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Abstract

The aim of the current studies was to explore encoding time differences in objects and relations and to investigate whether these differences lead to differences in allocation of attention to object similarity. Using a match-to-sample paradigm with 5- to 6-year-olds and adults, we found that (1) objects were encoded faster than relations for both adults and children, and that (2) children, but not adults, preferentially allocated attention to object similarity. Ultimately, these questions are aimed at identifying the factors responsible for the development of adult-like analogical reasoning. We suggest that changes in selective attention over development may account for the pattern of results seen across these two studies.

Keywords: analogical development; relational reasoning; selective attention; encoding time

Introduction

Reasoning by analogy is a fundamental and powerful aspect of human cognition (Gentner, Holyoak & Kokinov, 2001). Analogical reasoning is based on relational similarity. That is, two situations are analogous if they share a common relational structure (e.g., lava lamps and plate tectonics are both characterized by a system of *convection*); superficial commonalities like the perceptual features of the objects involved are generally irrelevant. However, reasoning on the basis of relational similarity is not trivial. Two analogous situations may share superficial commonalities that conflict with an alignment based on relational similarity. For example, to appreciate that 1:3 :: 3:9, one must understand that the relationship that holds between 1 and 3 is the same relationship that holds between 3 and 9. Based on this shared relationship, the two smaller numbers in each proportion correspond (1 → 3) and the two larger numbers correspond (3 → 9). In this case, the identity match between the two 3s must be disregarded, since this correspondence (3 → 3) is inconsistent with the overall relational match.

Although 1:3 :: 3:9 may not seem like a particularly challenging analogy for adults, instances where relational similarity conflicts with object similarity can be very challenging for young children (Gentner, 1988; Richland, Morrison & Holyoak, 2006) In cases like these, children will often reason on the basis of object similarity rather than relational similarity. This tendency is referred to as the *object bias*, but over development (with age as well as experience), a relational shift occurs whereby children become increasingly adept at reasoning on the basis of relational rather than object similarity (Gentner & Rattermann, 1991).

For example, Gentner and Toupin (1986) gave 6-year-old children a simple story and asked them to reenact it with new characters. They performed well when the corresponding characters were highly similar between the two stories, but performed very badly when similar characters played different roles across the two stories (the cross-mapped condition). Further studies have corroborated this finding that when relational similarity is pitted against object similarity children tend to be highly influenced by object matches and less able to attend to relational matches. For example, Richland and colleagues (2006) found the same pattern of results in a picture-matching task. The pictures depicted the same event structure, and the task was to point out correspondences based on the event patterns. When the object matches were inconsistent with the relational match, younger children were greatly impeded in choosing the correct relational match. This pattern of results, in which object similarity disrupts young children's analogical reasoning, has been found repeatedly in a variety of analogical tasks (Gentner & Rattermann, 1991) and even across cultures (Richland, Chan, Morrison, & Au, 2010).

The object bias is a robust and well-documented phenomenon, but a clear understanding of why it occurs is still lacking. Most accounts of analogical development that address the object bias implicitly or explicitly appeal to some processing difference (or differences) between objects and relations to explain the bias. Some of these differences include representational complexity, familiarity or fluency, salience, and automaticity. Improvements in relational reasoning over development are then explained by changes in this processing difference, and/or by improvements in some additional capacity that tempers the effects of these processing differences. For example, accounts of analogical development that emphasize the role of relational knowledge suggest that children are familiar with more object concepts than relational concepts, but as children gain more relational knowledge, and as this knowledge becomes more fluent, they become able to focus on relational similarity (Gentner, 1988, 2003). Other accounts appeal to the idea that object similarity is more salient than relational similarity, and that improvements in inhibitory control over development allow children to combat the influence of salient object similarity when reasoning about relations (Richland et al., 2006).

Without a clear understanding of the processing differences between objects and relations, it is difficult to precisely explain the object bias and to pinpoint what changes over development to decrease this bias. Thus, the goals of the present studies are to: (1) investigate one operationalization of processing differences in objects and relations, namely *encoding time*; (2) explore how encoding time differences impact analogical reasoning, in particular how it affects *allocation of attention*; and (3) examine how these patterns *change over development*.

Encoding time differences are a promising potential difference to investigate for a number of reasons. First, of the many proposed processing differences between objects and relations, faster encoding of objects than relations would be predicted by – or at least consistent with – nearly all of them. Second, prior research suggests that objects are encoded faster than relations by adults (Goldstone & Medin, 1994; Sagi, Gentner & Lovett, 2012), and it is likely that such a difference exists for young children as well. Finally, encoding time differences may have important consequences for how analogical reasoning unfolds.

During analogical reasoning, two representations are aligned so that elements from each are placed into correspondence with one another. According to Structure-Mapping Theory (SMT – Gentner, 1983; and modeled by SME – Falkenhainer, Forbus & Gentner, 1989), alignment is an incremental, multi-stage process. The mapping process begins with individual identical elements from each representation – including features, objects, and relations – being placed into correspondence with one another. These initial correspondences are promiscuous; individual elements may map to multiple other elements (e.g., both *cat* → *cat* and *cat* → *boy*). In successful analogical reasoning, the final one-to-one correspondences are based upon shared relational structure (e.g., *chase* → *chase*; therefore, *cat-chaser* → *boy-chaser*, *mouse-fleer* → *cat-fleer*).

We hypothesize that this incremental mapping process is interleaved with encoding, which is also incremental (Lovett, Gentner & Sagi, 2009). Pieces of the representations become available at different times, and correspondences between analogues are forged as these pieces become available. Correspondences made early in the mapping process may be particularly influential during analogical reasoning. For example, they may guide attention for further encoding and mapping (Kubose et al., 2002). Early correspondences may also be privileged if initial, incomplete mappings, rather than a full alignment, are used to make a decision (i.e., "satisficing", which young children may be especially likely to do, cf. Thibaut, French, & Vezneva, 2010). If objects are encoded faster than relations, then object correspondences should also be found earlier, resulting in attention initially being allocated to object similarity. With a "satisficing" strategy, earlier object correspondences would also lead to object-based (rather than relation-based) reasoning.

The present studies use a match-to-sample task to explore encoding time differences between objects and relations and the impact of such differences on the allocation of attention in children and adults. In Study 1 we ask whether objects are encoded more quickly than relations (at least for the stimuli used in these studies). In Study 2 we ask whether encoding time differences predict attention to object similarity. Integrating across these studies, we then ask what might change over development to yield this pattern of results.

Study 1

If objects are encoded faster than relations, then participants should require less time to encode a stimulus in order to find an object match and more time in order to find a relational match. Thus, this study manipulated the amount of time participants were given to encode a sample stimulus before they were asked to find either the object match or the relational match (a methodology used by Sloutsky and Yarlas, as cited by Lovett et al., 2009).

Method

Participants Thirty-two adults and 41 5- and 6-year-olds participated in this study. Adult participants came from the undergraduate subject pool and received partial course credit for their participation, or they were recruited from the university area and given monetary compensation. Children were recruited from an existing developmental research database and given a book and t-shirt for participating.

Stimuli and Procedures This study used a match-to-sample task administered on a touchscreen laptop. Stimuli consisted of three shapes arranged in one of three patterns: ABA, AAB, or BAA (Figure 1). On each trial, participants were shown a sample stimulus, which disappeared and was replaced by two choices. All participants completed two versions of the task: *object-matching*, in which they had to find the stimulus with the same shapes, and *relation-matching*, in which they had to find the stimulus with the same pattern. In both versions, the incorrect foil did not share objects or a relational pattern with the sample. Participants selected their choice by touching it on the screen.

Within each version of the matching task, there were three sections: practice, long-encoding-time (LET) test trials, and short-encoding-time (SET) test trials. The order of version and short and long trials was fully counterbalanced. In the practice sections, participants were shown an example triad and the matching criterion was explained ("Find the one with the same shapes/pattern"). Then, participants completed several practice trials with feedback to ensure that the task instructions were clear. Practice trials were followed by a block of LET test trials or SET test trials. LET trials displayed the sample stimulus for 1000ms. For adults, SET trials displayed the sample stimulus for 50ms, and for children, 150ms.

We hypothesize that for both adults and children in this study, objects will be encoded faster than relations. Therefore, we expect high accuracy for object matching on both LET and SET trials. In contrast, we expect high accuracy for relational matching only on LET trials, in which participants have had sufficient time to encode the relational pattern in the sample; SET trials should not provide enough time to encode the relational pattern, and therefore participants should not be able to reliably select the relational match in this case. In sum, we predict a Version by Encoding Time interaction, with a larger effect of Encoding Time for relation matching.

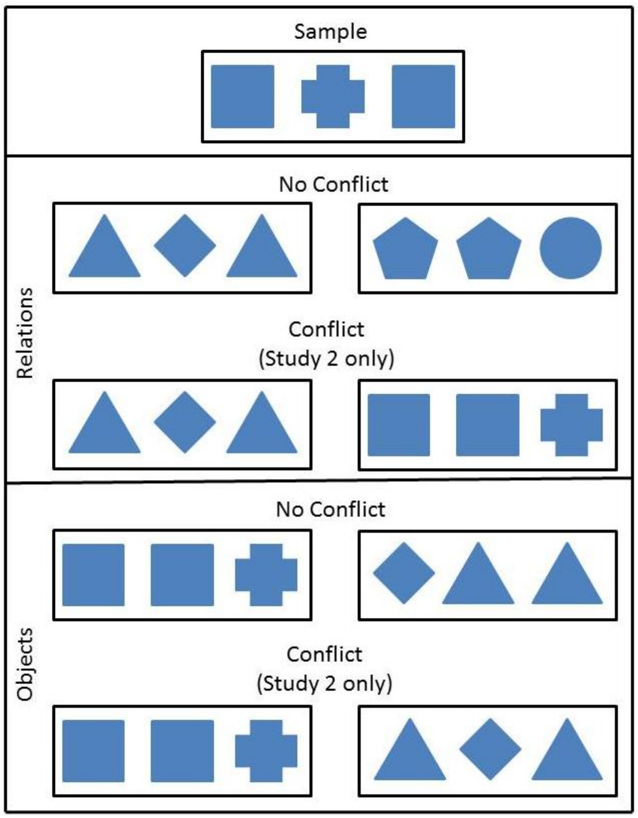

Figure 1: Example stimuli for Studies 1 and 2.

Results and Discussion

Results for Study 1 are shown in Figure 2.

Adults' mean proportion correct was entered into a 2(Version) x 2(Encoding Time) repeated-measures ANOVA. Overall, adults were more accurate on object-matching than relation-matching, $F(1,31) = 63.07$, $p < .001$, and more accurate on LET than SET trials, $F(1,31) = 51.27$, $p < .001$. However, these main effects are best interpreted in light of their interaction, $F(1,31) = 25.27$, $p < .001$. As predicted, adults showed a larger decrement from shorter encoding time for relation-matching than for object-matching.

Children's mean proportion correct was entered into a 2(Version) x 2(Encoding Time) repeated-measures ANOVA. Like adults, children were overall more accurate on object-matching than relation-matching, $F(1,40) = 182.97$, $p < .001$, and more accurate on LET than SET trials, $F(1,40) = 60.03$, $p < .001$. The predicted Version x Encoding Time interaction was marginally significant, $F(1,40) = 3.46$, $p < .10$. As with adults, short encoding times were more disruptive for relation-matching than for object-matching.

These results support the hypothesis that for both children and adults, objects are encoded faster than relations. Although this may not be true in all cases, for the stimuli used in this task, both groups needed less time to encode the object information than the relational information. These findings echo prior research suggesting that adults encode objects more quickly than relations (Goldstone & Medin, 1994). To our knowledge, this is the first time this processing difference has been shown for children as well.

What consequences might this difference have on analogical reasoning? Assuming incremental and interleaved encoding and mapping processes (Lovett et al., 2009), information encoded early (i.e., object information) could influence the allocation of attention during alignment. Specifically, early-available object information should initially direct attention toward object similarity. This would predict that conflicting object similarity should disrupt relational matching by diverting attention to the object match, potentially leading to more errors (i.e., selecting the object match instead of the relational match) and longer latencies to correctly select the relational match (because attention to the relational match should be delayed) (Sloutsky & von Spiegel, 2004). However, for object matching, conflicting relational matches should not disrupt accuracy or response times (RTs). In Study 2, we explore these predictions.

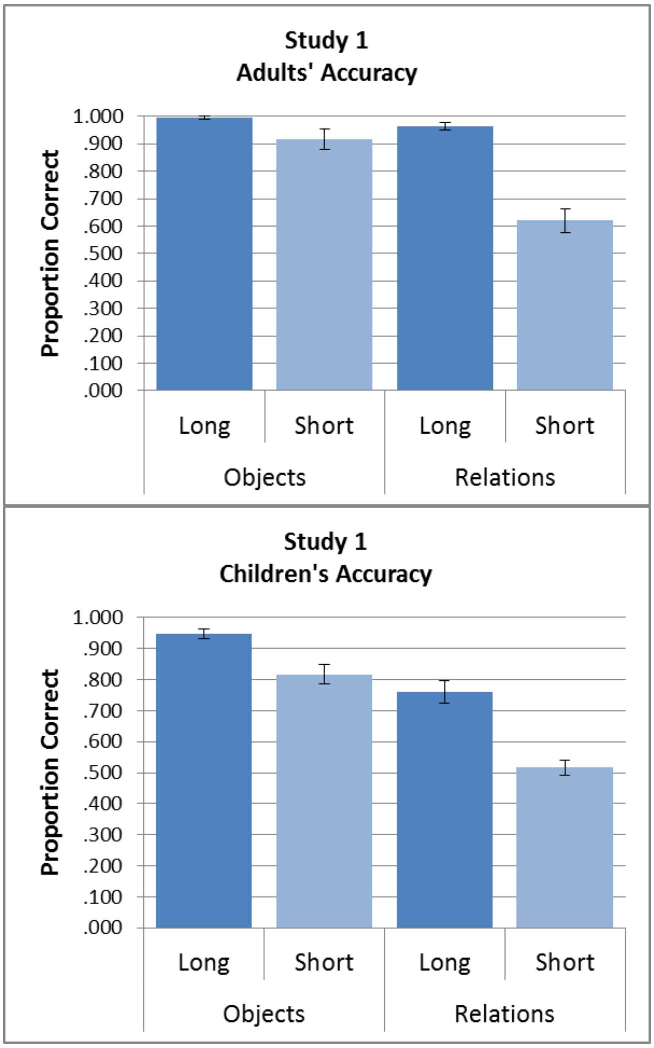

Figure 2: Adults' and children's match-to-sample accuracy in Study 1 by task version and encoding time.

Study 2

If object similarity captures attention as a result of early object encoding, then the presence of conflicting object similarity on a relation-matching task should result in more errors and slower correct RTs compared to cases without conflicting object similarity. In contrast, object matching should be largely unaffected by the presence of conflicting relational similarity. However, if this asymmetrical pattern is not seen, it would suggest that object similarity is not preferentially commanding attention, despite differences in encoding time.

Method

Participants Thirty-two adults and 37 5- and 6-year-olds participated in this study. Participants were recruited and compensated as in Study 1.

Stimuli and Procedures This study used the same basic match-to-sample task used in Study 1, with some modifications. As in Study 1, stimuli consisted of three shapes arranged in one of three patterns: ABA, AAB, or BAA (Figure 1). Also as in Study 1, all participants completed an *object-matching* and *relation-matching* version, counterbalanced for order.

There were two primary differences between the tasks used in Study 1 and Study 2. First, the encoding time manipulation was removed. In Study 2, the sample was displayed for 1500ms on all trials. Second, another type of trial – a *conflict* trial – was added. On conflict trials, the foil matched the sample on the non-relevant dimension. That is, on the object-matching version, the incorrect foil was a relational match, and on the relation-matching version, the foil was an object match. These trials were interspersed with *no conflict* trials, where the incorrect foil did not match the sample at all (the type used in Study 1) (Figure 1).

If object similarity preferentially captures attention – one possible consequence of faster object than relation encoding – we expect participants to make more errors and respond more slowly to conflict trials than no conflict trials on the relation-matching task. However, participants should not show this difference on the object-matching task. Alternatively, if object similarity does not capture attention (despite encoding time differences), we should not see this asymmetrical pattern. In sum, a Version by Trial Type interaction would suggest preferential attention to object similarity.

Results and Discussion

Results for Study 2 are shown in Figure 3.

Adults' mean proportion correct and RTs on correct trials were entered into separate 2(Version) x 2(Trial Type) repeated-measures ANOVAs. Adults were significantly more accurate on the object-matching version than the relation-matching version, $F(1,31) = 10.92$, $p < .01$. This main effect of Version was modulated by an interaction with Trial Type, $F(1,31) = 4.31$, $p < .05$. Adults showed a small but reliable decrement in performance on the relation-matching task when a conflicting object match was present, but no such difference on the object-matching task.

Consistent with faster encoding of objects than relations found in Study 1, adults showed a main effect of Version in their RTs. They made significantly faster correct responses on the object-matching task than the relation-matching task, $F(1,31) = 7.94$, $p < .01$. However, this did not interact with Trial Type. That is, on both the object- and relation-matching versions, adults were equally fast to respond to conflict and no-conflict trials.

Parallel analyses were carried out for children's accuracy and correct RTs. Children were significantly more accurate on the object-matching version than the relation-matching version, $F(1,36) = 42.09$, $p < .001$, and significantly more accurate on no conflict than conflict trials, $F(1,36) = 10.74$, $p < .01$. These factors also interacted, $F(1,36) = 15.79$, $p <$

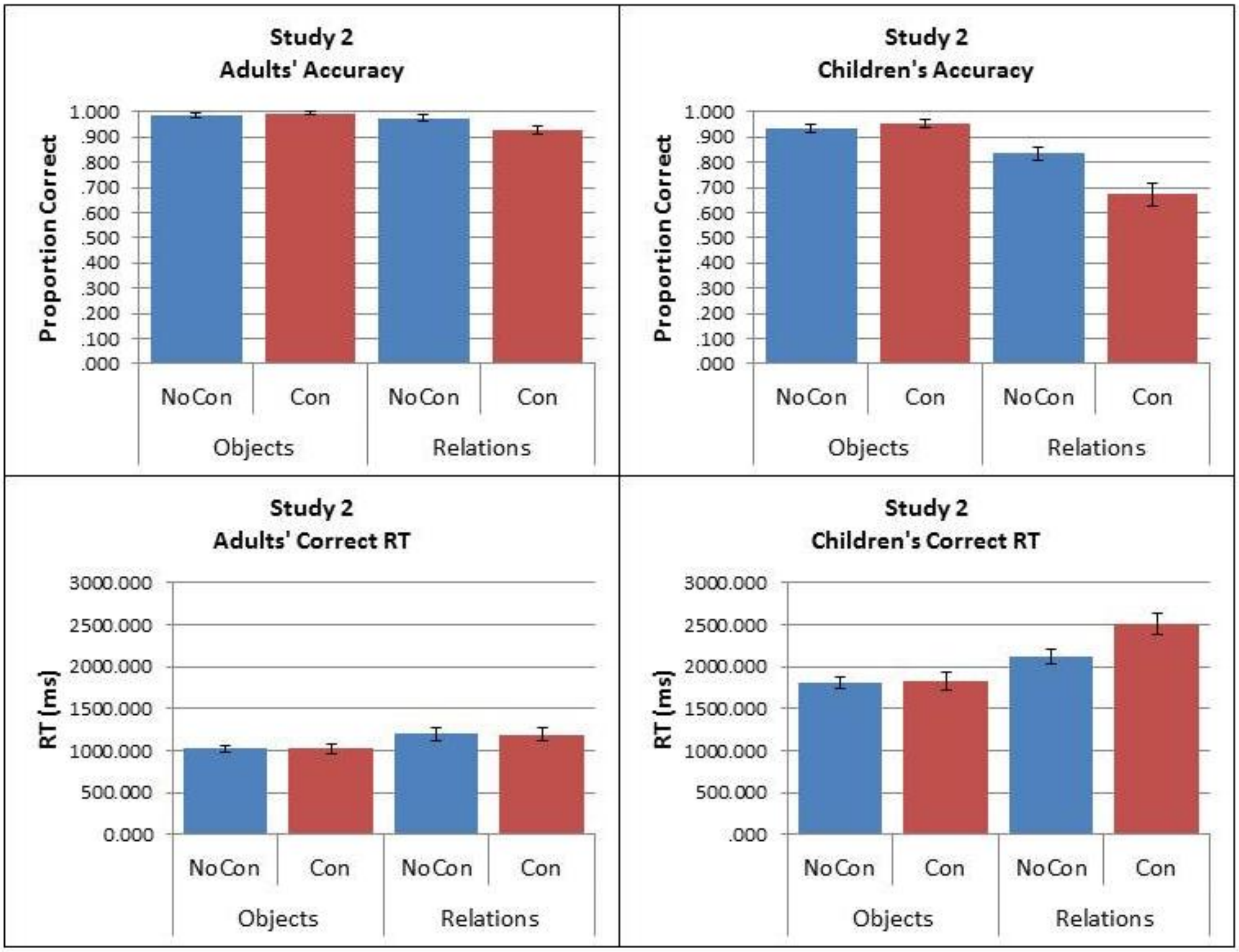

Figure 3: Adults' and children's accuracy and RT data from Study 2.

.001. The effect of conflict trials was larger for the relation-matching task than the object-matching task.

Children were also faster to respond correctly on the object-matching task than the relation-matching task, $F(1,36) = 11.30$, $p < .01$. Trial Type did not significantly interact with Version, though the data do qualitatively follow a pattern consistent with the accuracy results. Specifically, compared to no conflict trials, conflict trials showed longer latencies on the relation-matching task than the object-matching task.

Though somewhat mixed, the pattern of accuracy and RT results in Study 2 suggest a difference in adults' and children's attention to object similarity. Children's performance resembles the pattern that would be predicted if early object encoding led to preferential to object similarity. Conflicting matches led to more errors and longer RTs on the relation-matching task than the object-matching task.

In contrast, adults' performance suggests resilience against conflicting object similarity. Conflicting object matches did not increase response latencies on the relational matching task, and the decrement in accuracy on relational conflict trials was quite small. Altogether, the results from Study 2 suggest that encoding time differences between objects and relations may lead to preferential attention to object similarity for children but not adults.

General Discussion

The aim of the current studies was to explore encoding time differences in objects and relations and to investigate whether these differences lead to differences in allocation of attention to object similarity. Ultimately, these questions are aimed at identifying the factors responsible for the development of adult-like analogical reasoning.

In Study 1, we found that both children and adults encoded objects faster than relations. Study 2 found a pattern of object- and relation-matching that suggested children, more than adults, preferentially allocated attention to object similarity (but see Sloutsky & von Spiegel, 2004). Thus, we see continuity in a basic processing difference between objects and relations, but the consequences of this difference for analogical reasoning behavior changed over development. Together, the results of Studies 1 and 2 implicate a change in an additional factor as key in explaining the difference in children's and adults' susceptibility to conflicting object similarity.

We think our results are best explained by a change in *selective attention* over development. Although adults encoded objects faster than relations, object similarity did not capture their attention when relational similarity was the relevant matching criterion. Thus, it seems that adults were able to selectively attend to the relational information, despite the earlier availability of object information, whereas children were not. Further work is needed to build a strong case for the role of selective attention in analogical development. However, this account is consistent with other studies of analogical reasoning in children (e.g., Thibaut, et al., 2010).

Future research will also need to explore how selective attention interacts with other factors implicated in analogical development. For example relational language has been proposed to aid relational thinking in a number of ways (Gentner, 2010). Performance on difficult analogical reasoning tasks can often be improved by providing children with language to describe the relevant relations (e.g., Loewenstein & Gentner, 2005). With regards to selective attention, an intriguing possibility is that relational language may strengthen top-down control of attention to relational information.

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References

Gentner, D. (2010). Bootstrapping children's learning: Analogical processes and symbol systems. *Cognitive Science*, *34*, 752-775.

Gentner, D., Holyoak, K. J., & Kokinov, B. N. (Eds.). (2001). *The analogical mind: Perspectives from cognitive science.* Cambridge, MA: MIT Press.

Gentner, D., & Rattermann, M. J. (1991). Language and the career of similarity. In S. A. Gelman & J. P. Byrnes (Eds.), *Perspectives on thought and language: Interrelations in development*. London: Cambridge University Press.

Goldstone, R. L., & Medin, D. L. (1994). Similarity, interactive activation, and mapping. *Journal of Experimental Psychology: Learning Memory and Cognition*, *20*, 3-28.

Gentner, D., & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science*, *10*, 277-300.

Kubose T .T., Holyoak K .J., Hummel J. E. (2002). The role of textual coherence in incremental analogical mapping. *Journal of Memory and Language*, *47*, 407-435.

Loewenstein, J. & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psychology*, *50*, 315-353.

Lovett, A., Gentner, D., Forbus, K., & Sagi, E. (2009). Using analogical mapping to simulate time-course phenomena in perceptual similarity. *Cognitive Systems Research*, *10*, 216-228.

Richland, L. E., Chan, T. K., Morrison, R. G., & Au, T. K. F. (2010). Young children's analogical reasoning across cultures: Similarities and differences. *Journal of Experimental Child Psychology*, *105*, 146-153.

Richland, L.E., Morrison, R.G., & Holyoak, K.J. (2006) Children's development of analogical reasoning: Insights from scene analogy problems. *Journal of Experimental Child Psychology*, *94*, 249-273.

Sagi, E., Gentner, D. & Lovett, A. (2012). What difference reveals about similarity. *Cognitive Science*, *36*, 1019-1050.

Sloutsky, V. M. & von Spiegel, J. (2004). Automatic processing of elements interferes with processing of relations. In K. Forbus, D. Gentner, & T. Regier (Eds.), *Proceedings of the XXVI Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Erlbaum.

Thibaut J., French R., & Vezneva M. (2010). The development of analogy making in children: Cognitive load and executive functions. *Journal of Experimental Child Psychology*, *106*, 1–19.