Exploring Analogical Asymmetry

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Abstract

In similarity comparisons, people often show a preference for one direction over the other. Bowdle and Gentner (1997) proposed the *base systematicity advantage* account to explain this—namely, that people prefer similarity comparisons in which the more systematic item serves as the base. Results from a series of studies supported this account. However, the studies only covered literal similarity comparisons. The question of whether analogical comparison follows the base advantage pattern remained untested. Therefore, the present study investigated this question for analogical comparisons. We tested the prediction that a comparison will be preferred when the more systematic item serves as the base. This prediction was supported. We also found support for a further prediction: namely, that inferences were projected from the systematic to the less systematic passage. Further, these inferences spontaneously arose even when not requested. The overall results from these processes are consistent with the base systematicity advantage account.

Keywords: Psychology; reasoning; representation; knowledge representation

A key assumption among analogical researchers is that analogical mapping often leads to the projection of inferences from one analog to the other (Bowdle & Gentner, 1997; Clement & Gentner, 1991; Doumas & Hummel, 2013; Gentner, Rattermann, & Forbus, 1993; Holyoak & Koh, 1987; Holyoak & Thagard, 1989; Keane, Ledgeway & Duff, 1994; Markman, 1997). In this research, we test a key prediction of structure-mapping theory—that (assuming equal familiarity) the preferred direction of comparison is that the more systematic item should serve as the base (Clement & Gentner, 1991; Falkenhainer, Forbus, & Gentner, 1989; Forbus, Gentner, & Law, 1995; Forbus, Ferguson, Lovett, & Gentner, 2017; Markman & Gentner, 1997). A secondary goal is to follow up a surprising result that we obtained in a pilot study: namely, that, when processing an analogical pair, people fluently draw inferences without recognizing them as such.

Previous Accounts of Comparison Asymmetries

When making comparisons between two items, it is common for people to prefer one direction over the other. For instance, most people would prefer the statement "A heart is like a pump" over "A pump is like a heart." A number of different accounts have been proposed to explain comparison asymmetries. In Tversky's (1977) feature contrast model, similarity between two items increases as a function of their common features and decreases as a function of their distinctive features. In this account, asymmetry arises because the distinctive features of the target are weighted more heavily than those of the base. Therefore, similarity is maximized when the item with more (and more salient) distinctive features serves as the base. For example, in one study, comparisons such as Mexico is like USA, in which the country with more high-salient distinctive features (the USA) served as the base, were considered more similar than the reverse comparisons (e.g., USA is like Mexico). Gleitman, Gleitman, Miller and Ostrin (1996) took a different approach, centering their account around the notion of a cognitive reference point. The reference point is the more prominent or important item and is preferred in the complement or base position (e.g. "Vermillion is like red"). This account is not specific to comparison, but applies to directional asymmetry in various kinds of predicates: for example, people prefer "John met the Pope" over "the Pope met John."

Base Systematicity Advantage Account

Bowdle and Gentner (1997) proposed the base systematicity advantage as an account of comparison asymmetry. This account follows from structure-mapping theory (Falkenhainer, Forbus & Gentner, 1989; Gentner, 1983, 2002, 2010; Markman & Gentner, 1997) and from pragmatic principles of communication. A key idea in structure-mapping is systematicity-- the extent to which higher-order, constraining relations (such as cause or prevent) govern lower-order relations. There is much evidence that systematicity influences which predicates enter into the interpretation of a comparison and which inferences are drawn (Clement & Gentner, 1991; Gentner & Toupin, 1986; Markman, 1989).

Bowdle and Gentner (1997) therefore proposed the base systematicity advantage account—that people will prefer comparisons where the more systematic of two items serves as the base, since that favors drawing useful inferences from

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base to target[1]. The base systematicity advantage account also draws on the pragmatic maxim of informativity (Grice, 1975) and Havilland and Clark's (1975) given-new principle. The idea is that people should prefer the more informative direction when comparing two items—that is, the direction that maximizes the likelihood of inference projection. Since inferences are projected from the more systematic item to the less systematic item, the more systematic item should be preferred as the base. Specifically, the base systematicity advantage predicts (1) directional inference projection from the more systematic to the less systematic item and (2) directional preference as to which comparison direction is more informative. Bowdle and Gentner (1997) carried out a series of experiments that showed support for the base systematicity advantage. In their experiments, participants read pairs of similar stories. In each pair, one story (the Standard) had a systematic causal structure linking the events, and the other (the Variant) did not. Participants rated the direction "Variant is like standard' as more informative than the reverse direction. Further, when asked to generate inferences for one story based on the other, they made more inferences from the Standard to the Variant than in the reverse direction[2].

Bowdle and Gentner's results provided support for the base systematicity advantage account. However, the comparisons were literal similarity comparisons. Thus, it remains untested whether the base systematicity advantage also holds for analogical comparisons. According to structure-mapping, the same process of structural alignment and inference underlies both overall similarity comparison and analogical comparison (Gentner, 1983; Gentner & Markman, 1997; Markman and Gentner, 1993). Thus, the present work aims to test whether the systematicity advantage predicts directional preference and inference in analogical comparisons.

The Present Research

In order to study directionality in analogical comparisons, we adapted pairs of short stories from existing literature on analogy as experiment materials (Gick & Holyoak, 1980; Gentner, Rattermann, & Forbus, 1993; Day & Gentner, 2007; Trench & Minervino, 2015). The story pairs were high in relational similarity while low in surface similarities (i.e., characters, settings). We designated one standard story and one variant story for each story pair. Each standard story contained a causal pivot -- a sentence that causally connects the contents before and after it. To create systematicity imbalance, we replaced the causal pivots in the variant stories with a new sentence that was consistent with the overall plot, but that did not include the higher-order causal relationship. Thus, the variant stories were less systematic than the standard stories. (See Table 1 for a sample story pair and Commonalities response). In the following sections, we refer to comparisons in the direction Variant is like Standard (the predicted direction) as *forward comparisons* and comparisons in the opposite direction, Standard is like Variant, as *reverse comparisons*. The key initial prediction was that the base systematicity advantage would predict directional preference for these analogical pairs. That is, people should prefer the more systematic case as the base of an analogical comparison.

Following Bowdle and Gentner (1997), people were given pairs consisting of two analogical stories—a Standard and a Variant--and were asked to say which order of comparison they preferred--Variant is like Standard or Standard is like Variant. Because structural alignment is a critical first step for noticing the systematicity imbalance, we took steps to facilitate structural alignment. We divided the stories into paragraphs and presented corresponding points side by side. In addition, for each story pair, participants wrote out the commonalities prior to stating their preferred direction of comparison. A pilot study using this methodology bore out our key prediction that people would prefer the more systematic case as the base, providing encouragement for the full study.

However, this pilot study also revealed a surprising pattern: when asked to list commonalities, many subjects included inferences from the more systematic story to the less systematic story as though they were commonalities. While it is not surprising that inferences would be made in this direction, we did not expect people to list them as commonalities. That people did so suggests that the inferential process was sufficiently fluent as not to have been noticed. Thus, a second goal of the current study was to follow up this phenomenon, and test whether we would again see inferences listed as commonalities with materials more strictly controlled[3]. Therefore, in the current study, we coded participants' responses to the Commonalities question not only for the commonalities listed but also for whether they included any analogical inferences. We also scored the content of any inferences—whether they conveyed the predicted inference (the causal pivots) that were presented only in the Standard, or some other information.

Following Bowdle and Gentner (1997)'s account, the current study aimed to test the prediction that forward comparison (wherein the more systematic item serves as the base) will be judged as more informative than the reverse comparison. In addition, following up our pilot study, we asked whether participants would include in their Commonalities listings causal inferences projected from base to target.

[1] For example, "A heart is like a pump" is generally preferred over the reverse because the known causal structure of pumps allows inferences about hearts.

[2] As predicted, these predictions held only if the two stories were structurally alignable. If the base-target pairs were scrambled, the results were random.

[3] For example, we noted that in some cases, inferences were being made within a single story, rather than projected from one analog to the other; we redesigned the materials to avoid this kind of inference.

Method

Participants

A total of 91 undergraduate students at a Midwestern university completed the study in person in the laboratory. They received course credit for their participation.

Materials and Design

The task set consisted of five pairs of analogous stories, which had parallel relational structures but different surface content. Each task pair included two analogous stories: a Standard and a Variant. Each Standard contained a causal pivot—a sentence that stated the causal link between the events in the story. In the Variants, each pivot was replaced by a sentence that fitted the overall plot. In addition, two distractor pairs and one catch pair were interspersed among the task pairs. These had story pairs that were low in both relational similarity and surface content. The distractors were added to forestall participants from developing expectations about plots about the task pairs. In the catch-trial stories, we embedded the sentences that instructed participants to choose specific scores as an attention check. (i.e., "This sentence is not part of the story, it is to check if you are reading carefully: please choose one and six for this question."). Participants should choose the scores (one and six) according to the sentences if they were paying attention. All participants passed the catch trial.

Each pair was presented on a separate webpage, with the story on the left labeled "Story A" and the one on the right "Story B". The left-right order of Standard-Variant presentation was randomized across subjects and story pairs. For each story pair, there were two versions: one with the Standard labeled as "Story A" and the Variant as "Story B", and the other with the Standard as "Story B" and the Variant as "Story A". Each participant saw one of the two versions. The number of participants who saw each version was roughly equal. To facilitate participants' alignment of the stories, within each pair, we divided the stories into three sections, with corresponding sections aligned side by side. The order of story pair presentation was randomized. The design was within-subject: order of presentation – Standard first vs. Variant first.

Procedure

Instructions and Practice Participants first read instructions on definitions of analogy and how analogous situations can inform each other. They then read a pair of short example stories and were asked to practice writing down the ways in which two stories were similar/analogous to each other. Following the exercise, they saw an example answer to the Commonalities response question. Then they saw an example Directional Preference question and were asked to answer it according to their own intuition. After the example trial, participants completed three practice trials. No feedback was provided for these trials.

Main Task Participants then went on to the main task. For each story pair, they provided a Commonalities response and a Directional Preference rating.

Commonalities response. After each story pair, participants were asked "In what ways are the plots of A and B similar/analogous to each other? Please list the ways in which they are analogous to the best of your ability." They were provided with a blank text box for free responses. The stories were available for them to refer to during the task.

Directional Preference rating. Immediately following the Commonalities response, participants completed the Directional Preference rating. They were asked, "Which of the following statements is more informative?". They gave their responses on a 6-point informativity scale, with "Story A is like Story B" at 1, and "Story B is like Story A" at 6. Thus, a higher score indicates a greater preference for "Story B is like Story A" as more informative. (As noted earlier, the assignment of labels was counterbalanced.)

Scoring

Directional Preference For each story, we recorded participants' directional preference scores. Scores ranged from 1 to 6, with 3.5 as the midpoint score indicating indifference. Thus, in trials where the Standard was Story A (and the Variant was Story B), a score of 4, 5, or 6 indicates a preference for the forward direction (Variant is like Standard), while a score of 1, 2, or 3 indicates a preference for the Standard is like Variant order. Reverse coding was applied in trials where the Standard was Story B.

Response Coding Two coders, both blind to participants' directional preference responses, independently scored the Commonalities responses for *Content Alignment* and *inference* (Cohen's kappa = 0.74, $p < .001$). To achieve consistent coding, we provided explicit templates that laid out the content required for each story pair for each measure. For *Content Alignment*, the template included four key common content points for each story pair, for a maximum of four points. For *Inference,* we coded for the causal pivot that was only present in the standard. Thus, the maximum Inference score is one. For a given story pair, each coder was presented with the coding templates and judged each response on *Content Alignment* and *Inference*.

Results

Prediction 1 – Directional preference

Participants rated the forward direction (Variant is like Standard) as more informative than the reverse direction. The mean preference for the forward order was $M = 3.85$, $SD = 1.42$, on a scale of 1 to 6, where 6 = preference for the forward direction. This overall forward directional preference was greater than the mid-point rating (i.e., 3.5), $t(90) = 4.19$, $p < 0.001$. We also tested, for each story pair, whether the mean preference was greater than the mid-point rating. For four of the five story pairs, the mean preference ratings were greater than 3.5: S2: M = 3.87, SD = 1.37, $t(90) = 2.55$, $p < 0.01$; S3: M = 3.89, SD = 1.50, $t(90) = 2.49$, $p < 0.01$; S4: M = 3.84, SD = 1.39, $t(90) = 2.30$, $p < 0.05$; S5: M = 3.84, SD = 1.50, $t(90) = 3.11$, $p < 0.01$. Story pair 6 showed a trend in the predicted direction: M = 3.69, SD = 1.31, $t(90) = 1.40$, $p = 0.08$. Overall, as predicted, the more systematic item was preferred to be the base of the comparison.

Prediction 2 – Inferences

Most participants showed evidence of analogical inference. 89% of the participants included the causal pivot inference among their commonalities for at least one pair during the study, and about a third of the participants (33%) did so for three or more of the five story pairs (Table 2). Across story pairs, the percentage of participants who made at least one causal inference ranged from 32% to 51%. Inferences in the reverse direction (from the Variant to the Standard) did show up in participants' responses. However, there were very few of them compared to the causal pivot inferences.

A further analysis explored whether those who included the causal inference in their response were likely to show a preference for the forward direction. A binomial test across the five story pairs showed that participants who included the causal inference in their responses were more likely to prefer the forward direction than chance (0.5): CI 95% [0.96, 1], $p<0.001$.

Content Alignment

The mean *Content Alignment* score was M = 2.69, SD=1.10 (out of a maximum of 4). Based on the critical role of structural alignment in inference projection and directional preference, we expected that people who achieved a full structural alignment between the stories would be those most likely to prefer the forward direction. Therefore, we examined correlations between *Content Alignment* scores and Directional Preference scores. To carry out the analyses, we calculated by-participant means for Content Alignment scores and for Directional Preference scores across the five story pairs. The results showed a trend for the predicted correlation: $r(89) = 0.18$, $p = 0.09$.

We also asked whether high performance on *Content Alignment* would predict the inclusion of the causal inference. Here the prediction is less clear. On the one hand, we might expect that people who successfully aligned to two stories would be more likely to draw the analogical inference. On the other hand, these participants might also be those most likely to have attended to the instruction to write *commonalities*. These more attentive participants might have realized the inferences were actually not present in both stories and omitted them from their commonality response. Nonetheless, we carried out a correlation between the by-participant mean score for *Content Alignment* across the five story pairs and their total number of inferences across the five story pairs. A Pearson correlation test showed a trend that higher performance on *Content Alignment* was associated with fewer inferences about the causal pivot: $r(89) = -0.2$, $p = 0.06$—suggesting that the more attentive participants may have recognized the inference as such, and therefore omitted it from the commonality response.

General Discussion

The main goal of the current study was to test the base systematicity advantage as an account of asymmetries in analogy, following Bowdle & Gentner(1997)'s findings for literal similarity. According to this account, (1) people should rate the forward direction (i.e., Variant is like Standard) as more informative than the reverse direction for the analogous pairs; (2) people should draw inferences, if any, from the more systematic Standard to the less systematic Variant. These two predictions were borne out. Participants showed the predicted directional preference: The more systematic item was preferred to be the base, with the less systematic item as the target. Thus, analogical comparisons showed the same directional preference as literal similarity comparisons. This parallel adds support to the idea that analogy is a form of similarity comparison and that both follow the structure-mapping process model (Falkenhainer et al. 1989; Markman & Gentner, 1993; Gentner, 2010).

The second prediction—that any inferences would be from the more systematic analog to the less systematic analog—was also borne out. Although we did not test this second prediction directly, many participants nonetheless provided evidence for it by including causal inferences in their responses to the commonalities question. That people were seemingly unaware that they were listing inferences rather than commonalities is a testament to the fluency with which analogical inferences are made.

Our findings are consistent with prior studies showing that systematicity determines the direction and content of analogical inferences. Clement and Gentner (1991) showed that when people made predictions about stories based on their analogs, they imported only facts embedded in a higher-order relation (and thus more systematic) while ignoring equally available but isolated facts.

Our results are also consistent with prior studies of analogical inference. Previous research has shown that people spontaneously make inferences during analogical mapping (Blanchette & Dunbar, 2000, 2002; Day & Gentner, 2007). Blanchette and Dunbar (2002) found that when people were given analogical comparisons, they later labeled inferences in the target as actual statements that had occurred in the target, when in fact these statements had only been presented in the base. A further study showed that these inferences are drawn online while reading the passages. Day and Gentner (2007) built on these results to ask whether such inferences would occur without any explicit invitation to compare things. They gave people two similar passages (separated by unrelated passages), under the guise of a series of independent passages to remember. Participants were simply told to read and remember each passage; they were not invited to compare passages or look for analogous information. Yet, they made inferences from earlier passages to later analogous passages[4]. Further, participants mostly reported that they had not used any similarities between stories to understand the later passages. Finally, as in Blanchette and Dunbar's study, later findings showed that these inferences were made online while reading the second passage.

The present findings take this phenomenon a step further. Participants in the present study interpolated inference into the target despite the task being one of simply listing commonalities, and despite the fact that both passages were visible on the screen during the full task. (In the Blanchette and Dunbar (2002) and Day and Gentner (2007) studies, only the target passage was present when the inferences were made.) The Commonalities response question only asked for "the ways in which the two stories were similar/analogous to each other"—yet inferences were listed as commonalities between the two stories. The spontaneous inclusion of inferences, despite the nonconducive instructions, is testimony to the fluency of inference-projection during analogical mapping (Doumas & Hummel, 2013; Falkenhainer et al., 1989; Gentner, 1983, 2010; Hummel & Holyoak, 1997; Keane et al., 1994; Krawczyk, Holyoak & Hummel, 2005; Markman, 1997; Markman & Gentner, 1993; Trench & Minervino, 2015, 2020). Across these prior studies and the present work, we see consistent evidence that analogical inference flows from structural alignment in a highly fluent manner.

However, as discussed earlier, people who included the inference were, strictly speaking, making a mistake. Those who did not include inferences in the commonalities response could have made the inferences, realized that these were not commonalities and decided not to include them in their responses. Therefore, our estimates of the degree to which people made the inference are almost certainly underestimates. To clarify the degree to which participants in this task are making the causal inference, we are currently running studies that explicitly test the content and direction of inference projection for these materials.

In sum, our findings bear out the importance of systematicity in analogical processing, and lend further evidence for the fluency of analogical inference.

Table 1: Sample story pair with a sample response for the Commonalities Response question

Story A	Story B
Karla, a red-tailed hawk, lived at the top of a tall oak tree. She was a beautiful bird with especially fine feathers.	Once there was a small country called Zerdia. Although it had a small population, it made exceptionally powerful computers.
One afternoon, she encountered a hunter with a bow and arrow. The hunter took aim and shot at the hawk--but he missed, because his arrows had no feathers. Karla knew the hunter wanted her feathers, **so she glided down and offered to give him a few.**	One day Zerdia was attacked by its warlike neighbor, Gagrach. The missiles were badly aimed, because Gagrach was lacking in technology, so the attack failed. Zerdia realized that Gagrach wanted their computer technology. Gagrach had not succeeded in developing such advanced technology.
The hunter was so happy with the feathers that he pledged never to shoot at a hawk again.	Gagrach promised to not attack Zerdia in the future.

Sample response:
"The plots both feature two primary actors, which are at a power imbalance with each other. Both plots demonstrate an attempted attack on the less powerful character. *Both plots show the less powerful character giving something to the attacker*, and the attacker promising mercy in the future in exchange."

*The causal pivot of the Standard is bolded in the table for clarity purposes, and it is not bolded in the actual experiment; the inference listed as a commonality in the response is italicized.

Table 2: Number of participants making at least one inference for X number of story pair(s) (N = 91 participants)

X	5 Pairs	4 Pairs	3 Pairs	2 Pairs	1 Pair	0 Pair
Number of Participants	0	12	19	32	18	10
Prop. of Participants	0	0.13	0.21	0.35	0.20	0.11

[4] The passages shared concrete surface features as well as structural relations.

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