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RESEARCH ARTICLE

Ask me why, don't tell me why: Asking children for explanations facilitates relational thinking

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Abstract

Identifying abstract relations is essential for commonsense reasoning. Research suggests that even young children can infer relations such as "same" and "different," but often fail to apply these concepts. Might the process of explaining facilitate the recognition and application of relational concepts? Based on prior work suggesting that explanation can be a powerful tool to promote abstract reasoning, we predicted that children would be more likely to discover and use an abstract relational rule when they were prompted to explain observations instantiating that rule, compared to when they received demonstration alone. Five- and 6-year-olds were given a modified Relational Match to Sample (RMTS) task, with repeated demonstrations of relational (same) matches by an adult. Half of the children were prompted to explain these matches; the other half reported the match they observed. Children who were prompted to explain showed immediate, stable success, while those only asked to report the outcome of the pedagogical demonstration did not. Findings provide evidence that explanation facilitates early abstraction over and above demonstration alone.

KEYWORDS
abstraction, cognitive development, explanation, relational reasoning

1 | INTRODUCTION

The ability to go beyond perceptual similarity to recognize abstract relations between objects and events is a key component of everyday reasoning (Gentner, 2010). A pair of salt and pepper shakers on the table can be used to explain how the moon rotates around the earth, describe the movement of cars in a collision, or illustrate highly flexible relations such as "opposites." Abstract relations play a particularly essential role in scientific and mathematical reasoning—skills that are especially important in educational contexts. Much of the research on the early development of relational reasoning has focused on children's capacity to recognize and apply the fundamental concepts of *same* and *different*, which are not restricted to a specific modality (e.g., *same* color, *same* sound) or cognitive domain (e.g., *same* number, *same* emotion), and lay the groundwork for more complex relations, such as "orbit," "collision," or "opposites" (Gentner, 2003; Hochmann et al., 2016).

The canonical test of *same-different* reasoning is the Relational Match to Sample (RMTS) task (Premack, 1983), which requires participants to identify a correspondence between stimuli on the basis of these abstract relations. A single trial of RMTS includes three pairs of objects: a sample pair and two choice pairs. Each pair contains two objects that are either the same or different. The correct choice pair is the one in which the relation between objects matches the relation in the sample pair (i.e., matching AA with BB, not CD, and matching EF with CD, not BB). Children must select the relational match (*same* or *different*) spontaneously to succeed.

A more challenging version of this task pits this relational match against a salient object match, in which one of the test pairs includes an item that is identical to one of the items in the sample pair (for example, given AA, participants choose between BB [relational match] and AC [object match]). There is no wrong answer in this formulation of RMTS, since it is reasonable to match on the basis of either relational similarity (matching AA with BB) or object similarity (matching AA with AC). Despite this, adults reliably match based on relational similarity, while 4.5-year-olds tend to match based on object similarity and 8.5-year-olds select between the two at chance (Christie & Gentner, 2007). Findings like these have traditionally been used to suggest that children tend to process object-based commonalities before they process relational ones in a given domain (i.e., Christie & Gentner, 2014; the *relational shift*, Gentner, 1977, 1988).

Recent work with a broader range of tasks has explored when and how children *do* engage in relational reasoning. These results suggest that even very young children not only recognize *same-different* concepts (Ferry et al., 2015), but use these and other abstract relations to guide future inferences and behavior (Hochmann et al., 2016; Goddu et al., 2020; Walker & Gopnik, 2014; Walker & Gopnik, 2017). For example, toddlers as young as 18-30 months can succeed on a causal relational reasoning task after only a few trials and without explicit linguistic cues or instruction (Walker & Gopnik, 2014). Although the causal paradigm differs from the classic RMTS task by providing learners with some evidence for the relation before they are asked to make a choice, children's early success—and later failure on this same task—suggests that they may *learn* to privilege object similarity over relational similarity in some domains (Carstensen et al., 2019; Walker et al., 2016; Walker et al., 2020).

Indeed, results from research with both children and adults indicate that although relational concepts are in place surprisingly early, their actual *use* in particular contexts is sensitive to a host of factors, particularly when a more concrete, object-based alternative is available. For example, when the depicted relation in an RMTS task is given a novel label (e.g., "truffet"), children as young as two perform above chance (Christie & Gentner, 2014, Experiment 4) and older children and adults show significant improvement (Christie & Gentner, 2007, Experiment 2; Gentner et al., 2011). In a modified version of Walker and Gopnik's (2014) causal relational reasoning task, in which pairs of *same* or *different* blocks cause a machine to play music, 3-year-olds are significantly more likely to make relational matches when the items are placed in openings on either side of the machine, rather than on top (Walker et al., 2020). Similarly, preschoolers are more likely to understand abstract relations when they are the result of causal transformations (Goddu et al., 2020).

Other results suggest that interventions that change a learner's orientation to the problem—inducing a *relational mindset*—can also lead to increased relational reasoning among adults and young children (Vendetti et al., 2014; Walker et al., 2018; Simms & Richland, 2019). For example, Vendetti et al. (2014) prompted adults to produce four-term analogies and then complete a relational picture-mapping task. They found that participants who generated far analogies (e.g., *"nose:scent::antenna:??"* [answer: *signal*]) identified a greater proportion of relational over object matches in the subsequent task, compared to controls. Related results have also been found with 4- and 5-year-olds (Walker et al., 2018; Simms & Richland, 2019).

The fact that abstract reasoning can be facilitated by using labels, providing contextual cues, or promoting a relational mindset provides strong evidence that children do not lack relational competence or

RESEARCH HIGHLIGHTS

- We examine prior claims that explanation supports abstraction using a task that pits abstract relational similarity against object similarity.
- Children who explained an experimenter's choice of relational matches in a modified Relational Match to Sample task privileged relations over objects in their own selections.
- Merely reporting the experimenter's matching behavior was insufficient to promote relational responding in controls, despite observing repeated demonstrations of the relational choice.
- Findings suggest that explaining successfully promotes abstraction among 5–6 year-olds, over and above pedagogical demonstration alone.

the ability to override the appeal of object matches. But it remains unclear how and why children succeed in exercising these abilities in some conditions but not others. It is also important to understand how these interventions can be generalized to provide a strategy for promoting relational thinking in educational and everyday contexts (see Gentner et al., 2016). Here, we consider two broadly applicable strategies that might promote relational thinking. The first strategy, *pedagogical demonstration*, disambiguates the classic RMTS task by providing evidence that a relational match is correct and that an object match is not. The second strategy, *explanation*, invites children to explain *why* a relational match is correct after observing the outcome of the same pedagogical demonstration.

We compared the effects of explanation to pedagogical demonstration alone in order to isolate the specific impact of explanation from the broader effects of instruction that relational matches are preferred. Several researchers have suggested that young children's consistent preference for object similarity may reflect their specific *inductive biases* (Carstensen et al., 2019; Kroupin & Carey, 2021; Walker et al., 2016). Given children's sensitivity to information presented in a pedagogical context (Bonawitz et al., 2011; Buchsbaum et al., 2011; Rhodes et al., 2010; Shafto et al., 2012), and findings suggesting that children expect this information to be more broadly generalizable than information that is presented naturalistically (Csibra & Gergely, 2009), simply disambiguating the learning problem might be sufficient to promote relational responding on RMTS. If so, we would expect 5-6-year-olds in both conditions to consistently privilege relationships over objects in their own matches, contrary to typical behavior at this age.

On the other hand, prior work demonstrating the effectiveness of labeling and comparison suggests that direct feedback alone may be insufficient to promote relational responding in young children (Christie & Gentner, 2014). Specifically, when 2- and 3-year-olds received corrective feedback over four successive training trials of RMTS (Experiment 2), they continued to perform at chance on subsequent trials, even in the absence of an object match. In fact, they performed no differently than children who received no feedback at all (Experiment 1). The authors concluded that symbolic-linguistic experience is instrumental in shaping relational reasoning abilities by highlighting common relational structure (Experiments 3 and 4).

Here, we consider another means to facilitate abstract reasoning in older children, who regularly produce *same-different* language (Hochmann et al., 2017), but do not yet spontaneously privilege relations when an object match is available (Christie & Gentner, 2007). Specifically, we predict that *explaining* will promote relational responding over and above any effect of pedagogical demonstration. Although there is evidence that both types of scaffold support learning, the effects of self-generated explanations often differ from those of experimenter-provided explanations in the context of direct instruction (e.g., Rittle-Johnson, 2006; Rittle-Johnson et al., 2008; Wittwer & Renkl, 2008). In particular, simply asking children to generate explanations has a powerful effect on learning outcomes, even when no corrective feedback is provided (e.g., Chi et al., 1994; Chi, 2000; Crowley & Siegler, 1999; DeLeeuw & Chi, 2003; Fonseca & Chi, 2011; Lombrozo, 2012; Walker et al., 2012; Wellman & Liu, 2007; Walker & Nyhout, 2019). Researchers have suggested that hypotheses that are formulated in the context of explaining (as opposed to observing, predicting, or describing) are particularly likely to be abstract, broad in scope, and widely generalizable (Walker & Lombrozo, 2017; Williams & Lombrozo, 2010; Williams & Lombrozo, 2013; for a review see Lombrozo, 2016). As a result, learners who explain—but not those who observe equivalent data—tend to privilege more inductively rich hypotheses that go beyond surface similarities (Legare & Lombrozo, 2014; Walker et al., 2014; Walker & Gopnik, 2017; Brockbank & Walker, 2022). In the context of a RMTS task that pits object matches against (same) relational matches, we might therefore expect children who explain instances of relational matching to better recognize abstract patterns in these observations, and to favor relations in their subsequent choices.

Critically, children in the control condition received identical information as those prompted to explain but did not engage in the constructive process of generating an explanation for the demonstrated matches. Instead, controls were simply asked to *report* the outcome they observed. In line with prior work on explanation (e.g., Walker et al., 2016; Walker & Lombrozo, 2017), reporting was selected as a control task because it shares many commonalities with explaining: It draws children's attention to the evidence, requires them to respond in a pedagogical context, and roughly matches the amount of time they spend engaging with each trial (e.g., Walker et al., 2016).

Finding that explaining relational matches promotes success on the modified RMTS task, whereas reporting on the pedagogical demonstration does not, would offer strong evidence that processes of abstraction and generalization are required to support children's relational thinking. Like labeling and prompts to compare, explanation may provide a route to abstraction in early life. This result would not only contribute to our understanding of the role of explanation in children's learning, but would also pave the way for the development of a novel, domain-general intervention to promote relational thinking.

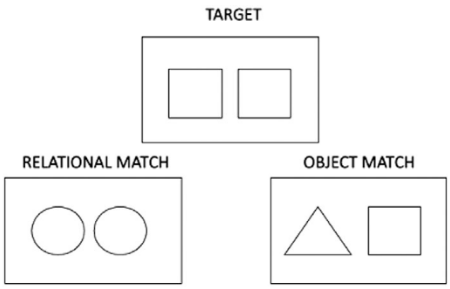

FIGURE 1 Sample triad consisting of a *target*, a *relational match*, and an *object match*.

2 | METHOD

2.1 | Participants

Forty-six 5- and 6-year-olds[1] (M = 71.3 months; SD = 7.6, range: 58.6–82.9; 20 girls) were included, with 23 children randomly assigned to each of two conditions (*explain* and *report*). There was no significant difference in age between conditions (M = 71.3 and 71.4, respectively, p = 0.98), and there were approximately equal numbers of males and females assigned to each. Six additional children were tested, but excluded, due to experimenter error (5) or failing to complete the study (1). Children were recruited from a local science museum and a range of ethnicities resembling the diversity of the population was represented. Though individual demographic data were not obtained at the time of data collection, the population of museum visitors consisted of approximately 38% white families, 24% that identify as Asian, 9% that identify as Hispanic or Latino, 4% that identify as Black or Afrian American, 1% identifying as Native Hawaiian or Pacific Islander, and 17% selecting mulitiple categories. The remaining visitors did not disclose this information.

2.2 | Materials

Children were presented with a total of 12 unique triads, each consisting of three 3″ x 5″ white cards depicting black line drawings of pairs of geometric shapes. Each triad included a target, an object match, and a relational match (see Figure 1). All 12 targets depicted the relation *same* (e.g., two squares). The choice to include only the *same* relation is consistent with prior developmental work (Christie & Gentner, 2007, 2014), and aligns with recent proposals that the concept *different* may be derived largely from its relation to *same* in both children and adults (i.e., "not same," Hochmann, 2021; Hochmann et al., 2018; Hochmann et al., 2016).

Within each triad, the object match included one shape that was identical to the target (e.g., a square) alongside a different shape (e.g., a triangle), and the relational match was composed of two novel shapes in the *same* relation (e.g., two circles). Left and right placement of the object and relational matches was semirandomized to avoid any discernable pattern, with each type of match appearing on the left and right sides an equal number of times (six per side). Learners were presented with a novel set of shape pairs in each trial for a total of 36 unique shapes across 12 trials. The shapes included basic geometric shapes (e.g., circle, square, diamond, pentagon) or other familiar shapes (e.g., teardrop, crescent, Pac-man-shape). No shapes appeared in more than one trial. Each participant saw the same 12 triads, with the order of presentation randomized across participants.

2.3 | Procedure

The child was seated at a table across from the experimenter. The experimenter explained that they would play a turn-taking game, and that the experimenter would begin. Children observed as the experimenter produced the first triad (T1), consisting of a target, an object match, and a relational match. The experimenter said, *"See this card?"* (placing the target card on the table), *"And see these two cards?"* (placing the object and relational match cards on the table below the target). *"In my game, this card* (pointing to the relational match) *goes with this card* (pointing to the target)*!"* She then placed the relational match card beside the target.

Next, depending upon the child's condition, the experimenter asked them to explain their selection (*"Can you tell me why I said this card* [pointing to the relational match] *goes with this card* [pointing to the target]?") or report their selection (*"Can you remind me which card I said goes with this card* [pointing to the target]?"), and the child's response was recorded. This nonverbal control task was chosen in order to similarly draw children's attention to the relational match, while limiting cognitive load. No feedback or requests for additional information were given to participants in either condition, even when children provided explanations that were uninformative or not relevant to the task (39 of 276 explanations; see coding criteria below). Afterwards, all three cards in T1 were removed from view. To provide children the opportunity to benefit from multiple examples, the experimenter then produced a second triad (T2), composed of a new set of three cards, and repeated the entire procedure.

After T1 and T2, the experimenter said, *"Now it will be your turn to play my game!"* and for both T3 and T4, the child was presented with a triad in the same manner described above. The child was then asked to select either the object match or the relational match to place next to the target card. The experimenter said, *"Can you tell me which of these cards* (pointing to the object match and the relational match) *goes with this card* (pointing to the target) *in my game?"* The child indicated their choice by pointing to one of the cards or by placing one of the cards next to the target. The experimenter provided no positive or negative feedback on the child's selection. Then, as in the previous trials, the child was prompted to either explain (*"Can you tell me why you said that this card* [pointing to the child's selection] *goes with this card* [pointing to the target]?") or report (*"Can you remind me which card you said goes with this card* [pointing to the target]?") their own selection.

After T3 and T4, it was the experimenter's turn again for T5 and T6, and this pattern continued for a total of 12 trials, with the experimenter and child alternating every two turns. Therefore, by the end of the game, each child had provided a total of 12 explanations or reports (six for the experimenter's selections and six for their own selections) and generated a total of six matches, which served as the dependent variable.[2]

2.3.1 | Coding

Children's responses were recorded by the experimenter during the testing session, and all sessions were video recorded for independent coding by a second researcher who was naïve to the hypotheses of the experiment. For the matching questions, children's matches were coded as "1" if they selected the *relational match*, and as "0" if they selected the *object match*. This produced a matching score between 0 and 6, or the number of matches consistent with relational responding. Interrater reliability on the matching questions was very high; the two coders agreed on 97% of children's matches, with minor discrepancies resolved by a third party.

Children's explanations were intially coded as belonging to one of four broad categories: 1) object focused (*"this one is pointy like this one," "this shape* [gesturing to the object match card] *matches this shape here* [gesturing to the target card]"), 2) relation focused (*"because they are doubles," "because they both have two of the same shape"*), 3) other (*"because circles fit in squares," "it looks like a rainbow"*), and 4) no response (*"I don't know"*). Explanations were coded as relation focused if they included *any* mention of relational properties, even if object properties were also mentioned, and were only coded as object focused if they strictly referred to object properties. This inclusive approach ensures that any explanation that could have reflected children's recognition of the relation was treated as relational. All explanations were coded separately by two individuals for whom the purpose of the study was unknown. The codes were then compared to assess agreement. Interrater reliability was again quite high: The two coders agreed on 93% of the coded explanations, with minor discrepancies resolved by a third party.

Given prior work suggesting that actively verbalizing relationships may be important to children's success (Hochmann et al., 2017; Simms & Richland, 2019; Christie & Gentner, 2014, Experiment 3), a second coding procedure was used to evaluate how often participants explicitly produced the words "same" or "different" in their explanations. Each explanation was coded as "1" if it included the words "same" or "different" and "0" otherwise. This analysis was restricted to explanations, since verbal reports did not require justification. "Same-different" language appeared in both relational explanations (e.g., *"because they both have two that are the same shape"*) and object-based explanations (e.g., *"this circle* [pointing to the target] *is the same as this circle* [pointing to the object-match]"). This allowed us to investigate whether producing "same-different" labels in their explanations impacted children's subsequent matching behavior.

3 | RESULTS

3.1 | Matching items

One-sample *t*-tests comparing children's total matching score (out of 6) with chance performance (3) indicated that those in the *report* condition demonstrated a clear preference for the object match ($M = 1.44$ out of 6, 95% CI = [0.53, 2.34]), $t(22) = -3.60$, $p = 0.002$, replicating previous research (Christie & Gentner, 2007). On the other hand, children in the *explain* condition significantly preferred the relational match ($M = 4.78$ out of 6, 95% CI = [3.84, 5.72]), $t(22) = 3.93$, $p < 0.001$, and there was a significant difference between the average match scores in the *report* and *explain* conditions, $t(44) = 5.33$, $p < 0.001$, 95% CI = [2.08, 4.61].

Notably, the average number of relational matches for children in the *explain* condition remained surprisingly consistent when comparing performance on the first set of child-initiated matches (T3 and T4) to the last set (T11 and T12) (T3-4: $M = 1.57$ out of 2, $SD = 0.84$; T11-12: $M = 1.57$ out of 2, $SD = 0.79$), indicating that there was no significant effect of learning across trials, $p =0\ 1$, 95% CI for the difference = [−0.23, 0.23]. In fact, there is already a significant difference between conditions on the very first child-initiated trial (T3) (*explain*: $M = 0.78$, $SD = 0.42$; *report*: $M = 0.22$, $SD = 0.42$), $t(44) = 4.55$, $p < 0.001$, 95% CI for the difference = [0.32, 0.82]. In contrast, the average number of relational matches for children in the *report* condition increased somewhat between the first set of child-initiated matches (T3-4: $M = 0.35$ out of 2, $SD = 0.71$) and the last set (T11-12: $M = 0.70$ out of 2, $SD = 0.93$), though this increase is not significant ($t(22) = 2.01$, $p = 0.057$, 95% CI for the difference = [−0.01, 0.71]. This suggests that providing children with pedagogical demonstrations repeatedly across trials may serve as an alternative, albeit weaker, method for facilitating relational reasoning over time. Despite this improvement, relational matches in the *report* condition did not differ significantly from chance by the last set (T12), ($N = 23$, $K = 8$), $p = 0.210$, 95% CI for success probability = [0.16, 0.57]. Figure 2 shows a detailed breakdown of the proportion correct on each trial across the two conditions.

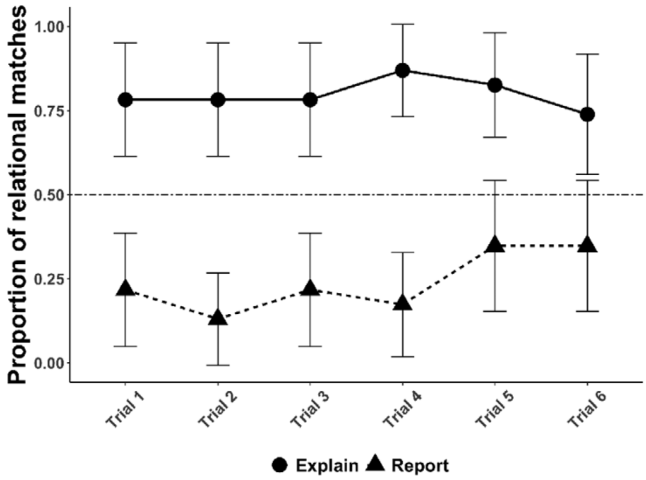

FIGURE 2 Proportion of relational matches made by children in *explain* and control *report* conditions over the six child-initiated trials. Error bars represent 95% confidence intervals.

TABLE 1 Mean relational matches as a function of child's modal explanation type for experimenter trials, child trials, and all trials

Modal explanation	Frequency	Mean Relational Matches
Experimenter trials		
Relational	15	5.7
Object	4	1.8
Other	3	3.7
No response	1	6.0
Child trials		
Relational	14	5.7
Object	7	3.0
Other	2	4.5
No response	0	–
All trials		
Relational	15	5.7
Object	6	2.5
Other	2	4.5
No Response	0	–

3.2 | Qualitative analysis of explanations

Next, we analyzed the frequency of different types of explanations. Most of children's explanations were relational (63% of all explanations produced). To analyze the relationship between explanation type and relational matches, we calculated a modal explanation for each child, which reflects the most common explanation type provided by that child (see Table 1). There were two cases where children had an equal number of "object" and "other" responses, and these were coded as object-based explanations.

The 15 children who appealed to the relation most often (i.e., as their modal response across all 12 trials) were more likely to select the relational match ($M = 5.73$ out of 6, $SD = 1.03$) than the six children who provided object-based explanations most often ($M = 2.50$ out of 6, $SD = 2.81$). Despite the small sample sizes, the difference between these groups is significant, $t(19) = 3.96$, $p < 0.001$, 95% CI of difference = [1.52, 4.95]. Interestingly, children who provided an object-based modal explanation performed no differently from children in the *report* condition ($M = 1.43$, $SD = 2.09$), $t(27) = 1.04$, $p = 0.308$, 95% CI of difference = [−1.04, 3.17]. The two remaining children who provided explanations that were not characterized as either relational or object-based were nevertheless more likely to select the relational match ($M = 4.50$, $SD = 2.12$). Together, these results suggest that although providing a relational explanation may not be necessary for the explanation prompt to increase relational matching, providing an object-based explanation may lead children to privilege object similarity in their selections or simply reinforce their prior preference for the object match.

Finally, children's explanations generally remained consistent over the course of the 12 trials, with no significant difference in the proportion of relational explanations between T1 (70%) and T12 (65%), $p = 1$. Children's explanations for the experimenter's matches were also surprisingly consistent with explanations for their own, with 65% of children providing modal explanations that appealed to the relational property in the experimenter trials (which always followed a relational match) and 61% in the child-initiated trials.

To determine whether explainers' success was a function of explicitly verbalizing the relational concept, rather than engaging in the process of explanation, we also analyze whether children used the words "same" or "different" in the explanations they provided. We first determined that not all relational explanations relied on "same-different" language; across all relational explanations, 42% *did not* include the terms "same" or "different" (e.g., saying *"because these two are circles,"* while pointing to the two shapes in a pair). As noted above, "same-different" language also sometimes appeared in object-based explanations, though this occurred less often (73% *did not* include these terms).

We also examined whether producing "same-different" language increased children's tendency to select a relational match. As above, we first calculated a modal category for each child, which reflects whether they used "same-different" language in the majority of their explanations. There were four cases where children produced an equal number of explanations that did and did not include "same-different" language, and these were coded as "same-different" (however, the pattern of results does not change when these are coded in the opposite direction). We found no significant difference in the mean number of relational matches across modal explanation groups ("same-different" $M = 5.45$, $SD = 1.81$; no "same-different" $M = 4.17$, $SD = 2.37$), $t(21) = 1.46$, $p = 0.16$, 95% CI of the difference = [−.55, 3.13].[3]

The results above provide a coarse indication that producing "same-different" language did not impact children's overall matching behavior. To complement this, we also examine the relationship between each individual explanation produced and children's matches on the immediately subsequent trial. On trials in which participants produced explanations using "same-different" language, the average percent of relational matches was 85% ($SD = 4.25$) on the following trial. Meanwhile, participants who did *not* verbalize "same-different" language subsequently selected the relational match an average of 76% ($SD = 6.58$) of the time. Including children's production of additional relational terms ("alike," "similar," and "match," following Hochmann et al., 2017) does not change this outcome: Relational choices following trials that did not include *any* of these terms remained high ($M = 73.51\%$, $SD = 8.57$). The number of children choosing the relational match after providing a "same-different" explanation was not significantly different from the number of children who did not produce these terms, $t(5) = -1.07$, $p = 0.335$. In short, relational matching behavior was common in the *explanation* condition, even following explanations that did not rely on "same-different" terms.

While these results provide a direct comparison of participants' match behavior immediately following individual explanations that did or did not include relational terms, it remains possible that producing the words "same" and "different" *at any point* during the experiment may have led to increased relational reasoning overall. To evaluate this possibility, we fit a logistic mixed effects model to participants' match responses with a random intercept for each subject. In a model comparison between this null model and one which included a binary fixed effect term indicating whether each participant used the words "same" or "different" on a given trial, the addition of this predictor did not provide a significantly better fit to the data, $\chi^2(1) = 3.25$, $p = 0.071$. When we include a broader set of relational terms in the predictor ("alike," "similar," and "match," once again following Hochmann et al., 2017), the results are similar, $\chi^2(1) = 0.79$, $p = 0.373$. These findings suggest that relational responding was not inextricably linked to children's production of relational terms in the explanations they provided.

4 | DISCUSSION

In the current experiment, prompting children to explain encouraged relational reasoning in a modified Relational Match to Sample task. Specifically, children who explained were more likely to discover and apply the abstract relational property *same* than those who observed pedagogical demonstrations of the relational match and reported what they saw. These findings support existing claims that explanation influences how learners exercise their representational abilities by introducing systematic biases toward more abstract, generalizable hypotheses (Brockbank & Walker, 2022; Lombrozo, 2016; Schulz, 2012; Walker et al., 2014; Williams & Lombrozo, 2010; Williams & Lombrozo, 2013). Here we find that these effects extend to promote relational reasoning in children. Not only is this domain particularly challenging for young learners, but prior interventions that have been used to facilitate early relational responding have been largely task-specific (e.g., providing a novel label for relation-matched pairs). In contrast, we show that prompts to explain offer a highly effective and general solution to encourage children's recognition of abstract relations.

These findings also provide additional support for the claim that children's tendency to privilege objects and superficial properties in relational reasoning tasks is due to their failure to appropriately conceptualize the problem (Walker et al., 2016). This is compatible with several recent proposals regarding the nature of early relational inferences. For example, Kroupin and Carey (2021) propose that children have distinct inductive biases relative to adults—that is, they may not expect that *same-different* relations are likely to inform decisions in RMTS (see Carstensen et al., 2019 for a similar argument regarding cross-cultural differences in the development of relational reasoning). As noted in the introduction, prior work has also emphasized the role of a "relational mindset" (Vendetti et al., 2014; Walker et al., 2018; Simms & Richland, 2019) and environmental cues (Goddu et al., 2020; Walker et al., 2020) which prompt learners to favor relations. The fact that explanation—but not demonstration alone—promotes relational reasoning sheds light on the potential mechanisms underlying these prior effects. In particular, these interventions are unlikely to reflect mere shifts in orientation, attention, or the reduction of task ambiguity. Instead, to prioritize relational over object-based solutions, children must also conceptualize the problem at the appropriate level of abstraction.

Several possible accounts of the observed condition differences are worth considering. One possibility is that the increase in relational matches in the *explain* condition was not due to generating *explanations* per se, but due to verbalizing relations. This might impact children's relational responding in two ways. First, prior work has shown that training young children to apply the words "same" and "different" to familiar stimuli can promote their success on RMTS (Christie & Gentner, 2014, Experiment 3). However, if generating these relations was critical for success, we might expect to observe particular benefits for children whose explanations contained "same-different" language. Although children's explanations did make frequent use of relational terms, many did not include the specific words "same" or "different." Further, verbalization of these terms was not related to children's tendency to select relational matches, either immediately following their production of this type of explanation or overall. Instead, we find similar rates of relational matches for children who did and did not use same-different labels. In fact, participants sometimes applied these terms to justify their selection of the object match (e.g., *"because it* [the object match] *has the same shape as this one* [the target]*"*).

Second, the act of expressing relations, regardless of the specific type produced, may increase children's attention to relations on subsequent trials. Indeed, Simms and Richland (2019) show that actively *generating* a diverse set of relations like "grows into" is more likely to support children's future relational reasoning than *receiving* an explanation with the same relational content (also see Hochmann et al., 2017). In line with this account, we find that explainers in the current study who provided object-focused modal explanations performed no differently from controls. However, if children became increasingly attentive to relational matches after generating relational concepts in their explanations, we might have expected them to improve over the course of the experiment. While control participants exhibited a small increase in relational responding over repeated trials, explainers did not. Future work is needed to better understand the precise mechanisms underlying these effects.

Another possibility is that explaining prompted children to engage in rich comparison, leading them to identify the source of commonality between the target and relational match. Indeed, prior work on explanation shows that children will sometimes engage in comparison in pursuit of broad patterns (Edwards et al., 2019; Williams & Lombrozo, 2010). On the other hand, explanation has also been shown to support abstraction in a wide range of settings, including those where comparison is less likely to play a role. For example, Walker and Lombrozo (2017) found that 5- and 6-year-olds who were prompted to explain the events in a story were more likely to abstract the moral lesson than children who simply reported the same narrative events. Finally, although it is possible that explanation encouraged comparison in the current task, children in the control condition also had ample opportunity to spontaneously compare the demonstrations across repeated trials. While the current experiment cannot test the relationship between comparison and abstraction directly, if the process of comparison was central to children's relational match behavior, this was apparently only triggered by the prompt to explain.

We prefer an alternative possibility that draws on the broader explanation literature highlighted in the introduction, which argues that the process of generating an explanation during learning leads children and adults to pursue abstract, generalizable solutions (Lombrozo, 2016). Specifically, prior work has shown that the search for "good explanations" leads learners to generate solutions that are simple (Bonawitz & Lombrozo, 2012) and broad (Walker et al., 2014), and to seek information that is causally relevant (Frazier et al., 2009). In the current task, searching for a simple, unifying explanation should make children more likely to embrace a relational hypothesis to account for the experimenter's matching behavior by abstracting beyond trial-specific object similarity. Additionally, recent results suggest that explanation supports abstraction by encouraging children to recognize features that apply more broadly (Ruggeri et al., 2019) and by biasing which hypotheses are *generated* in the first place (Brockbank & Walker, 2022). This might account for explainers' success on the very first trial; explaining may have made them more likely to generate the relational hypothesis from the outset.

While the current results suggest that explaining may have supported children's relational reasoning through the pursuit of broad, abstract solutions, there are several open questions to be explored in future research. First, in line with prior work (Christie & Gentner, 2007), our modified RMTS task only required that children match the identity relation (*same*), rather than interleaving *same* and *different* trials. As a result, children may have succeeded by recognizing that on any given trial, their task was to select the card that instantiated the *same* relation without reference to the particular target. However, even if this simplified task partly accounts for explainers' success, it cannot explain the clear condition differences observed.

Second, additional work is needed to examine the precise mechanisms by which explanation supports abstraction, and why, in some domains, learning by example is insufficient (see Rittle-Johnson, 2006 for related findings). One possible explanation for the low frequency of relational matches among controls comes from pedagogical work emphasizing the distinction between *active* and *constructive* learning, where active learning is demarcated by "attending processes" (e.g., reporting) and constructive learning by "creating processes" (e.g., explanation) (Chi, 2009). Prior findings predict that we should see improved learning outcomes in constructive settings relative to active ones, but most existing work in this area has focused on learning outcomes for fairly concrete materials (Chi et al., 1994; Hausmann & VanLehn, 2007; Rittle-Johnson, 2006). Far less is known about the pedagogical approaches that best support general cognitive processes like abstraction. The current results highlight the distinction between *active* and *constructive* learning processes, and raise further questions about why active processes like explanation foster abstraction. Future studies using the current paradigm might explore this further by contrasting the effects of actively *generating* relational explanations with passively *receiving* these explanations (Simms & Richland, 2019). Future work should also compare the value of explaining with *other types* of constructive learning activities to provide new avenues for improving the effectiveness of instructional approaches, particularly in science and math education, where abstract relations play a central role. Finally, additional research is necessary to better understand the conditions under which children engage in explanation spontaneously—even without an experimental prompt to explain (Liquin & Lombrozo, 2020).

In sum, these results provide strong evidence that asking children to explain observations in the world around them opens doors to abstract relational reasoning processes that may be unavailable when they simply view adult demonstrations. In educational settings, asking children to explain material themselves may be the best way to get them to think abstractly.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest in this work. All funding sources are disclosed in the Acknowledgements.

AUTHOR CONTRIBUTIONS

C. Walker, T. Lombrozo, and A. Gopnik developed the study concept. C. Walker designed the study. Testing and data collection were performed by C. Walker. E. Brockbank performed the data analysis and interpretation under the supervision of C. Walker. E. Brockbank and C. Walker drafted the manuscript, and T. Lombrozo and A. Gopnik provided critical revisions. All authors approved the final version of the manuscript for submission.

DATA AVAILABILITY STATEMENT

The data that support this study, along with scripts to reproduce all analyses presented here are available online at the following https://github.com/erik-brockbank/rmts.

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ENDNOTES

[1] This sample size was chosen based on Experiment 3 of Walker et al. (2016), which mirrored the current experimental setup using a causal version of the RMTS task with 3-4 year-olds. A power analysis based on these results suggested that a similar effect size would be detected with 80% power with at least 21 participants. Additionally, Experiment 4 of Christie & Gentner (2014) reports that 4-year-olds in the labeling condition averaged 79% relational responding across eight RMTS trials. If explanation has a similar effect on relational reasoning ($d = 1.38$), we would have 99.6% power with the 23 participants in the *explain* condition.

[2] The full set of match data, as well as code for the analyses presented here, are available at: https://github.com/erik-brockbank/rmts.

[3] Additionally, if we treat the number of explanations that included "same-different" language as a continuous variable, the correlation between the number of "same-different" explanations and the number of relational responses is not significant, $r = .29$, $p = 0.184$, 95% CI of the correlation $= [-0.14, 0.63]$.

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