the cross-task commonalities that can serve as the basis for analogical remindings are limited to specific levels of abstraction. That is, the present study investigated retrieval rooted in common surface features, first-order relations, and higher-order relations (respectively). Including these different levels of abstraction as controls for each other in the analyses ensured a more adequate test of analogical retrieval. That is, a retrieval based in surface features across task domains without relational controls is not very surprising, given people's sensitivity for retrieval of surface features (Gentner, Rattermann, & Forbus, 1993). Further, retrieval of relational content across task domains is more valid when controlled for by the possibility of a surface feature retrieval. That is, it is more likely that a source story was retrieved because of a relational match to the letter-string cue when a surface feature alternative was also possible.

The schema induction account assumes that analogical comparison abstracts one's stimulus representation, i.e., relational commonalities are highlighted, and mismatches of features are ignored. To further test this account it is important to examine the representation formed from the comparison independently from the test of retrieval. Gentner et al. (Experiment 1; 2009) used a post-retrieval transfer task to confirm participant representations, but scoring was based on how well participants' descriptions matched a target schema, not directly analyzing the schema used by the participants. Hofstadter's (1995) letter-string proportional analogies could be used as a clearer way of determining the type and level of representation a person currently has. For instance, if asked "Suppose the letter-string abc were changed to abd; how would you change the letter-string mrrjjj in 'the same way'?" (Hofstadter, p. 238), one answer could be *mrrkkk*, if succession relation is used because *k* follows *j*, just as *d* follows *c*. A higher-order response represents *abc* as 1-2-3 and *abd* as 1-2-4, as per their order in the alphabet. The quantity of different letters in the string *mrrjjj* can also be represented numerically as 1-2-3. This higher-order relational mapping leads to the inference that the fourth term in the analogy should be a quantity successor of *mrrjjj* that can be numerically represented as 1-2-4, i.e., *mrrjjjj*.

Present study

The present study extends the late analogical abstraction effect (Gentner et al., 2009) to investigate far analogical retrieval, i.e., retrieval across disparate task domains. Letter-string analogies were used as cues to retrieve story narratives (see Figure 1). This will be referred to as *far analogical retrieval*, as analogues are retrieved across *task* domains, a significantly more disparate – and conceptually *far* – retrieval than in previous studies. Each comparison cue had one analogous initial source story that matches the underlying schema. A pilot study (Dekel, 2016) showed that these source stories could be retrieved by analogous stories, replicating the late analogical abstraction effect (Gentner et al.). In the present study, correct source story retrieval after the letter-string comparison provided evidence for far analogical retrieval. A subsequent transfer task with a novel letter-string analogy determined participant schema representation for each level of abstraction (surface features, first-order relations, and higher-order relations).

The main hypothesis was that participants that compare two target letter-string analogies that share a particular schema would retrieve the source story that emphasizes the same schema, significantly more than participants comparing target stories that do not share this schema. For the transfer task, it was hypothesized that participants will respond to the transfer task according to their schema condition (see Figure 4).

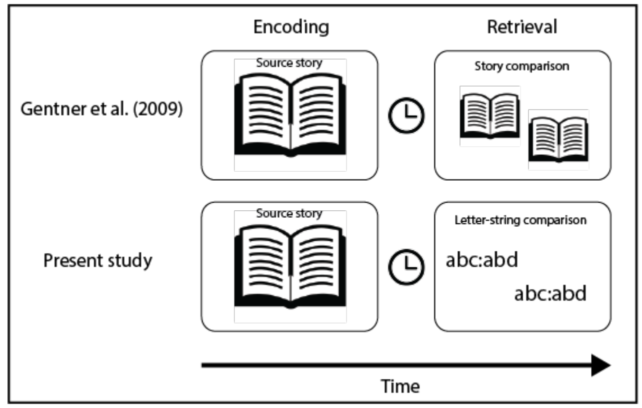

Figure 1: Comparison of simplified designs in Gentner et al. (2009) and the present study. While participants in Gentner et al. retrieved source stories from a comparison of *story* cues, participants in the present study retrieved source stories from a comparison of *letter-string* cues.

Method

Participants

One hundred and eighty-one first-year undergraduates from the University of Sydney subject pool were recruited online, and were given course credit for their participation. Participants were randomly allocated to one of three schema conditions: surface schema, first-order relational schema, higher-order relational schema. One participant did not complete the first filler task and another did not complete the analogy example page (both due to computer error), so their data was excluded from the analysis of retrieval rates.

Materials

The experiment was completed online and all materials were webpages coded with HTML and JavaScript.

Source stories The three source stories, shown in Table 1, were designed to differ in semantic content, but be equivalent in structure and length. Each story presented an initial conflict, and a subsequent resolution. Critically, the resolution of each story also provided the information that made up the target schema for that story, which would then either match or mismatch with the later letter-string analogies. The first story schema is simply *changing an E to an F*. It is considered a surface story because its similarity to the later cues is based on an identical change. The second story schema is *succession* (of Valerie by Sylvia), considered to be a first-order relational story because it is related to the later cues by virtue of one relation (succession) and no surface features. The third story schema is the correspondence of quantity to an order (number of staff to a day's order in the week), considered to be a higher-order story because it relies on a mapping of first-order relations. That is, numerical representation connects the first-order relational structure of two types of succession: ordinal succession, as in the order of days in the week, and quantity succession, as in the number of staff allocated.

Table 1: Source Stories and Explicit Principles.

Schema condition	Story text	Explanation text
Surface	John is an owner of a small-town computer company and wanted to advertise his company to the town. He printed out some flyers with large font size to put up. However, there was a typographical error in the flyers, with the title printing out as 'Elash Computers' instead of 'Flash Computers', which John knew would confuse potential customers if put up around town. As such, he had to rewrite the company name for the posters, changing the 'E' to an 'F', and printing them again. There was only a typo in the word 'Elash', so only the letter 'E' was changed from the letter 'E', to the letter 'F', correcting the word 'Elash' to 'Flash'.	Both pairs rely on the same rule: Change E to F.
First-order relation	Jerome is an advisor to the King of a large nation and wanted to confirm the successor to the throne. He thought of Valerie, who was the king's eldest daughter. However, the advisor found out that despite being the next in line to the throne, Valerie had run away to a mountain town because she did not want to take on the responsibilities associated with being a Queen. As such, he worked out that Sylvia should be the next in line to the throne as she is the second-oldest sibling. The order of succession in the kingdom is found by birth order, so if the first born child is not able to uphold the throne, then the second born is next in line.	Both pairs rely on the same rule: Succession. For example: Triangle changes to square because of the number of sides, and G to H because of alphabetic order.
Higher-order relation	Julia is a manager at a local information centre and wanted to staff her centre efficiently. She usually has about three people working every day. However, the number of visitors to the centre increases consistently each day, with almost no visitors on Mondays and peak number of visitors on Sundays, so most days the centre is either overstaffed, or understaffed. As such, she decided that she will roster on an amount of staff that corresponds with the order of that day in the week. The centre will have one staff member on Monday, being the first day of the working week, two on Tuesday, and so on, with seven people working on Sundays.	Both pairs rely on the same rule: Order corresponds to quantity. For example: E (fifth in the alphabet) changing to F (sixth in the alphabet) = five symbols (letters or shapes) changing to six symbols.

Letter-string analogue comparison Participants received one of three pairs of proportional letter-string analogies to compare, as shown in Figure 2. In the figure, all three pairs are presented together to facilitate comparison of the differences between each pair. The first pair was designed to induce the surface schema, the second the first-order schema, and the third the higher-order schema. The same basic structure and symbols (letters and shapes) were used for all three of the comparisons. Below this comparison, participants read a short explanation of the target principle, shown in Table 1 and then completed a short test of the principle.

Procedure. The experiment was run as an online study through a series of webpages. Participants read three one-paragraph narratives and typed how each story was resolved. They then completed two minutes of an unusual uses task (Diamond, 2013) and a page designed to inform and train participants about the structure and function of proportional analogies.

Participants then completed the comparison task, as per their schema condition, and on the subsequent page were asked to retrieve the source story that matched the comparison they just did. They then completed two minutes of a new unusual uses task. Participants then responded to the letter-string proportional analogy *Suppose that the letter-string A B C was changed to A B D; how would you change the letter-string C S S N N N in the same way?* Following this, participants rated some prototypical responses to the analogy, and then a subsequent follow-up page asking participants to indicate the extent to which they used any of the letter-strings or stories when generating the letter-string analogies. Figure 3 shows this procedure.

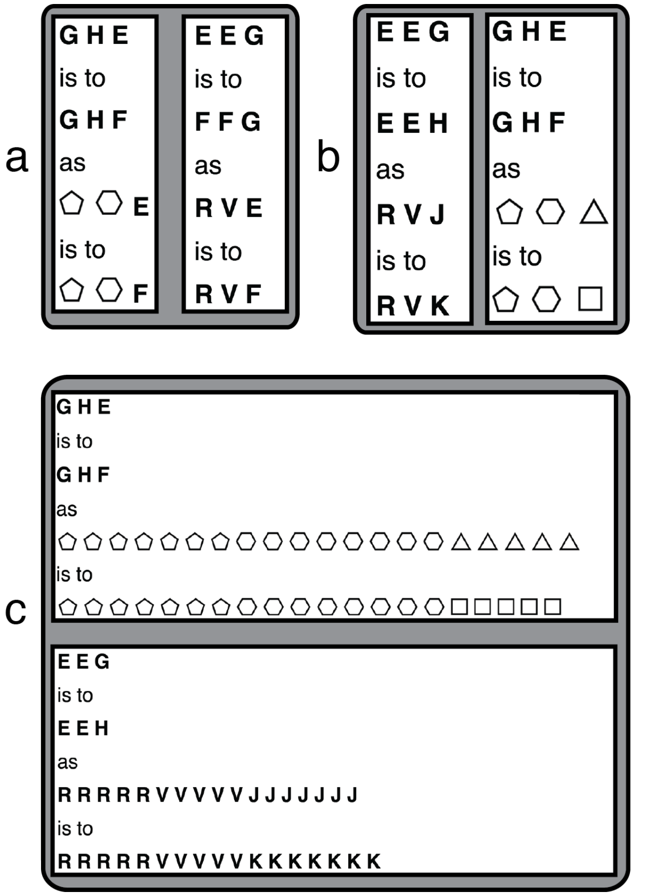

Figure 2: The three pairs of comparison cues. The surface comparison (a) makes it apparent that the critical change is that from *E* to *F*, regardless of position in the string or presence of shapes. In the first-order relational schema comparison (b) the increase in the letters' alphabetic order and shape's number of sides, expresses the concept of succession. The higher-order relational schema comparison (c) connects the alphabetic succession of the initial strings to the ordinal succession of the latter shape or letter strings. The higher-order relationship *numerical representation* connects these two forms of succession.

Results

Far analogical retrieval

A chi-square test was conducted for the cross-tabulation of retrieval by schema condition (Table 2). The retrieval variable had four levels: null retrieval, surface story, first-order story, and higher-order story. Schema condition had three levels: surface schema, first-order schema condition, and higher-order schema condition. The overall effect was significant, χ^2 (6, N = 179) = 46.55, $p < .001$, suggesting an association between people's schema condition and story retrieval rates. To investigate the specific effects, the conditions were collapsed into 2 x 2 tables for each predicted effect. For each effect, schema condition was recoded into a dichotomous variable of those in the target schema condition and those that are not. Retrieval condition was recoded into a dichotomous variable of those that retrieved the target schema story and those that did not.

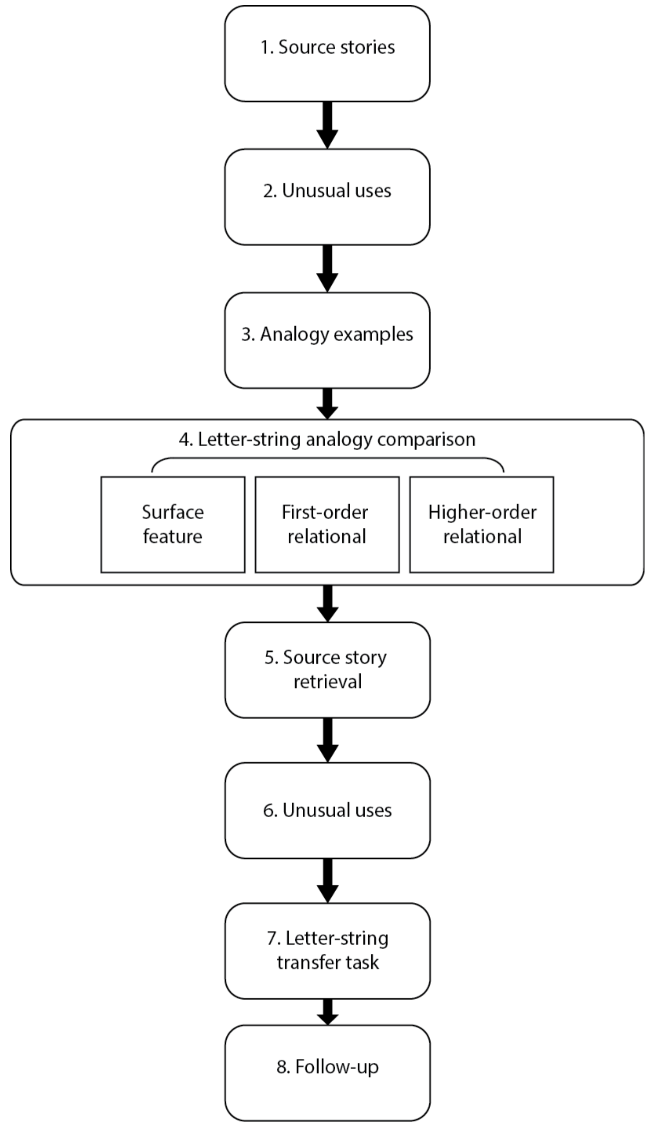

Figure 3: Experimental procedure.

Participants in the surface schema condition retrieved the surface schema story (86.4%) significantly more than those not in the surface schema condition (40%), χ^2 (1, N = 179) = 34.51, $p < .001$. Those in the first-order schema condition retrieved the first-order schema story (31.1%) significantly more than those not in the first-order schema condition (13.6%), χ^2 (1, N = 179) = 7.91, $p < .001$. Those in the higher-order schema condition retrieved the higher-order schema story (37.3%) significantly more than those not in the higher-order schema condition (10.8%), χ^2 (1, N = 179) = 17.6, $p < .001$. The main hypothesis was thus supported by these results as a comparison of letter-string analogies facilitated correct retrieval of source stories with the same underlying schema.

Table 2: Frequency of Story Retrievals by Schema Condition.

	Schema Condition			
Story retrieval	Surface	First-order	Higher-order	Total
Surface	51	28	20	99
First-order	5	19	11	35
Higher-order	1	12	22	35
Null	2	2	6	10
Total	59	61	59	179

Transfer response

Responses were coded through the schema they presumably expressed. As in Burns (1996), letter-string responses generated by two or fewer participants were collapsed into the category *Other*. Figure 4 shows the structural hierarchy of the three prototypical responses to the letter-string analogy task. Participant response of *DSSNNN* was considered a *Surface* response, since it only takes into account the *C* changing into *D*. Participant responses of *CSSOOO*, *CSSNNO*, *CSTNNO* were collapsed into category *First-order*, since they all use the first-order principle of succession. Participant response of *CSSNNNN* was considered *Higher-order*, since it takes into the higher-order correspondence of numerical representation. Table 3 shows the frequencies of these responses for each schema condition.

A chi-square test was conducted of letter-string response by schema condition. Letter-string response had four levels: surface, first-order, higher-order, and other. Schema condition had three levels: surface schema, first-order schema condition, and higher-order schema condition. The overall effect was significant, χ^2 (6, N = 176.04) = 176.04, p < .001, suggesting an association between people's schema condition and letter-string response rates. To probe the specific effects, the conditions were collapsed into 2 x 2 tables for each predicted effect. For each effect, schema condition was recoded into a dichotomous variable of those in the target schema condition and those that are not. Letter-string response condition was recoded into a dichotomous variable of those in that generated the target letter-string response and those that did not.

The surface schema response was generated significantly more by those in the surface schema condition (70%) than those not in the surface schema condition (0.03%), χ^2 (1, N = 181) = 94.12, p < .001. First-order schema responses were generated significantly more by those in the first-order schema condition (82%) than those not in the first-order schema condition (26.7%), χ^2 (1, N = 181) = 49.91, p < .001. The higher-order schema solution was generated significantly more by those in the higher-order schema condition (60%) than those not in the higher-order schema condition (0.006%), χ^2 (1, N = 181) = 108.16, p < .001. As per the initial hypothesis, the selective generation of letter-string responses were congruent with one's schema condition.

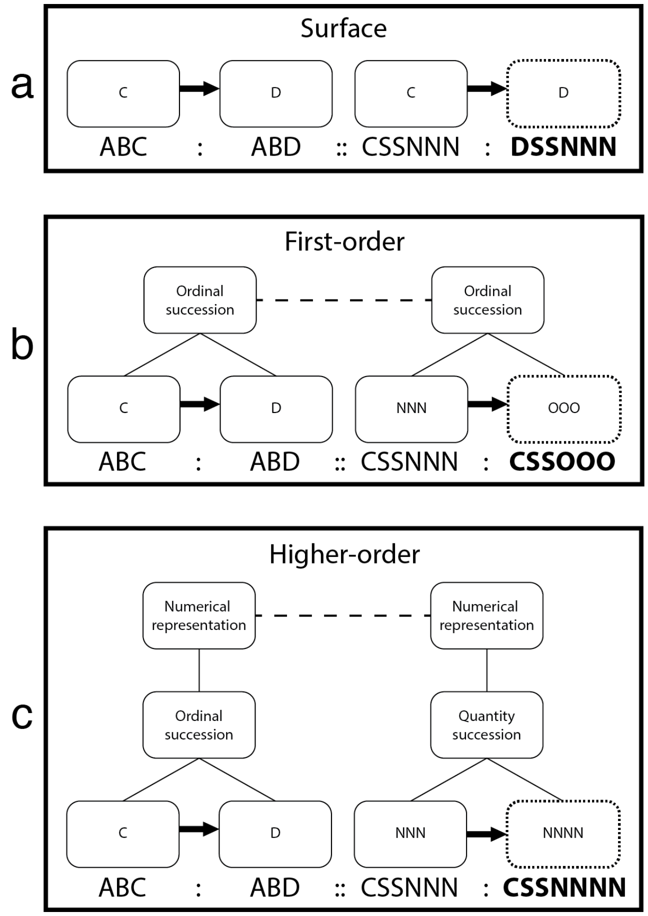

Figure 4: A representation of three responses to the analogy ABC:ABD::CSSNNN:?. The surface response (a) considers the change from C to D, per se, so merely changes the C in CSSNNN to a D. The first-order relational response (b) considers the change from C to D as one of ordinal succession, as per their order in the alphabet. Since C is the last term in the string, NNN, as the last string of CSSNNN, is also changed to its successor in the alphabet: OOO. The higher-order response (c), on the other hand, considers the entire string and each letter's position in the alphabet, representing ABC as 1-2-3 and ABD as 1- 2-4. The change is still an ordinal succession, as C and D are successors in the alphabet, but the letters have been represented numerically. The quantity of different letters in the string CSSNNN can also be represented numerically as 1-2-3. This numerical representation allows this first-order relation to map to the ordinal succession relation of ABC. This higher-order relational mapping leads to the inference that the fourth term in the analogy should be a quantity successor of CSSNNN that can be numerically represented as 1-2-4, i.e., CSSNNNN.

Table 3: Frequency of Letter-string Responses by Schema Condition.

	Schema Condition			
Letter-string response	Surface	First-order	Higher-order	Total
Surface	42	4	0	48
First-order	11	50	21	77
Higher-order	0	1	36	35
Other	7	6	3	21
Total	60	61	60	181

Discussion

Successful cross-domain analogical retrieval is rare. Despite this, the results of the present study provide evidence that schema induction can facilitate far analogical retrieval, i.e., analogical retrieval across disparate task domains. The effect was found for surface, first-order relational, and higher-order relational schemas. As well as providing support for a schema induction account of analogical retrieval, the results of the present study also address the three limitations in this literature were identified above. First, there is now evidence that analogue comparison can facilitate analogical retrieval across stimuli that share no surface features, except for the presence of alphabetic characters. Second, while prior research usually neglects to consider different levels of abstraction in analogical retrieval, the present study investigated retrieval of surface features, first-order relations, and higher-order relations. Third, the present study used a transfer task to probe the way participants were representing their schema.

The main limitation of the present study is that the apparent *retrieval* effects, might actually be *mapping* effects. The combination of a relatively small number of source stories and short delay might mean that participants were considering each source story as a potential match to their comparison cue and then actively deciding on the best perceived mapping. Future replications of the present study should therefore include a larger set of source stories and a longer delay between source story encoding and the retrieval phase. Further, it is not clear what exact role the explicit principle played in cuing the source stories. In general, it seems that explicit principles are not *sufficient* to induce a schema, but do seem to *facilitate* induction. Thus, future replications should systematically manipulate the explicit principle and its inclusion with comparison to determine its role as a retrieval cue for the far analogical retrieval.

Relational priming is sometimes used to explain analogical retrieval effects (Holyoak, 2012). It is unlikely to explain all of the present retrieval results because most relational priming effects are demonstrated using individual word pairs of highly familiar relations. There is little evidence to suggest that a higher-order relation can be primed in the same way, and the participants in our study had little to no previous experience with the specific relations presented to them. Further, pilot data (Dekel, 2016) shows that changing the explicit principle in the higher-order condition to a more specific form does not significantly impact retrieval rates. This suggests a lesser role of explicit principle wording in any potential priming.

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