

# Achieving Abstraction: Generating Far Analogies Promotes Relational Reasoning in Children

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Analogical reasoning is essential for transfer by supporting recognition of relational similarity. However, not all analogies are created equal. The source and target can be similar (near), or quite different (far). Previous research suggests that close comparisons facilitate children's relational abstraction. On the other hand, evidence from adults indicates that the process of solving far analogies may be a more effective scaffold for transfer of a relational strategy. We explore whether engaging with far analogies similarly induces such a strategy in preschoolers. Children were provided with the opportunity to solve either a near or far spatial analogy using a pair of puzzle boxes that varied in perceptual similarity (Experiment 1), or to participate in a control task (Experiment 2). All groups were then presented with an ambiguous spatial reasoning task featuring both object and relational matches. We were interested in the relationship between *near* and *far* conditions and two effects: (a) children's tendency to spontaneously draw an analogy when solving the initial puzzle, and (b) their tendency to privilege relational matches over object matches in a subsequent, ambiguous task. Although children were more likely to spontaneously draw an analogy in the *near* condition, those who attempted the far analogy were more likely to privilege a relational match on the subsequent task. We argue that the *process* of solving a far analogy—regardless of a learner's spontaneous success in identifying the relation—contextualizes an otherwise ambiguous learning problem, making it easier for children to access and apply relational hypotheses.

*Keywords:* cognitive development, relational reasoning, inference, representation, analogy

The flexible use and transfer of knowledge is an essential feature of early learning. Simply acquiring new information is not enough; this dynamic process depends upon the generalization and application of knowledge to novel contexts. However, in order for a learner to apply what they know, they must first recognize those situations in which transfer is appropriate. This

becomes increasingly difficult when surface similarities between the context in which information is learned and the context in which it must be applied are misleading or unavailable as a cue. A well-documented challenge for transfer—particularly in early childhood—is learning to ignore irrelevant surface features to attend to relational similarities instead. The development of analogical reasoning plays a key role in recognizing these relations by mapping correspondences between objects or events, facilitating generalization.

However, not all analogies are created equal. Instead, the amount of overlap between domains has been used to characterize an analogy along a continuum from “near” to “far” (Gentner, 1983; Ward, 1998). That is, in addition to sharing relational structure, source and target domains can be perceptually and/or conceptually similar (a near analogy), or quite different (a far analogy). According to Gentner (2010), the same mapping process operates over near and far comparisons, with both ultimately highlighting common structure. Nevertheless, research with adults suggests that solving far analogies is uniquely associated with increased generalization and abstraction (Gick & Holyoak, 1983; Halpern, Hansen, & Riefer, 1990; Knowlton, Morrison, Hummel, & Holyoak, 2012), creativity (Bowdle & Gentner, 2005; Holyoak & Thagard, 1995), innovation (e.g., Dunbar & Blanchette, 2001), understanding (Barnett & Ceci, 2002), and attention to relations (Vendetti, Wu, & Holyoak, 2014).

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Research was partly funded by the American Psychological Foundation to Caren M. Walker. We thank the parents and children who participated in the study, as well as the Childhood Creativity Center at the Bay Area Discovery Museum, the Birch Aquarium at Scripps Institute of Oceanography, the Lawrence Hall of Science, and the Reubin H. Fleet Science Museum. We are grateful to Alison Gopnik for her early contributions to this project, as well as members of the Early Learning & Cognition Lab at University of California, San Diego for their invaluable feedback. Finally, we thank Nadia Keddo, David Lee, Andrea Nishimi, Taylor Osman, Michael Revelo, Gillian Rush, and Nicky Sullivan for facilitating data collection.

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Overcoming the bias to map features on the basis of perceptual similarity presents a challenge for children: Their tendency to focus on surface properties results in fewer instances of relational mapping. In fact, much of the existing literature suggests that preschool-aged children often struggle to reason analogically—that is, they do not tend to privilege relational information (e.g., Christie & Gentner, 2010, 2014; Gentner & Rattermann, 1991; Halford, 1992; Loewenstein & Gentner, 2001; Richland, Morrison, & Holyoak, 2006), with only limited evidence indicating whether or not they spontaneously employ analogical reasoning during problem-solving. This has led to the belief that relational transfer is difficult to engineer for preschool-aged children. For example, Crisafi and Brown (1986) presented preschoolers with the opportunity to transfer a process (i.e., locating a coin and inserting it) that could be used to obtain a desired object. Children learned this process using one set of materials (e.g., gumball machine), and were then provided a new set (e.g., dump truck), that could be solved by applying the same abstract steps. Results indicated no evidence of spontaneous transfer, unless explicit instruction (e.g., to apply the same solution) was offered.

On the other hand, when minimal scaffolding, such as prompts to compare or explain are provided, children are far more likely to succeed (e.g., Brown & Kane, 1988; Brown, Kane, & Echols, 1986; Christie & Gentner, 2010, 2014; Crisafi & Brown, 1986; Loewenstein & Gentner, 2001; Tunteler & Resing, 2002; Walker, Bridgers, & Gopnik, 2016; Walker & Lombrozo, 2017). The benefits of scaffolding on analogical reasoning are often interpreted as evidence that children are initially unable to reason about relations without explicit instruction, language, or cultural input (e.g., Gentner, 2010; Richland, Zur, & Holyoak, 2007). Then, over the course of development, children are thought to expand their understanding of similarity to include relational information (i.e., the relational shift, Gentner, 1988). Here we consider an alternative explanation: scaffolding is successful because it highlights those contexts in which the application of existing relational hypotheses is an appropriate strategy.

What are the conditions under which a relational strategy becomes privileged and relevant for young children? Previous research has proposed that the amount of perceptual distance between the target and source might be manipulated as a cue to common relational structure. In particular, children are more likely to spontaneously discover relations in the context of highly similar pairs, presented in close proximity (i.e., progressive alignment, Kotovsky & Gentner, 1996). According to Loewenstein and Gentner (2001, p. 215), engaging in the “small step” of comparing highly alignable objects or events should facilitate the “large step” of more distant comparisons. They offer evidence for the facilitative effect of close comparison using a search task modeled after DeLoache’s (1987) classic studies: Children watched an experimenter hide a toy in one room, and were then asked to find an identical toy in the *same place* in an analogous room. Prompting children to first compare two highly similar rooms (i.e., containing the same furniture in the same location, and differing only in color), facilitated their subsequent performance on a more challenging version, in which the furniture in the analogous room was also differently shaped. They conclude that noting the correspondences between highly similar spaces renders common relational structure more salient, aiding subsequent mapping.

The current experiments assess whether the process of mapping highly similar spatial objects would also inspire children’s application of a relational strategy when generalizing to a novel spatial task. Or whether children, like adults, might reap greater benefits from mapping dissimilar cases in the context of a far analogy. In particular, we examine two issues related to this question. First, we explore whether distance (near, far) influences children’s tendency to spontaneously draw an analogy in the absence of explicit instruction to do so. Second, we investigate whether attempting to generate solutions to more distant analogies invokes the use of a relational strategy across distinct tasks.

To do so, 4- and 5-year-olds were first provided the opportunity to locate a hidden object in the context of either a near or far analogy (Experiment 1), or in a non-analogy control task (Experiment 2). Unlike in the adult literature, children were not instructed to use analogical reasoning, since we were interested in examining children’s spontaneous use of this strategy. Regardless of their initial tendency to draw an analogy, however, children all had the opportunity to observe the relational similarity between items. Next, all children were asked to make selections in a second, distinct task, in which both object and relational solutions were available. Although the two tasks were presented as unrelated, they shared some features: (1) both tasks required that the learner search for a hidden sticker, and (2) both solutions included a spatial relation. We therefore examined transfer of a relational strategy in the context of relatively near transfer (e.g., as compared to Crisafi & Brown, 1986). Given this task similarity, Experiment 2 served as a control condition, using the same materials to assess children’s baseline tendency to make relational selections on the subsequent task without first solving an analogy. Including this *baseline* condition also allowed us to further explore the condition effects in Experiment 1.

We included 4- and 5-year-olds based on previous studies demonstrating children’s ability to use relational information in similar contexts (Blades & Cooke, 1994; Marzolf & DeLoache, 1997). For example, Blades and Cooke (1994) investigated children’s use of spatial relations to locate a hidden object when comparing analogous models of a room. Specifically, they modified DeLoache’s (1987) task by including two types of hiding locations: (a) unique items (e.g., under the bed), and (b) twin items (e.g., behind one of two identical chairs). This change allowed them to probe changes in strategy. When the hiding place was unique, children could locate the hidden toy using object similarity alone (e.g., if the toy is hidden under the bed in Room 1, then search for the bed in Room 2). However, when the hiding place included a twin item, children could not rely upon this simpler strategy. Instead, they were *required* to reason about spatial relations in order to successfully distinguish between locations. Results indicated that 3-year-olds were unable to locate the toy unless it was hidden in a unique location, suggesting that they relied exclusively upon object attributes in this task (see also Marzolf & DeLoache, 1997). By 4 years of age, children could use spatial relationships to locate the toy in a twin item, as long as the rooms were highly aligned (i.e., a near analogy), but had difficulty when they were not (i.e., a far analogy). Only 5-year-olds were successful in all contexts. Given evidence that 4- and 5-year-olds are *able* to do this task, but differ in their proficiency, we were interested in whether children at each age would spontaneously employ analogical reasoning as a solution without an explicit prompt to do so, and also whether they would generalize this relational strategy.

To summarize, the current studies examine relationships between age, analogical distance (near, far), and two effects: (a) 4- and 5-year-olds' tendency to spontaneously generate analogies and (b) their tendency to privilege relational matches in a subsequent task. We hypothesized that while children in the *near* condition would be more likely to spontaneously generate an analogy on the first task, children in the *far* condition would show increased subsequent relational selections when compared with *near* and *baseline* (Experiment 2) conditions. These findings would support the claim that children's difficulties with relational thinking are at least partly due to a failure to recognize those contexts in which relational solutions are appropriate.

## Experiment 1

### Method

**Participants.** A total of 96 4- and 5-year-olds ( $M = 58.6$  months, range = 47.9–71.2 months,  $SD = 6.6$ , females = 47) participated, with 48 randomly assigned to *near* or *far* conditions. An additional 7 children were excluded due to experimenter error (3), failing to complete the experiment (2), or parent intervention (2). All were recruited from local preschools and museums. Individual demographics were not collected, but the population was largely middle-class, with a range of ethnicities representing the local diversity. Institutional Review Board approval was obtained for this research at the University of California, San Diego (*Causal Learning and Reasoning in Childhood*, protocol 151866S).

### Materials and procedure.

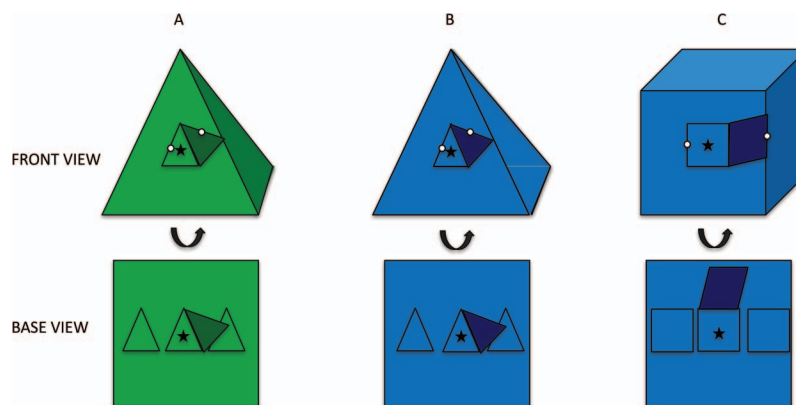
**Spatial analogy task.** The spatial analogy task gave children the opportunity to solve either a near or far analogy using puzzle boxes constructed from green or blue poster board (Figure 1; see Appendix A for a complete script of the procedure). All children were presented with the source puzzle, which was green and pyramid-shaped, with four triangular sides. The box featured a triangular door on its front, held closed with a rubber band, and three identical triangular openings on its base, covered by trian-

gular felt flaps. Participants were told, "I have never seen this toy before, but someone told me there is a sticker hidden inside. Would you help me find the sticker by exploring the toy?" Children were encouraged to explore until they located the sticker, which was first hidden in either the bottom-center opening ( $n = 47$  children) or in the opening on the front ( $n = 49$ ). The experimenter provided leading prompts to any child who failed to find the sticker themselves. Once the child successfully located the sticker, the puzzle was removed.

Participants were then presented with a near or far target puzzle box, according to their condition. Both boxes contained analogous hiding locations as the source but varied in the degree of surface similarity. Children in the *near* condition were presented with a target that was identical to the source, except for its color (blue). To prevent children from relying exclusively on the perceptual correspondence between hiding locations, the three doors on the base of the source and target puzzles were identical, serving as twin items (see Blades & Cooke, 1994). Given the presence of three potential object matches, solving the near analogy for the bottom-center location *required* that children use the relational correspondence among the doors. In other words, if children attempted to locate the sticker by exclusively searching for an object match, they would be forced to search randomly from among the three doors.

Children in the *far* condition were presented with a target that differed from the source in both color and shape. The far target box was blue and cube-shaped, with four square sides. This puzzle featured a square-shaped door on its front, held closed with a rubber band, and three identical square-shaped openings on its base, covered by square-shaped felt flaps. In both conditions, a sticker could be found in the analogous location. Upon presentation of the target, the experimenter said, "I have never seen this toy before either, but someone told me there is also a sticker hidden inside it. If you had one guess, where would you look to find the sticker?"

Children were not explicitly instructed to compare the two boxes, nor were they prompted to draw an analogy. Instead, we



*Figure 1.* Spatial analogy task. Illustration of spatial analogy task, including the (a) source puzzle box, (b) near analogy target puzzle box, and (c) far analogy target puzzle box. The front view (top row) shows how each box was presented to the children, with the front door visible and the bottom doors hidden underneath the base of the toy. The base view (bottom row) shows the same boxes flipped to reveal the base of the toy. See the online article for the color version of this figure.

were interested in assessing whether preschoolers would first search for the sticker in the same location as the hiding box, and whether this tendency would be influenced by condition. In particular, we were interested in children's tendency to spontaneously use an analogical reasoning strategy when confronted with a novel problem. Spontaneous analogies were coded on the basis of the child's first action (children received a 1 if they first searched in the analogous opening and a 0 if they first performed any other action). The production of an analogy on children's first action was interpreted as evidence that children spontaneously used relational similarity as a strategy. However, regardless of whether the child correctly located the sticker on this first action, all children were prompted to *continue to search* until they found the sticker. As a result, all children had the opportunity to observe the relational similarity between the two hiding events.

After children located the second sticker in the first hiding event, they were told that the experimenter was going to hide the stickers in both boxes again. Children were asked to turn around and close their eyes so that they could not see where the stickers would be hidden. The experimenter moved the stickers in the source and target boxes to the second hiding location, either behind the bottom-center or front door. Then, all children were shown the location where the sticker was hidden in the source box and were again given the opportunity to locate the sticker inside either the near or far target box on their own. Production of spontaneous analogies for this second hiding event were coded according to the same criteria, based on children's first action. We were particularly interested to assess any increase in children's reliance on a relational strategy during this second hiding event, given their exposure to the analogical mapping during the first hiding event in both conditions. Regardless of whether children correctly located the sticker on their first try, all children were again provided the opportunity to continue to search until they located the sticker in the analogous location. Children in both *near* and *far* conditions were therefore provided with two hiding events, and two opportunities to observe the relationship between the source and target puzzle boxes. The sequence of hiding locations was counterbalanced.

**Transfer task.** A perceptual mapping task adapted from Gentner and Rattermann (1991) was used to assess transfer of relational reasoning in both conditions. To differentiate this task from the spatial analogy task, the experimenter introduced the materials saying, "Now we are going to play a different game!" The experimenter then assigned a set of three cups to themselves and to the child. The cups were arranged in a row, from smallest to largest (see Figure 2). The cups in the experimenter's row were sized small (A), medium (B) and large (C), and the cups in the child's row were sized medium (B), large (C), and extra large (D). Therefore, the midsized cup in the experimenter's row was identical to the smallest cup in the child's row. The experimenter revealed a sticker hidden inside the midsized cup (B) in her row and prompted the child to locate the sticker hidden inside their own row. The experimenter said, "The sticker in your row is hidden in the same place as the sticker in my row." This instruction was left intentionally ambiguous so that it might be interpreted in terms of an object or relational match. Children were then given one opportunity to select a cup to locate the sticker. Critically, children could privilege the cup of the same absolute size (object match B) or a cup of the same relative size (relational match C). Children received 1 point for selecting the relational cup

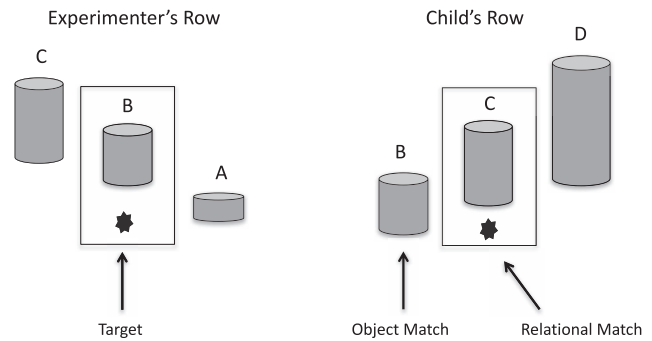


Figure 2. Transfer task. Illustration of transfer task (adapted from Gentner & Rattermann, 1991). A sticker was hidden in the midsized cup (B) in the experimenter's row. There are two possible matches in the child's row: the cup in the same location (relational match, C), or the identical cup (object match, B).

(C) and 0 points otherwise. Sets of cups were composed of silver measuring cups, striped boxes, or unfinished wooden stacking dolls. The three types of stimuli were counterbalanced with no differences found.

In both conditions, a second researcher who was naïve to the purpose of the experiment recorded responses for both tasks. Interrater reliability was very high; the coders agreed on 98% of responses. Minor disagreements were decided by discussion with a third researcher.

## Results and Discussion

We were interested in comparing performance between ages and *near* and *far* conditions on two measures: whether children spontaneously drew an analogy between the puzzle boxes in the spatial analogy task, and whether children privileged the relational match (C) in the transfer task. We report the results of each analysis below.

**Spontaneous analogy production.** Children in both *near* and *far* conditions were provided with two opportunities to produce a spontaneous analogy during the spatial analogy task, and the hiding locations and sequence of these events were counterbalanced. We therefore first examined differences in the frequency of children's production of a spontaneous analogy for each condition (*near*, *far*), age (4-year-olds, 5-year-olds), hiding location (front, bottom), and event order (1st hiding event, 2nd hiding event).

Loglinear analysis revealed a main effect of age,  $\chi^2(1, N = 96) = 3.87, p < .05$ , with 5-year-olds significantly more likely to produce a spontaneous analogy than 4-year-olds, and a significant interaction between age and order,  $\chi^2(1, N = 96) = 4.57, p < .05$ . Specifically, older children were more likely than younger ones to improve across trials. Although there was an equal difference between the two age groups when considering those who correctly produced a spontaneous analogy during the first hiding event and those who did not (correct minus incorrect = 14 for 5-year-olds and 14 for 4-year-olds), there was a difference between age groups during the second hiding event (correct minus incorrect = 26 for 5-year-olds and 16 for 4-year-olds). There was also a main effect of hiding location,  $\chi^2(1, N = 96) = 77.75, p < .001$ , and a significant interaction between hiding location and order,  $\chi^2(1,$

$N = 96$ ) = 11.13,  $p < .001$ , on spontaneous analogy production. Proportion of spontaneous analogies for each of these variables is reported in Table 1.

As illustrated in Table 1, spontaneous analogies were at ceiling for the front hiding location, regardless of condition. Whenever the sticker was hidden in the front hiding location during the first hiding event, 100% of children in both conditions produced a spontaneous analogy. This is likely because the front door, unlike the three identical doors on the base of the box, was a perceptually unique hiding location, which allowed children to rely exclusively on an object matching strategy (Blades & Cooke, 1994). The door was also located directly in front of the child, was the only hiding location that was clearly visible upon introducing the puzzle, and the child had not yet been exposed to other hiding locations. When the sticker was hidden in the front during the second event, after children had been exposed to other possible hiding locations, performance decreased a small amount (92% overall). These results provide reason to believe that children's success in this case reflects their baseline assumptions and/or perceptual matching, not analogical transfer.

Given these results, we ran a second, more informative loglinear analysis, excluding the front hiding location. This analysis reveals a significant effect of order on the production of spontaneous analogies for the bottom location,  $\chi^2(1, N = 96) = 6.56, p = .01$ , and a marginal effect of condition,  $\chi^2(1, N = 96) = 7.81, p = .06$  (see Figure 3). In particular, relatively few children drew a spontaneous analogy on the first hiding event, with 30% in the *near* condition and 25% in the *far* condition, and no difference between conditions,  $\chi^2(1, N = 96) = .17, p = .68$ . However, on the second hiding event, performance improved, with 68% of children in the *near* condition and 38% of children in the *far* condition producing a correct analogy, with a significant effect of condition,  $\chi^2(1, N = 96) = 4.57, p = .03$ . In line with our first hypothesis, children in the *near* condition were therefore significantly more likely than children in the *far* condition to generate a spontaneous analogy. The proportion of spontaneous analogies was particularly high, given the large number of possible actions that a child could take (i.e., open the front door, check the bottom-left or bottom-right flaps, explore the sides, top, seams, or corners). However, order effects indicate that this strategy was only spontaneously employed after children had the opportunity to observe the outcome of the first hiding event, even when there was a high amount of perceptual similarity between the source and target boxes.

An analysis of the number of unique actions on each puzzle shows no differences between children in the *near* and *far* conditions in terms of the average number of actions taken for those who did not generate a spontaneous analogy. The mean number of actions prior to sticker discovery was statistically equivalent (*near*:

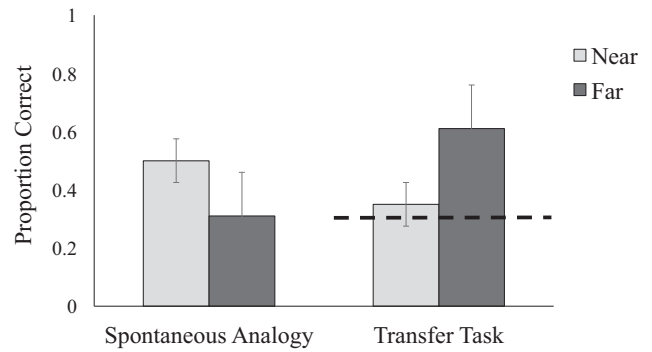


Figure 3. The proportion of spontaneous analogies generated for the bottom hiding location of the spatial analogy task (including both first and second hiding events; left) and the proportion of relational matches selected in the transfer task (right) for children in *near* and *far* conditions. The dashed line indicates chance performance (.33%), for the transfer task only.

$M = 1.33, far: M = 1.42$ ),  $t(53) = -.56, p = .58$ . It is therefore unlikely that the *far* puzzle was simply more difficult to solve. Instead, the degree of perceptual similarity between the two puzzles in the *near* condition probably served to scaffold children's spontaneous analogy production (e.g., Gentner, 2010).

An analysis of the total amount of time (in seconds) each child spent searching for the sticker in the second (target) puzzle box across the 1st and 2nd hiding events (beginning when the experimenter passed the puzzle to the child, and ending when the child located the sticker) also shows no difference between conditions (*near*:  $n = 33, M = 56.39$ ; *far*:  $n = 33, M = 57.94$ ),  $t(64) = -.21, p = .83$ . We can conclude, therefore, that the *far* puzzle did not result in increased processing or errors.

**Transfer task.** The proportion of relational matches (C) in the transfer task for children in *near* and *far* conditions appear in Figure 3. Children in the *near* condition selected the relational match no more often than chance (35%),  $p = .87$  (exact binomial, chance = .33), with a non-significant majority selecting the object match (B) (40%),  $p = .44$ , and a minority selecting the non-match (D) (25%). In contrast, children in the *far* condition selected the relational match (C) significantly more often than chance (61%),  $p < .001$  (exact binomial, chance = .33), with a minority selecting the object match (B) (27%) or non-match (D) (12%).

We next examined differences in the frequency of relational matches in the transfer task for each condition (*near, far*) and each age (4-year-olds, 5-year-olds). Loglinear analysis revealed a significant main effect of condition on relational transfer,  $\chi^2(1, N = 96) = 6.07, p < .01, \Phi = .25$ , and no effect of age,  $\chi^2(1, N = 96) = 1.27, p = .26$  (ns),  $\Phi = .12$ . In line with our second hypothesis, these findings demonstrate that generating a far analogy facilitates subsequent relational reasoning in preschool-aged children.

Finally, we examined the relationship between spontaneous analogies produced in the spatial analogy task, and subsequent relational matches in the transfer task. Given that we found no significant effect of order (bottom 1st, bottom 2nd) on transfer,  $\chi^2(6, N = 96) = 6.38, p = .84$ , we again excluded the front hiding location, due to ceiling performance. We then categorized all children according to whether or not they generated a spontaneous

Table 1  
Proportion of Spontaneous Analogies Produced by Condition, Hiding Location, and Hiding Event Order

Condition	First hiding event	Second hiding event		
Near	Front	1	Bottom	.68
	Bottom	.3	Front	.87
Far	Front	1	Bottom	.38
	Bottom	.25	Front	.96

analogy and compared each group's performance on the transfer task. Children in the *near* condition who generated a spontaneous analogy ( $n = 24$ ) were significantly more likely to select the relational match (50% relational matches) than children who did not ( $n = 24$ , 21% relational matches),  $\chi^2(1, N = 48) = 4.46, p = .03, \Phi = .30$ . This suggests that successfully solving a near analogy does not dampen or disrupt relational responding. Interestingly, this effect did not hold for children who generated a spontaneous analogy in the *far* condition ( $n = 15$ ). These children were no more likely to select the relational match (53%) than children who did not ( $n = 33$ , 64%),  $\chi^2(1, N = 48) = .46, p = .50, \Phi = -.1$ . In fact, when combining children across conditions, generation of spontaneous analogies did not significantly predict relational selections on the subsequent task,  $\chi^2(1, N = 96) = .3, p = .58, \Phi = .06$ .

However, given the possibility of a difference in strategy used during the 1st hiding event and 2nd hiding event (i.e., after children observed initial evidence for the relation between the puzzles), we also conducted a more stringent test of the relationship between spontaneous analogy and transfer by dividing all participants into groups based on their order (bottom first, bottom second). Results of loglinear analysis found no significant effect of spontaneous analogy production in either group,  $\chi^2s(N = 48) < 1, (p = .96; p = .99, ns)$ . These data suggest that relational transfer is not solely driven by individual differences in analogical ability.

Taken together, the results of Experiment 1 are consistent with the claim that engaging in far analogies supports subsequent relational reasoning in children. However, the alternative—that solving a near analogy may *promote* attention to objects, bypassing relational reasoning altogether—is also a possibility. You might imagine, for example, that locating a sticker in a nearly identical box leads children to search for identical elements in the transfer task. In Experiment 2, we therefore further examine the mechanisms underlying these effects.

## Experiment 2

Given our interest in examining the specific impact of distance (*near* vs. *far* analogies) on children's subsequent relational selections, Experiment 2 was designed to assess their *baseline* tendency to privilege relational matches in the transfer task. To do so, we replaced the spatial analogy task that was used in Experiment 1 with a non-analogy search task. By comparing children's search behavior and relational selections in this *baseline* condition with their performance in Experiment 1, we assess whether children's relational reasoning was supported or disrupted in each condition above.

## Method

**Participants.** A total of 48 4- and 5-year-olds ( $M = 60.3$  months, range = 48.8–70.9 months,  $SD = 6.8$ , females = 28) participated. Recruitment procedures were identical to those used in Experiment 1, and participants were comparable in age, gender, and demographics. One additional child was tested but excluded due to experimenter error.

**Materials and procedures.** Materials were identical to those used in Experiment 1, with one critical change to the procedure: Children in Experiment 2 did not receive the initial spatial analogy

task. Instead, children in this *baseline* condition searched for a sticker in two hiding events (front and bottom-center) on the *same* (source) puzzle box (see Appendix B for a complete script of the *baseline* procedure). The experimenter used the same instructions that appeared in the spatial analogy task, informing the child that there was a sticker hidden inside the box. However, after the child located the first sticker, the experimenter told the child that the sticker would be rehidden, and they were given a second opportunity to locate the sticker in the same puzzle box. As in the two conditions assessed in Experiment 1, the order of the hiding locations in this *baseline* condition was counterbalanced, with half of the children assigned to the front location and half assigned to the bottom-center location for the 1st hiding event. Therefore, unlike in the *near* and *far* conditions in Experiment 1, children in Experiment 2 never had the opportunity to draw an analogy between two puzzles. The subsequent transfer task was identical to the one described in Experiment 1.

Again, a second naïve researcher recorded responses for both tasks. Interrater reliability was very high; the coders agreed on 95% of responses. Minor disagreements were decided by discussion with a third researcher.

## Results and Discussion

The primary purpose of Experiment 2 was to compare the frequency of children's relational selections in the transfer task following a non-analogy with those in the *near* and *far* conditions reported in Experiment 1. However, since the data for this *baseline* condition was collected after the completion of Experiment 1 and participants could not be randomly assigned, we used a more conservative alpha level of .025 to establish significance for all condition comparisons.

To do so, we first calculated the frequency of relational matches (C) for children in the *baseline* condition. Like children in the *near* condition, those in the *baseline* condition selected the relational match no more often than chance (33%),  $p = .1$  (exact binomial, chance = .33). However, unlike in the *near* condition, those in the *baseline* condition selected the object match (B) significantly more often than chance (63%),  $p < .0001$ , with very few children selecting the non-match (D) (4%).

We next examined differences in the frequency of relational matches in the transfer task for each condition (*near*, *far*, *baseline*) and each age (4-year-olds, 5-year-olds). Loglinear analysis revealed a significant main effect of condition on relational transfer,  $\chi^2(1, N = 144) = 8.89, p < .02, \Phi = .25$ , and no effect of age,  $\chi^2(1, N = 144) = .70, p = .40$  (ns),  $\Phi = .07$ . Results of chi-squares reveal no significant difference in relational responding between *baseline* and *near* conditions,  $\chi^2(1, N = 96) = .05, p = .82, \Phi = -.02$ , and a significant difference in relational responding between each of these conditions and the *far* condition,  $\chi^2(1, N = 96) = 7.07, p < .01, \Phi = -.27$  and  $\chi^2(1, N = 96) = 6.01, p < .02, \Phi = -.25$ , respectively. However, there was a significant difference in selections of the object match between *baseline* and *near* conditions,  $\chi^2(1, N = 96) = 5.04, p < .03, \Phi = -.23$ , with children in the *baseline* condition significantly more likely to privilege the object match. This evidence suggests that the *near* analogy condition in Experiment 1 did not serve to disrupt relational responding by increasing children's focus on object similarity.

To provide additional support for this claim, we also analyzed children's search behavior in the non-analogy hiding task. As in Experiment 1, this analysis was limited to those participants with video recordings available ( $n = 26$ ). This analysis included the total number of unique actions, as well as the total time spent searching for the sticker across the two hiding events (i.e., including both front and bottom-middle, regardless of order). The mean number of actions prior to sticker discovery across the two (unrelated) hiding events ( $M = 4.54$ ) was statistically greater than the mean number of actions for the two (related) hiding events in either the *near* ( $M = 2.76$ ),  $t(73) = 7.76$ ,  $p < .0001$  or *far* conditions ( $M = 2.98$ ),  $t(71) = 6.65$ ,  $p < .0001$ . There was also a significant increase in search time ( $M = 76.84$ ) compared with both *near* ( $M = 56.39$ ),  $t(57) = -2.5$ ,  $p < .01$  and *far* ( $M = 57.94$ ),  $t(57) = -3.27$ ,  $p < .001$  conditions. These differences suggest that children in both conditions in Experiment 1 likely relied upon analogical reasoning as a strategy to facilitate efficient search.

### General Discussion

Previous research has proposed that generating analogies makes it easier for learners to encode, store, and retrieve relational information in novel situations (Holyoak, 2012). Here we examine children's tendency to spontaneously employ analogical reasoning in the context of a novel problem, as well as their ability to transfer a relational strategy between tasks. The current research extends and elaborates upon two existing claims. First, preschool-aged children *do* spontaneously use analogical reasoning, but do so to a greater extent when the target and source share a greater amount of surface features, and after observing evidence for the relation between them (i.e., in the second hiding event). These results are consistent with previous findings (e.g., DeLoache, Kolstad, & Anderson, 1991; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001). However, engaging in a close comparison did *not* lead to increased relational responding in a subsequent task. Instead, the generation of far analogies, in which the target and source shared *less* perceptual similarity, was a more effective trigger. These findings support the proposal that attempting to generate far analogies evokes transfer of a relational strategy in children. They also contradict previous claims that mapping between highly aligned cases (i.e., a near analogy) necessarily "seeds" further abstraction (Gentner, 2010, p. 761; see also, Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001; Marzolf & DeLoache, 1997; Uttal, Schreiber, & DeLoache, 1995). While progressive alignment works well for fostering relational mapping across highly similar tasks, it does not appear to lead learners to generalize a relational strategy to a novel context.

We also report findings regarding individual differences. Children in the *near* condition who generated a spontaneous analogy were more likely to select the relational match at transfer than children who did not. This provides initial evidence that solving a near analogy does not dampen or disrupt analogical reasoning. However, we did not find this same correlation for children in the *far* condition. These findings suggest that it is the *process* of attempting to solve a far analogy that facilitates relational transfer, regardless of whether the learner gets the analogy right (i.e., the *product* of analogical inference). In other words, the effects of engaging in far analogical reasoning are not entirely reducible to

the benefits of identifying the relation (e.g., see Gentner, Loewenstein, & Thompson, 2003; Novick & Holyoak, 1991; Shtulman, Neal, & Lindquist, 2016).

This work leaves several open questions. First, although we provide evidence that a relational strategy can be induced *within* a domain (i.e., generating a far spatial analogy evokes relational reasoning in another spatial task), future work should consider cases of cross-domain transfer, which would more closely parallel adult work (Vendetti et al., 2014). Relatedly, the semantic relation "middle" happened to appear more than once: first in the solution for one of the two initial hiding events (the center door on the base of the puzzle box), and again in the transfer task (midsized cup). It is unlikely, but possible that children were inadvertently primed to consider this relation. That said, this would not explain the difference of interest (i.e., relational responding in *near* vs. *far* conditions), given that all children received this input. Further, if results were due to priming a specific relation, then we would expect to observe a correlation between the two tasks in the *far* condition. In fact, we find the opposite. Additionally, according to Loewenstein and Gentner (2001), comparing highly similar cases should *better* enable children's tendency to recognize relational information. In other words, if the *near* spatial analogy task served to prime the "middle" relation, this should have been *more* salient for the subsequent inference. Again, however, we find the opposite pattern of results.

Finally, although we provide evidence *that* far analogies promote relational reasoning, future research is needed to assess *why* this occurs. Comparing the results of Experiments 1 and 2 provide substantial evidence against the possibility that solving a near analogy promotes attention to objects, bypassing relational reasoning altogether. Specifically, while there was no evidence for differences in relational responding between *near* (Experiment 1) and *baseline* (Experiment 2) groups, we did find significantly *fewer* object-matches during the transfer task in the *near* condition. If it were the case that the *near* condition promoted attention to objects, we should see an *increase* in object-based responses. Also, as noted above, the correlation found between spontaneous analogies and subsequent relational responses in the *near* condition indicate that successfully solving a near analogy does not disrupt relational responding.

Another possibility, suggested by Vendetti and colleagues (2014), is that generating far analogies results in a "relational mindset," allocating attention to relations, as opposed to perceptual features. It is also possible that generating far analogies promotes the flexible use of knowledge, making both relational and object-based hypotheses more accessible at transfer. This might change the requirements of the learning problem from generating the most appropriate kinds of hypotheses to evaluating them. Of course, another possibility is that this process deemphasizes attention to object-based hypotheses. Specifically, when solving a far analogy, reasoners are unable to rely upon object-based cues, as this would interfere with mapping. To reduce this interference, the reasoner may inhibit overall attention to these cues.

In line with these possibilities, we suggest that the process of solving far analogies provides essential contextual cues to facilitate hypothesis generation and/or evaluation in children (i.e., which hypotheses are considered and/or ultimately selected). This is particularly helpful in ambiguous contexts in which more than one hypothesis is possible. In fact, Brown and colleagues (1986)

suggest that children's tendency to prioritize surface features, rather than assuming structural similarity, may be a rational response to reduce interference in learning. After all, successful learning involves instances of generalization between related events and discrimination between unrelated ones.

In sum, given the large literature on the benefits of scaffolding for relational reasoning and emerging evidence that relational abilities are in place much earlier than was previously believed (Ferry, Hespos, & Gentner, 2015; Hochmann, Mody, & Carey, 2016; Walker & Gopnik, 2014, 2017), the relational shift may be better characterized as a process of coming to recognize those learning contexts in which generalization is an appropriate strategy. It is not that children cannot engage in abstract relational reasoning, but that they typically do not. From this perspective, the source of children's difficulty in generating relational solutions is due to difficulties associated with decontextualized problems. Once context is provided, children are able to capitalize on what they know and apply this knowledge in a flexible way.

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## Appendix A

### Scripts for Near/Far Spatial Analogy Task

[Place the source toy on the table.] “Look! I found a toy for us to play with. I have never seen this toy before, but someone told me there is a sticker hidden inside of it! Would you help me find the sticker by exploring the toy?” [Child searches until the sticker is found.]

“Look, here’s another toy for you to play with! I have never seen this toy before either, but someone told me there is also a sticker hidden inside it. If you had one guess, where would you look to find the sticker?” [Record first action.]

(If found) “Great job!”

(If not found) “Nope. Keep looking! Can you explore the toy to help me find the sticker?” [Record all actions.]

“Great. Now I am going to hide the stickers again! Turn around and close your eyes while I hide the sticker.” [Move the stickers to the second hiding location. Place the source toy on the table again.]

“Now the sticker is here!” [Reveal the second hiding location. Remove the source toy from view, and place the target toy on the table again.]

“Where do you think the sticker is now? If you had one guess, where would you look to find the sticker?” [Record first action.]

(If found) “Great job!”

(If not found) “Nope. Keep looking! Can you explore the toy to help me find the sticker?” [Record all actions.]

## Appendix B

### Script for Baseline Hiding Task

[Place the source toy on the table.] “Look! I found a toy for us to play with. I have never seen this toy before, but someone told me there is a sticker hidden inside of it! Would you help me find the sticker by exploring the toy?” [Child searches until the sticker is found. Record all actions.]

“Great job! Now I am going to hide the sticker again! Turn around and close your eyes while I hide the sticker.” [Move the sticker to the second hiding location. Place the source toy on the table again.]

“Can you help me try to find the sticker again by exploring the toy? Where would you look to find the sticker?” [Child searches until the sticker is found. Record all actions.]

“Great job!”

Received October 4, 2017

Revision received May 7, 2018

Accepted May 11, 2018 ■