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Generating Relations Elicits a Relational Mindset in Children

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Abstract

Relational reasoning is a hallmark of human higher cognition and creativity, yet it is notoriously difficult to encourage in abstract tasks, even in adults. Generally, young children initially focus more on objects, but with age become more focused on relations. While prerequisite knowledge and cognitive resource maturation partially explains this pattern, here we propose a new facet important for children's relational reasoning development: a general orientation to relational information, or a *relational mindset*. We demonstrate that a relational mindset can be elicited, even in 4-year-old children, yielding greater than expected spontaneous attention to relations. Children either generated or listened to an experimenter state the relationships between objects in a set of formal analogy problems, and then in a second task, selected object or relational matches according to their preference. Children tended to make object mappings, but those who generated relations on the first task selected relational matches more often on the second task, signaling that relational attention is malleable even in young children.

Keywords: Relational mindset; Analogical development; Relational reasoning; Relational shifts; Relational similarity; Object similarity

1. Introduction

Analogical reasoning is a hallmark of human higher cognition. The ability to find relationships and draw connections across disparate phenomena is fundamental to creativity and innovation, abstraction, mathematics, and other such complex cognition (Markman &

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Woods, 2009; Polya, 1954). It is also a type of reasoning in which young human children surpass all other species—for instance, in being able to notice and reason on the basis of abstract relationships such as "same" or "different" with very little training—and thus provides unique insights into the nature of human thought (Christie & Gentner, 2014; Penn, Holyoak, & Povinelli, 2008).

At the same time, noticing and reasoning about analogous relational representations is not ubiquitous, with adults often showing low spontaneous attention to relations (Gick & Holyoak, 1980, 1983), though attention to relations does tend to increase with age (e.g., Gentner & Rattermann, 1991; Richland, Morrison, & Holyoak, 2006; but see Carstensen et al., 2019). Younger children tend to rely on object appearance and perceptual features during analogy tasks, which can disrupt performance when that information is irrelevant or in conflict with the analogy. Older children and adults, in contrast, tend to focus more on relationships and disregard object similarity (Daehler & Chen, 1993; Gentner & Rattermann, 1991; Richland, Morrison, & Holyoak, 2006; Thibaut, French, & Vezneva, 2010a). This difference holds true even when children are explicitly instructed to use relational information, suggesting that there are significant challenges involved in relational reasoning.

Subsequently, accounts of this *relational shift* (Gentner, 1988) have focused on two main factors that enable successful analogical reasoning and that improve with age: relational domain knowledge and executive function (EF) capacity. Gains in relational domain knowledge enable content-specific, but potentially rapid, improvements in analogical reasoning, since aligning relations in an analogy requires some knowledge of those relations (e.g., Goswami & Brown, 1990; Rattermann & Gentner, 1998). Consistent with this idea, children (and adults) rely more on object similarity than on relations when they have low knowledge of a domain, while experts tend to reason on the basis of relations (Chi, Feltovich, & Glaser, 1981; Loewenstein, Thompson, & Gentner, 1999).

Even when knowledge is held constant, children continue to improve with age in their abilities to inhibit distraction from non-relational, object-based similarity and handle increasingly complex relational structures. These gains have been attributed to maturation of executive function (EF), including working memory capacity and inhibitory control, which allow children to modulate attention to relations versus object properties with greater control (Richland et al., 2006). Indeed, children's analogical skill is related to individual differences in EF (Blums, Belsky, Grimm, & Chen, 2017; Richland & Burchinal, 2013; Simms, Frausel, & Richland, 2018). Unlike increases in relational domain knowledge, gains in EF should support general, content–independent improvements in analogical reasoning; yet these gains should be slower and less malleable.

Thus, a general relational shift across development may be partly explained by improvements in children's ability to recognize and manipulate relations, supported by age-related growth in relational domain knowledge and executive resources.

1.1. Relational mindset

Here we propose that another key contributor to the development of analogical reasoning may be the cultivation of a *relational mindset* (e.g., Vendetti, Wu, & Holyoak, 2014)—a general inclination to seek out and prioritize relational information. Relational domain knowledge and EF skills are important factors in whether a child will be able to reason analogically, but there may be additional variation in whether children are inclined to construe a situation as relational and engage analogical reasoning processes at all. For example, when adults were asked to explain metaphors like "How is a plant stem like a drinking straw?" they tended to explain them in terms of shared relations (e.g., both draw liquid up) rather than shared attributes (e.g., both are long and thin), though both explanations are equally applicable (Gentner, 1988). Children, in contrast, tended to prefer attributional explanations.

However, adults' tendency to privilege relations seems to involve something beyond greater pre-requisite knowledge and processing capacity, because it can be enhanced—independently of the semantics of the relations—in adults with mature EF. Vendetti, Wu, and Holyoak (2014) asked participants to either generate or judge the validity of solutions to analogies that differed in how abstract the relationship between the base and target was. Following this task, participants completed an ambiguous scene-mapping task, where both object and relational matches were available. Participants who had generated answers to the abstract analogies were more likely than those in the other conditions, and more likely than participants in prior studies using the scene-mapping task (e.g., Markman & Gentner, 1993), to select relational matches. For adults, then, active and effortful analogical reasoning promoted a generalized relational mindset. That is, adults could be predisposed to notice and rely on relational information, independently of the particular relations and tasks involved. Although the mechanisms that gave rise to this phenomenon in adults are not entirely clear, a comparable demonstration in children would suggest that eliciting a relational mindset may be one influence on children's analogical reasoning development.

Much work has explored how to prompt and support children's relational thinking. This work suggests that the general relational shift seen across development may be a consequence of the accumulation of many local shifts that occur within particular content and contexts. For example, comparing multiple examples highlights relational commonalities and supports insights about those relations (e.g., Begolli & Richland, 2016; Christie & Gentner, 2010; Son, Smith, & Goldstone, 2011). Likewise, providing relational labels can help children attend to and represent relational information (e.g., Fyfe, McNeil, & Rittle-Johnson, 2015; Loewenstein & Gentner, 2005). It is possible that interventions like these elicit a general increase in children's prioritization of relations (e.g., Walker, Hubachek, & Vendetti, 2018), as Vendetti et al. (2014) found with adults. However, none of the prior work with children has shown transfer to new relations on a separate task; thus, these improvements could also have been driven by increasing the quantity, quality, or accessibility of specific relational knowledge representations needed during the task (e.g., Glady, French, & Thibaut, 2017; Loewenstein & Gentner, 2005) or by decreasing the burden placed on cognitive resources while reasoning on the task (e.g., Richland & McDonough, 2010; Thibaut, French, & Vezneva, 2010b).

1.2. The present study

We propose that a relational mindset, reflecting a reasoner's general inclinations when using similarity in reasoning, may also contribute to the relational shift in children's analogical development. That is, if children's prioritization of relations is malleable in a content-general way, this offers another avenue—in addition to the content-specific channels that have been demonstrated in prior work (e.g., Loewenstein & Gentner, 2005)—by which children's analogical reasoning may develop.

The current study tests the hypothesis that a generalized relational mindset can be induced in children. In particular, we predicted that it would occur through effortful engagement in constructing and manipulating relational information, as it did for adults (Vendetti et al., 2014). Our design is inspired by the generative dimension of Vendetti and colleagues' priming paradigm. In the study reported here, children first completed a relation-orienting task: a matrix analogy task in which children either actively generated relations or passively listened to an experimenter. Next children completed a scene-mapping task that could be solved using either relational or object similarity. We expected that children who completed the active orienting task would show a stronger preference for relational matches compared to the passive group.

Importantly, our study design precludes the possibility that specific relational knowledge, task-specific procedures (Glady et al., 2017; Thibaut & French, 2016), or EF could account for increased relational responding. The orienting and mapping tasks used different relations, preventing semantic priming or learning and transfer. The formats of the two tasks were also different, so that procedures learned on the orienting task could not be transferred directly to the mapping task. Finally, changes in EF capacity cannot explain such rapid changes, and random assignment means individual differences in EF should not be able to explain differences between the groups.

2. Method

2.1. Participants

Forty-eight 4-year-olds were recruited from an existing developmental research participant database at the authors' university and randomly assigned to one of two experimental conditions (Active or Passive). Children of this age were selected because they exhibit a strong perceptual focus on tasks like those used in this study (e.g., Rattermann & Gentner, 1998; Richland et al., 2006). Sample sizes were chosen to be comparable to those used in the original version of our outcome task (Richland et al., 2006), and to ensure all combinations of task counterbalancing were presented. Two participants were excluded due to experimenter error and one for failure to complete the tasks, leaving 23 participants in the Active condition ($M_{\text{age}} = 4.53$ years) and 22 in the Passive condition

(M_{age} = 4.43 years). The study was approved by the university's Institutional Review Board and adhered to the standards of the US Federal Policy for the Protection of Human Subjects. All children and their caregivers gave consent to participate.

2.2. Materials and procedure

Children were tested individually by an experimenter in a single session. All children completed two tasks: first, a matrix analogy task, which varied by condition, and second, a scene-mapping task, which was the same for both groups. The matrix analogy task was intended to orient children toward relations and provided children with an opportunity to talk and think about relations, more or less actively, in service of completing analogies. The scene-mapping task was designed to assess children's sensitivity to, and preference for, relational similarity. That is, performance on the scene-mapping task reflected the degree of children's relational mindset.

2.2.1. Matrix analogy task

Children completed one of two versions of the matrix analogy task. In the Active version, participants were asked to identify and actively construct descriptions of relations involved in the analogies while solving them. In the Passive version, participants completed the same analogies, but passively listened to descriptions of the relations provided by the experimenter (Table 1).

The task consisted of six matrix analogy problems of the form *A: B:: C: ?* (Fig. 1a), presented in one of six counterbalanced orders. Each problem presented three objects in a two-by-two matrix, with the final space left empty. In the first block of the task (spontaneous production), children were asked to provide their own answer to complete each matrix. In the second block (forced choice), children saw the same problems again but were given three choices from which to select their answer. Thus, both the Active and Passive groups were tasked with finding solutions to the matrix analogies, but only the

Table 1
Key differences between conditions on the matrix analogy task

		Active	Passive
Block 1: Spontaneous Generation	AB	Ask for relation "How do caterpillars go with butterflies?"	Tell relation "Caterpillars *grow into* butterflies."
	CD	Ask for D without relation "What goes with flowers the same way?"	Ask for D with relation "What *grows into* flowers?"
Block 2: Forced Choice	AB	Ask for relation "Do you remember how caterpillars go with butterflies?"	Tell relation "Remember, caterpillars *grow into* butterflies."
	CD	Ask for D without relation "Which one goes with flowers the same way?"	Ask for D with relation "Which one *grows into* flowers?"

Active group was also required to construct and flexibly revise relational representations to achieve that aim. Matrix analogy problems were designed to use objects and relations that were familiar to children of this age and did not vary systematically in the level of abstraction needed to solve them (i.e., in whether they were *near* or *far* analogies).

During spontaneous production (the first block), children in the Active condition were first asked to describe the relationship between the A and B objects (e.g., butterfly, caterpillar). If children provided a relation that would not support a valid analogy (e.g., "Butterflies and caterpillars are both bugs"), they were prompted with increasing levels of support to provide a relation that would create a valid analogy (e.g., "That's one way these go together, but can you think of another way?"). If the child could not generate an appropriate relation after prompting, the experimenter described the relation for them. After describing the A/B relationship, children were asked, without reference to the relation, to think of an object to complete the matrix (e.g., "What goes with flowers the way caterpillars go with butterflies?"). Again, if children provided an answer that did not

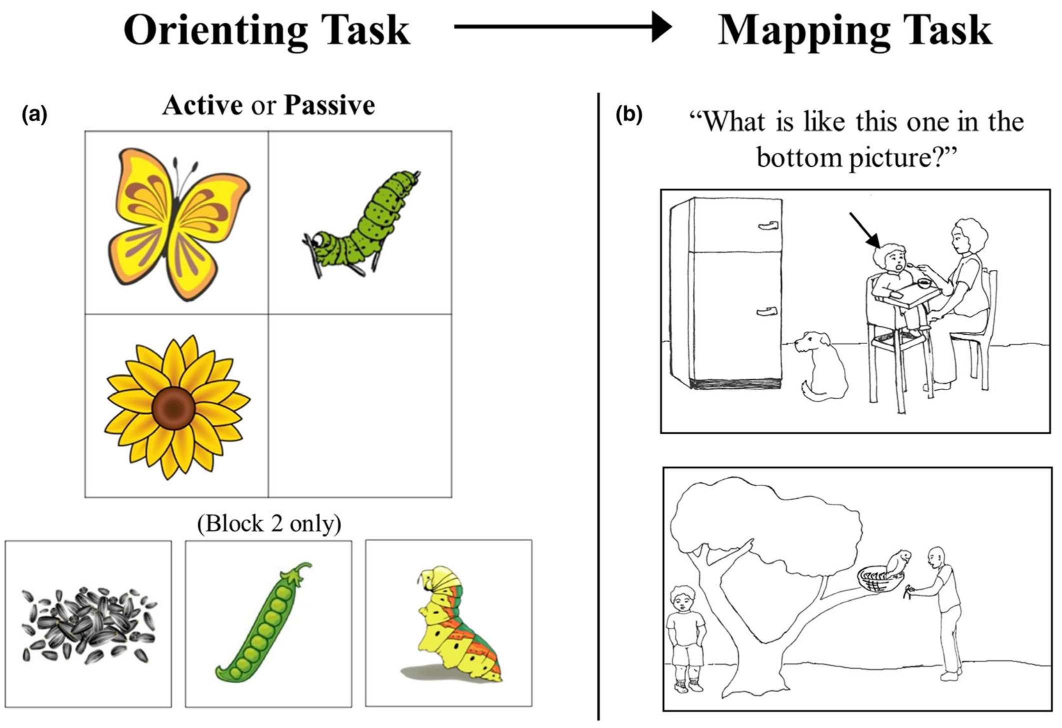

Fig. 1. (a) Sample formal analogy from matrix analogy task—*grows into* (butterfly: caterpillar:: flower: [seeds]). The other five analogies were as follows: *stores inside* (money: piggy bank:: socks: [drawers]), *eats* (acorn: squirrel:: cupcake: [girl]), *lives in* (beehive: bee:: igloo: [Inuit]), *needs to work* (battery: flashlight:: gasoline: [car]), and *makes* (sandcastle: bucket and tools:: cake: [mixer]). (b) A sample scene mapping set with the relation *feeding*.

create a valid analogy (e.g., a bee), children were prompted with increasing levels of support to generate an acceptable answer, first by reminding them of the A/B relationship (e.g., "Remember, caterpillars *grow into* butterflies, so what goes with flowers the same way?") and then, if needed, by extending that relationship to the C object (e.g., "Caterpillars grow into butterflies, so what *grows into* flowers?"). At the conclusion of each trial, the experimenter summarized the completed analogy (e.g., "That's right, seeds grow into flowers just like caterpillars grow into butterflies!").

During the spontaneous production block, children in the Passive condition were led through the matrix in a similar way but were never asked to generate descriptions of the relationships on their own. Instead, the experimenter provided descriptions of the A/B relations (e.g., "Look, caterpillars *grow into* butterflies.") and had the children repeat them. When prompting children to produce the object to complete the analogy, the experimenter also provided the same relation for the C object (e.g., "What *grows into* flowers?"). As in the Active condition, children were prompted again if they did not initially generate an acceptable answer, and at the conclusion of each trial, the experimenter summarized the completed analogy. The prompt scaffolds were used in the Active and Passive conditions to ensure that the two groups would not differ in ultimately finding a valid solution to the analogy, while maintaining the difference in whether children had to attempt finding an appropriate relational description on their own.

In the second block, children were shown the same six matrix analogy problems, but were asked to choose the final object to complete the analogy from among three choices —a correct relational match (relationally similar to B, in that it plays the same role with respect to C as B does with A), a perceptual match (perceptually similar to B), and an object match (taxonomically similar to B; Fig. 1a). Children in the Active condition were asked to recall and describe the relations between A/B, and then to choose the object that "goes with C the same way" (without the experimenter describing the relation). Children in the Passive condition were told the relations between A/B again and were asked by the experimenter to choose the object using a relational description (e.g., "Which of these grows into flowers?"). No corrective feedback was provided on the forced choice trials for either condition. The second block of matrix analogy problems was included to verify that following the spontaneous production block, children in both conditions were equally capable of selecting the correct choice to solve the analogy. Indeed, both groups were highly likely to choose the relational item: The average percentage of correct responses by children in the Active condition was 87.8% and by children in the Passive condition, 86.2%.

2.2.2. *Scene-mapping task*

Immediately after the orienting task, children completed the scene-mapping task (Richland et al., 2006), modeled after the mapping task from Markman and Gentner (1993). In the task, children were shown 20 pairs of scenes, each depicting the same event relations (e.g., *feeding*). One object within the top (source) picture was highlighted with an arrow (either the agent or patient in the event relation). That object was also present in the bottom picture, though it was no longer part of the focal relational group (e.g., a boy;

Fig. 1b). This meant that in all picture sets shown to the child, there was both relational similarity between the source and target pictures (e.g., in both scenes there is someone feeding someone else), and object similarity (e.g., in both scenes there is a boy). Though in some scene pairs, the relational match may have shared some perceptual similarity with the source object, the object match was always the most perceptually similar object in the target scene (Richland et al., 2006). Thus, if a child were seeking perceptual matches, they should have found the perceptual match most compelling. In addition, there were always several objects in the target picture that were neither perceptual nor relational matches to the source object, so strategies such as "avoid the object match" would not have necessarily led to increased relational responding. (See Richland et al., 2006 for additional details about the stimuli.)

Children were told that they would be seeing pairs of pictures, and that their job was to find the thing in the bottom picture that was "like" the one indicated by the experimenter in the top picture. They were also told that they might find more than one thing that was like it, but that they should pick the one that they thought was the best answer. Thus, the task instructions left the matching criteria open for interpretation and did not explicitly guide children toward relational matches, as had been done in previous usage of the task (Richland, Chan, Morrison & Au, 2010; Richland et al., 2006). Children saw one practice item before completing the 20 test items, which were presented in one of four counterbalanced orders. The practice item was like the test items and served to ensure that children understood that they should point to one thing in the bottom picture to respond. No other feedback on children's responses, either on the practice or test items, was given.

3. Results

The data that support the findings of this study are available from the corresponding author upon reasonable request. All items selected by children on the scene analogy task (Fig. 1b) were coded as either a relational match (object in corresponding relational role, e.g., the one feeding), an object match (e.g., boy), a relational error (object participating in the relation but in a different role, e.g., the one being fed), or an "other" object.

Next, we compared the proportion of children's relational matches on the scene-mapping task across conditions using a two-tailed independent-samples t-test. Participants in the Active condition made significantly more relational match choices ($M = 0.35$, $SD = 0.21$) than participants in the Passive condition ($M = 0.23$, $SD = 0.15$), $t(43) = 2.11$, $p = .041$, Hedges' $g = 0.64$ (Fig. 2).

A parallel comparison was carried out on the proportion of children's object match responses. Participants in the Active condition made marginally fewer object match choices ($M = 0.48$, $SD = 0.30$) than participants in the Passive condition ($M = 0.62$, $SD = 0.21$), $t(43) = 1.77$, $p = .083$, Hedges' $g = 0.53$.

Children's relational errors (Active: $M = 0.10$, $SD = 0.08$; Passive: $M = 0.09$, $SD = 0.08$; $t(43) = 0.17$, $p = .869$, Hedges' $g = 0.05$) and other errors (Active: $M = 0.07$,

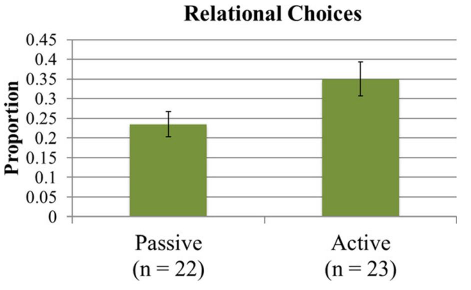

Fig. 2. Children's proportion of relational choices on the scene analogy mapping task.

SD = 0.10; Passive: *M* = 0.05, *SD* = 0.07; $t(43) = 0.68$, $p = .503$, Hedges' $g = 0.20$) did not differ significantly between conditions.

To provide a reference point for these patterns, 3- to 4-year-olds' relational matching on the same items from Richland et al. (2006)—on which they were explicitly asked to match relations—was 38%, about the same as children in the Active condition in this study.

4. Discussion

This study explored the possibility that a relational mindset could be induced in young children. Using a mapping preference task—which contained both relational and object similarity—to measure spontaneous prioritization of relations, we found that children who actively generated relational descriptions in a preceding matrix problem solving task responded more relationally on the following mapping task than children who passively heard relational descriptions. This pattern suggests that, like adults (Vendetti et al., 2014), children can be oriented toward relations in a content-general way, and that active engagement in constructing and deploying relational representations is one avenue through which this mindset is elicited.

It is important to note that although both groups of children in our study were still more likely to select object matches over relational matches, the condition differences highlight how context before a reasoning opportunity can shift children's orientation to similarity. Indeed, children who practiced constructing relational descriptions on the first task were just as relational on the subsequent mapping preference task as children from Richland et al. (2006), who had been explicitly instructed to find and map relations.

Several alternative explanations of our findings warrant mentioning. First, children in the active orienting task may have been more engaged during the session, and differences on the scene mapping task may have reflected differing levels of engagement, rather than relational focus, per se. For instance, less attentive children may have been more likely to choose the most readily available, rather than most ideal, answer—which in this case, may have been an easily perceptible object match. However, this alternative is still consistent with the overall argument that these children were naturally oriented toward perceptual, and not relational, responding. Second, although the two tasks were very different, preventing rote transfer of task procedures, it is still possible that children formed some unidentified strategy in the active orienting condition that spuriously led to increased relational matching on the scene mapping task. For instance, if children in the Active condition were more engaged during the orienting task, they may have been more likely to notice that the analogical choice was often an "oddball" that was not an identity or perceptual match to any of the other items in the problem (though they did not receive feedback that the analogical choice was the correct one). A "find the oddball" strategy on the scene analogy task could have led to the correct relational match for some (though not all) of the scene pairs. Future work on this topic will need to be mindful of these potential alternative strategies.

Nonetheless, these data have important implications for theories of analogy development. The facilitation seen here reflects a distinct factor in relational reasoning development. It cannot be accounted for by specific knowledge, as the two tasks drew on different relations. Likewise, maturation of cognitive capacities cannot be the source of such immediate effects on behavior. Rather, this study documents a rapid, but content-independent shift in children's tendency to seek and use relational similarity. Our findings highlight the need for future work to explore the conditions under which children become not only able, but inclined, to reason relationally, and theories will need to expand to consider the broader set of experiences that shape children's relational thinking outside the immediate context of reasoning.

Further work will be needed to understand the mechanisms that gave rise to the phenomenon we have described here as a relational mindset, and whether and how these mechanisms support the development of analogical reasoning. Our findings, along with those of Vendetti et al. (2014), are consistent with the idea that once effortful relational processing is engaged, its momentum can carry forward to new situations. Encoding and manipulating relational information can be effortful and cognitively costly (e.g., Glady et al., 2017; Richland et al., 2006), and reasoners may be disinclined to engage these more burdensome processes without a compelling reason to do so. However, once engaged, they may be easier to sustain, and their utility may become apparent. As learners repeatedly encounter situations in which relational reasoning is required, they may develop a habit of mind to orient to information with the goal or expectation to consider the relations therein. At some point children may even have the insight that even when the relational information is not easily or readily available to them, it is worth exerting additional effort to discover the relations, given their great utility. Self-generated relational descriptions may have supported this relational insight in our paradigm by prompting reflection on the types of representations necessary for the task, a mechanism suggested by Miller and Marcovitch (2011). They also found that child-generated descriptions led to better performance than experimenter-generated descriptions on an EF-taxing search task. In line with this proposal, Gray and Holyoak (2019) found that individual differences in adults' cognitive reflection predicted relational reasoning proficiency, suggesting that analytical reflection supports relational thinking. Flexibly formulating and revising relational representations, for instance re-interpreting relational descriptions that may not initially align with the presumed structure (Son, Smith, Goldstone, & Leslie, 2012), may play an important role in relational insight.

Our study design points to social interactions as one important source for cultivating a relational mindset in children. Parents and educators who actively engage children in relational description may be shaping children's orientation to similarity more generally, and if such interactions are regular, their effects may coalesce into stable biases. Cross-cultural evidence supports this proposal. Across cultures, caregivers differ in whether and how they draw children's attention to relations and objects (Fernald & Morikawa, 1993; Ogura, Dale, Yamashita, & Murase, 2006; Senzaki, Masuda, Takada, & Okada, 2016), and corresponding cultural differences in disposition toward relations and objects emerge early (Carstensen et al., 2019; Imada, Carlson, & Itakura, 2013; Kuwabara & Smith, 2012; Senzaki et al., 2016; Waxman et al., 2016). Thus, caregivers may impart habitual modes of attending to certain types of information through interactions with their children (e.g., Luce, Callanan, & Smilovic, 2013; Valle, 2009).

In summary, we demonstrated a malleable, generalized relational mindset in children for the first time, suggesting that relational thinking can be encouraged beyond particular relations and tasks. This opens a new avenue for exploring a unique and potentially important component in the development of relational thought: individuals' habits or tendencies toward relational or object-based thinking.

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Conflicts of interest

The authors declare no conflicts of interest.

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