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Bias and sensitivity to task constraints in spontaneous relational attention

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ABSTRACT

Two experiments examined factors that predicted children's tendencies to match objects versus relations across scenes when no instruction was given. Specifically, we assessed the presence of higher relational responding in children by (a) age, (b) greater presumed experience in generating relations through socialization in China versus the United States, and (c) in children with greater manipulated experience via a relational priming task. Experiment 1 showed that Chinese and U.S. children across all ages showed an initial bias to match objects versus relations across scenes. However, older children in both regions were more likely to notice features of the task that indicated attending to relational matches was a more reliable solution, and shifted their responding toward relations over the course of the task. Experiment 2 replicated the object-mapping bias and age effects within U.S. children while also examining the impact of directly manipulating children's relational experiences to test the malleability of the bias. Before the main scene-mapping task, children did a relation generation task known to prime attention to relations. This did not override the initial bias toward object mapping, but it magnified the role of age, making older children increasingly sensitive to task features that prompted relational matches, further shifting their responding toward relations over the course of the task.

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Introduction

Analogical reasoning, the ability to identify and reason on the basis of relational similarities between distinct sets of relationships (Gentner, 1983), is a powerful cognitive process involved in problem solving and creative thinking (see (Alexander, 2016; Blums, Belsky, Grimm, & Chen, 2017; Gentner, 2003; Richland & Begolli, 2016)). This cognitive skill underpins higher-order thinking abilities such as making generalizations, inferences, and categorizations (for discussion, see Richland & Simms, 2015). Attending to relations also supports individuals in recognizing the constraints of a context and adapting their prior knowledge to new situations (Brown & Kane, 1988; Holyoak & Thagard, 1995) or academic and real-world tasks (Bain, 2008; Richland & Begolli, 2016; Treagust, Duit, Joslin, & Lindauer, 1992). Accordingly, the ability to notice and reason on the basis of relationships (described as drawing connections) has been identified as an important area of focus for improving students' academic and personal success (National Research Council, 2013).

At the same time, the mechanisms that support youth in successfully using analogical reasoning skills in everyday settings are not well understood. Importantly, few studies have differentiated between the *ability* to successfully reason analogically when opportunities present themselves and the *tendencies* to notice and use relational similarities in situations when it is not explicitly required. Most developmental studies have focused on the ability to reason analogically, with age (Richland, Morrison, & Holyoak, 2006), knowledge (Gentner & Rattermann, 1991; Goswami & Brown, 1990), and executive function (EF) cognitive resources (Simms, Frausel, & Richland, 2018) contributing to this ability. As described in more detail below, these mechanisms seem to function as thresholds such that without them, reasoners will tend to focus on object-based similarity matching.

In contrast, the current study aimed to begin elucidating children's spontaneous tendencies to attend to relational versus featural similarities without experimenter instruction. The field has not provided strong data to determine whether meeting thresholds of knowledge and cognitive ability would mean that children will automatically reason relationally or whether there are other factors that systematically affect the likelihood of spontaneously attending to relations. The conditions that can lead children to become more relational, sometimes described as inducing "relational mindsets" (Vendetti, Wu, & Holyoak, 2014), are not yet well understood (but see Simms & Richland, 2019; Walker, Hubachek, & Vendetti, 2018).

In the current study, we examined the impact of factors, including age, culture (operationalized as nationality), and prior task experiences, to determine how and when children's mindsets become more relational. We specifically examined children's choices in a task to match objects across scenes where children of all ages would understand the core relations depicted in the scenes, but where relational similarity and featural similarity were competing. Examining relationships among relational mindsets and age, social, and task contexts can provide novel insights into how children's spontaneous engagement in relational reasoning may differ from the literature on developmental reasoning patterns that derive from tasks where children are explicitly instructed to use analogy.

Analogical reasoning development

The developmental literature on relational reasoning has so far shown a relatively clear developmental trajectory. When asked to make a relational comparison between representations, or when given an opportunity to draw from one representation to generate inferences about another, younger children tend to find the task more challenging when the featural similarities are not aligned with the intended mapping of the relational similarities (e.g., Gentner & Toupin, 1986), suggesting that object similarity is highly salient to young children (e.g., see Gentner & Clement, 1988; Richland et al., 2006). However, as children grow older, they are more likely to attend to the structural relationships of contexts and reason about the underlying relational similarities between representations (Brown, 1989; Daehler & Chen, 1993; Gentner & Rattermann, 1991; Gentner & Toupin, 1986; Rattermann & Gentner, 1998; Richland et al., 2006; Thibaut, French, & Vezneva, 2010). This change in focus from featural similarities to relational similarities has been described as the *relational shift* (Gentner & Rattermann, 1991; Gentner & Toupin, 1986; Gentner, 1988).

The accretion in knowledge that naturally occurs with age has been posited to contribute to this relational shift. Children can complete A is to B as C is to ? analogy tasks with familiar relations (e.g., melting) but fail with unfamiliar relations (e.g., steering) (Goswami & Brown, 1990). Thus, when completing analogy tasks involving domain-specific knowledge, children, and even adults, with high-domain knowledge are more likely to focus on the relational similarities between the representations, whereas children and adults with low-domain knowledge tend to focus on similarities between objects and/or object properties (Gentner & Rattermann, 1991; Goswami, 1992; Loewenstein, Thompson, & Gentner, 1999). Indeed, expertise has been characterized as the ability and tendency to encode and represent knowledge based on deep relational structure as opposed to surface details about object features (Chi, Feltovich, & Glaser, 1981; Goldwater & Schalk, 2016).

Cognitive abilities have also been identified to correlate with accuracy and complexity of relational thinking even in cases where the knowledge demands of a problem are held constant (Richland et al., 2006; Simms et al., 2018; Thibaut et al., 2010). Analogical reasoning relies on both working memory and the inhibitory control systems within EFs, which are rapidly developing throughout adolescence (Luciana & Nelson, 1998), and individual differences in these EFs predict differences in analogical reasoning ability (Morrison, 2005; Simms et al., 2018; Waltz, Lau, Grewal, & Holyoak, 2000).

Working memory is employed as a cognitive resource to hold and manipulate a mental representation of the relations in mind in order to make the comparison. Greater working memory is required to handle greater complexity of relations that will be mapped structurally (see Bunch & Andrews, 2012; Halford, 1993; Todd, Andrews, & Conlon, 2019), meaning that as children's cognitive resources mature, children are able to handle increasingly complex relations. This may further vary by types of EF demand such that in addition to the traditional "cool" EF, "hot" EF (EF that involves affective reward systems) may allow for an earlier ability to handle more complex relations. Bunch and Andrews (2012) found that 4- and 5-year-olds performed better on ternary-relational items in hot tasks than in cool tasks matched on complexity, presumably because of the differential rates of maturation in the underlying neural regions responsible for hot and cool EFs. Inhibitory control is further posited to support relational reasoning based on reasoners' ability to control prepotent responses to distracting stimuli or attention to information that is irrelevant to a task, such as irrelevant surface similarity when one is intending to reason analogically (Morrison et al., 2004; Richland et al., 2006; Richland and Burchinal, 2013). The ability to handle distraction and relational complexity both increase as children mature (Halford, Andrews, & Wilson, 2014; Richland et al., 2006) and decline as older adults age (Todd et al., 2019), mirroring the rise and decline of EFs, providing further support for the argument that EF development plays a critical role in the developmental trajectory of relational thinking.

The role of spontaneous attention to relations over development is generally less well understood. Most developmental analogy research has focused on age-related patterns of relational reasoning when this is the explicit task goal. In everyday contexts, however, individuals rarely state that the goal of the moment is relational reasoning. Therefore, the spontaneous noticing of opportunities to draw on one's prior knowledge or to make inferences about relational similarities is quite important (Alexander, 2016). Spontaneous attention refers here to what people naturally attend to without being explicitly prompted to seek relational similarity and is often a function of experiences, maturation, and contexts. This can have real-world or educational implications. Relational reasoning constitutes an important mechanism in educational interventions that aim to promote transfer, generalization, and mapping of higher-order relationships across contexts (Richland & Simms, 2015) or to improve relational reasoning skills themselves (Tzuriel & George, 2009), with the educational goal being to support youths in future reasoning opportunities. Therefore, it is pressing to better understand what contextual and situational factors have the potential to draw children's attention to relations and to shape transfer to new contexts.

Socialized differences in attention to objects and relations

One explanation for individual differences in spontaneous attention to structural features over perceptual features of representations has been socialization and culture. Cross-cultural variation has been identified in the patterns by which children and adults parse scenes and draw inferences about objects and their relationships (e.g., see Carstensen et al., 2019; Kuwabara & Smith, 2016; Masuda & Nisbett, 2001), which may indicate that attention to relations is socialized and reliant on context rather than solely dependent on domain knowledge or cognitive maturation. For example, in an object recognition task, Kuwabara and Smith (2016) found that U.S. children relied more on perceptual features (i.e., features characteristic to just the object in question) than their Japanese peers when identifying objects, suggesting that U.S. children attend more to local, visually salient information. On the other hand, Japanese children made more errors in judging whether pairs contained the same objects when one of the objects was inverted, suggesting they rely more on holistic spatial relations and configurations than individual object-level processing when identifying objects. In another study, U.S. 4-year-olds were more likely than their Japanese peers to be distracted by featural information when identifying relational similarities in a matching task (Kuwabara & Smith, 2012).

Besides object recognition, differential attention toward relations has also been documented in other tasks. In a relational abstraction task, Carstensen and colleagues (2019) found that Chinese 3-year-olds were more likely to make relational matches to sample inferences than U.S. children. In a scene description task, Masuda and Nisbett (2001) reported that U.S. children described an aquarium scene only with respect to the large fish in the center of the tank, whereas Japanese children described the large fish in relation to other objects in the scene. In judging emotions, when 4-year-old Japanese and U.S. children were asked to match facial expressions to emotions, Japanese children were influenced by the surrounding context, whereas U.S. children interpreted emotions as a more trait-like property of the individual (Kuwabara, Son, & Smith, 2011; see also Ji, 2008; Lockhart, Nakashima, Inagaki, & Keil, 2008). Furthermore, Richland, Chan, Morrison, and Au (2010) found that Chinese children were able to handle relational complexity better than their U.S. peers, although these preschoolers were equally distracted by object matches, suggesting that skill with relations might not always lead to relational responding when in competition with object featural correspondences.

Taken together, these studies suggest that children's attention to relations may also be culturally constructed. Examining spontaneous attention to relations in a cross-cultural comparison study would provide evidence for or against socialization as a predictive factor in children's natural attention to object features of a visual scene. Although children of the same age across countries are likely to have comparable EF skills, their attention to relations versus object features in a scene might vary based on cultural experiences. This study would not provide insight into specific aspects of culture that influence reasoning practice, but it would allow us to further understand the role of socialization in children's spontaneous sensitivity to relational features of contexts.

The effect of relational priming on analogical reasoning

Along with culture writ large, there are growing reasons to suspect that relational attention on one task can be shaped by experiences on a prior task. A prior exercise of active relational reasoning may lead to more relational responding on a subsequent task, as shown in both children (Andrews, Halford, & Boyce, 2012; Simms & Richland, 2019; Walker et al., 2018) and adults (Andrews & Bohadana, 2018; Goldwater & Markman, 2011; Vendetti et al., 2014). This suggests that when individuals actively identify and construct analogous relations, a general relational mindset can emerge. However, the impact of age on susceptibility to shifting toward a relational mindset is not well understood.

Some studies have demonstrated that sensitivity to relational information can be affected by task demands and cues; for example, Goldwater and Markman (2011) showed in adults that strategies for drawing attention to relational information led participants to greater sensitivity to relational categorization when the initial attention interventions were removed. Vendetti and colleagues (2014) further revealed that generating far distance relations in a verbal analogy task led to increased relational attention on an entirely different scene-mapping task.

Similarly, with children, Simms and Richland (2019) found that having children generate relations on a matrix task led to increased relational responding on different relations in a scene-mapping task. The impact of age, however, remains to be addressed. In addition to the cross-task priming, children's sensitivity to task-specific features that would implicitly support relational responding is also not well understood. Learning from built-in, task-based constraints to attend to relations would indicate that a reasoner is able to spontaneously inhibit prepotent nonrelational responses and instead focus on the relevance of relational responding.

The current study

In the current study, we examined children's spontaneous relational responding by measuring children's tendencies to match objects versus relations across scenes when no instruction was given. We also explored several factors that predicted those tendencies. Experiment 1 examined the roles of children's age and their nationality as a proxy for cultural differences in experiences with relations, based on the argument that Chinese children might have greater experience with generating and using relational similarity than children raised in the United States. Experiment 2 manipulated this experience more directly, testing the effect of adding a relation generation task before the scene-mapping task. We aimed to understand whether there would be overall tendencies in relational responding that reflected a relational shift such that relational responding would increase with age, and whether there would be differences in relational responding based on experience. Specifically, we assessed the presence of higher relational responding in children with (a) greater presumed experience in generating relations through socialization in China versus the United States and in children with (b) greater manipulated experience via the relation generation task.

We measured relational responding in two ways. First, we gave children two scenes, with one object highlighted in the top scene (e.g., a cat), and we recorded the object in the bottom scene that children selected as the one that best "goes with" the highlighted object. There were two primary options in the bottom scene: an object that shared superficial surface features with the object highlighted in the top picture (e.g., a cat and a cat) and an object that shared role-based relational similarity with the object in the top picture (e.g., a cat chasing a mouse and a boy chasing a girl). Second, we also examined increases in children's relational responding across blocks of the task as a measure of their sensitivity to constraints of the task indicating that role-based relational responding was a more reliable solution type. As described in more detail below, there were three blocks to the task, with the second block including scenes with no object similarity match options (e.g., no cat-to-cat option). Thus, if children were sensitive to noticing this difference as an indicator that object-based similarity might not always be the optimal criterion for matches, they might continue to match based on roles in Block 3 when both options were again available.

Taken together, these two experiments allowed for a more nuanced understanding of how age and experiences both before and during a task can affect children's spontaneous attention to relational versus object mappings and their sensitivity to changing that focus based on information provided within the task regarding the reliability of either similarity type.

Experiment 1

Method

Participants

The sample consisted of 117 children from the United States with English as a primary language (48% female; M_{age} = 8.41 years, *SD* = 2.37) and 172 children from a large city center in China (51% female; M_{age} = 7.99 years, *SD* = 2.39) aged 4 to 11 years. Data from 21 additional participants were excluded from the U.S. sample to provide a more stringent cultural comparison (7 participants whose primary language was not English, 12 participants who spent more than 6 months outside of the United States, and 2 participants with parental interference). None of the Chinese participants were excluded. The U.S. sample was recruited from a local museum in a large city in the Midwest region of the United States. The Chinese sample was recruited from local kindergartens and primary schools in Henan Province, China. To ensure that all ages were represented equally and to more clearly illustrate age-related patterns, we grouped participants into four age groups: 4- and 5-year-olds, 6- and 7-year-olds, 8- and 9-year-olds, and 10- and 11-year-olds (Table 1). Informed consent was received from a parent or guardian of each participant, and all children in the experiment assented to participation.

Table 1
Experiment 1 demographics.

		Total	4–5 years	6–7 years	8–9 years	10–11 years
United States	n	117	28	22	26	41
	M_{age} (SD) (years)		5.02 (0.51)	7.19 (0.53)	9.19 (0.53)	10.87 (0.58)
China	n	172	44	41	44	43
	M_{age} (SD) (years)		4.82 (0.58)	7.00 (0.68)	9.16 (0.53)	10.97 (0.53)

Materials

Scene analogy task. In the Scene Analogy Task, participants were shown 10 pairs of images depicting analogous relationships corresponding to motion verbs familiar to children aged 3 years and above, previously tested in the United States and in Hong Kong (Fig. 1) (see Richland et al., 2006, 2010). For each trial, participants were shown a pair of scenes with one object in the top scene highlighted with an arrow. They were then asked to identify an object in the bottom image that "goes with" that key object (see Fig. 1). Of the 10 pairs of scenes, seven had bottom scenes with both a relational match as an option (an object in the same relational role as the key object in the source image) and a featural match as an option (an object that is featurally similar to the key object but does not play the same relational role). The number of objects per scene was always the same, but the scene pairs varied in their level of relational complexity. Some involved only one relation (e.g., dog chasing cat), and others involved two simultaneous relations (e.g., dog chasing cat chasing mouse).

Importantly, for three pairs that were administered in the second of three blocks of the task, no featural matches were present. This was designed to serve as a cue that object matching was not a consistently optimal mode for solving these ambiguous matches, thereby providing subtle information that could be used for inferring the utility of relational responding.

In total, the 10 scene analogy problems consisted of four different types of problems (four two-relation problems with featural matches [2RD; Fig. 1A], three one-relation problems with featural matches [1RD; Fig. 1B], two two-relation problems without featural matches [2RND; Fig. 1C], and one one-relation problem without a featural match [1RND; Fig. 1D]).

Research design. The seven scene pairs containing both object and relational matches were randomized across the first and third blocks, and the three pairs without intended featural matches were randomized within the middle (second) block, as shown in Fig. 2. The blocks were further specified such that the first block consisted of two 1RD and two 2RD pairs, the second block consisted of one 1RND and two 2RND pairs, and the third block consisted of one 1RD and two 2RD pairs. Therefore, the middle block served as the critical task-based constraint that should implicitly prompt children to attend to relational similarities.

Procedure

The Scene Analogy Task was administered on an iPad through the Qualtrics offline app and took approximately 5 min to complete. Children were informed that they were going to play a picture game where they would see two pictures on each page. They then were asked to pick an object in the bottom picture that "goes with" the object marked with an arrow in the top picture. For the Chinese instructions, "goes with" was translated into "fu he" and was shown to share the same meaning through a translation/back-translation process. We chose this neutral framing instead of terms such as *like* or direct relational instructions in order to assess children's spontaneous matching performance.

During the task, children selected one of five lettered objects in the target picture. Answer choices consisted of a "relational match" (e.g., in Fig. 1A, Option C, the mother), the object in the same relational role as the source object; a "relational error" (Option B, the father), which was part of the relation but not in the same role as the source object; a "featural match" (Option E, the girl), an object that shared high semantic or perceptual similarity with the source object; or an "irrelevant match" (Option A, the chair), an object that was not intended to share featural or relational similarity to the source object. The fifth choice consisted of either a second relational error or a second irrelevant match. There

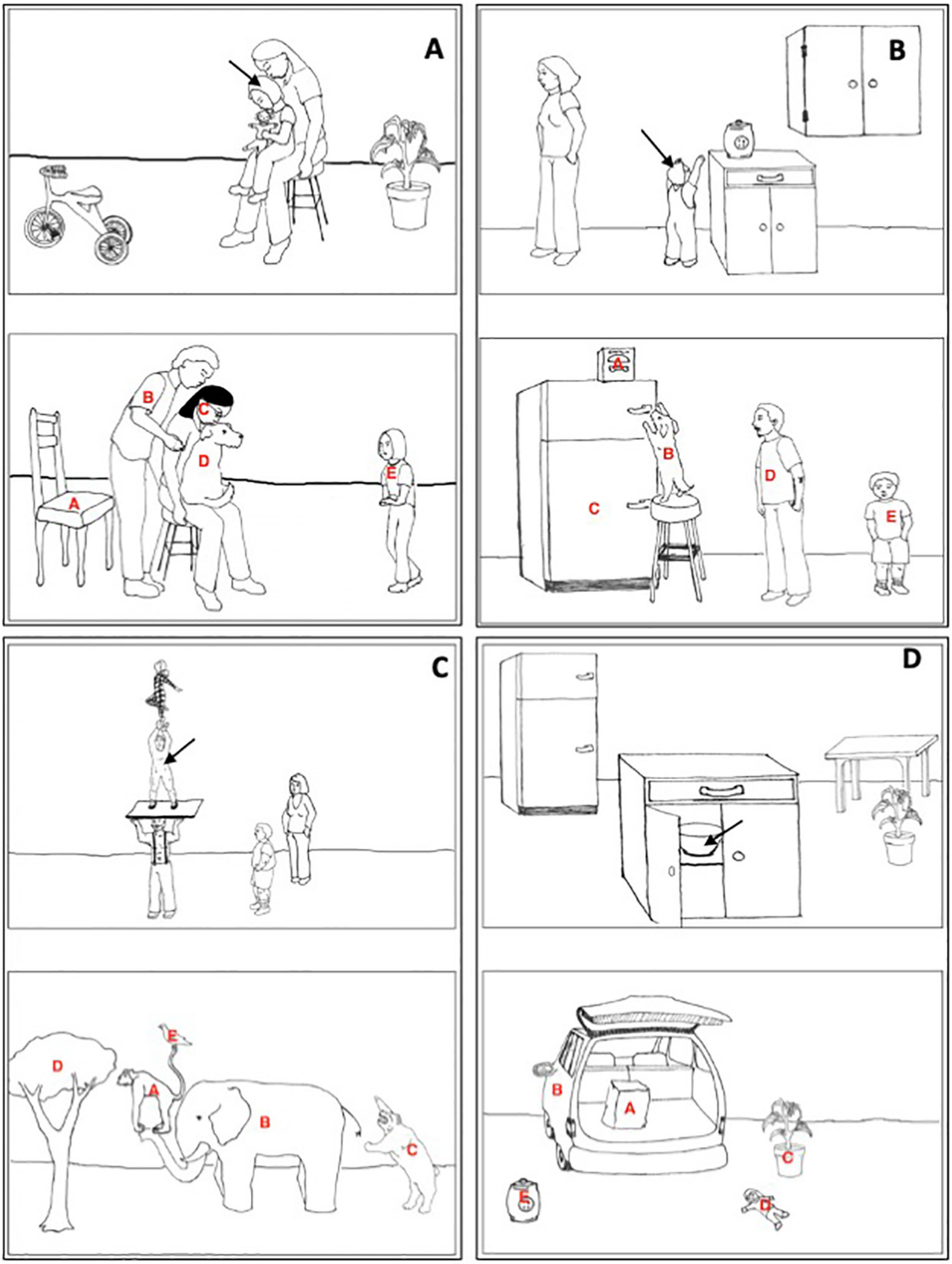

Fig. 1. Four example scenes from the Scene Analogy Task. (A) Two relations, ‘‘kissing,” with girl as an object similarity match. (B) One relation, ‘‘reaching,” with boy as an object similarity match. (C) Two relations, ‘‘lifting,” with no object similarity match. (D) One relation, ‘‘inside,” with no object similarity match.

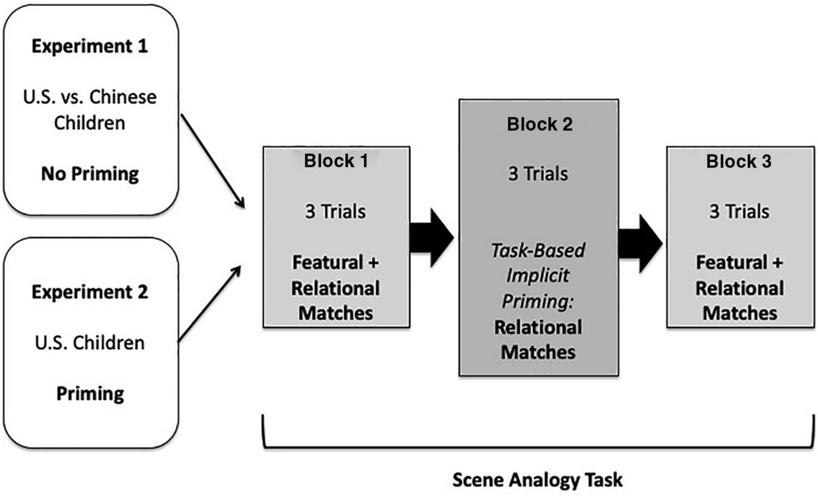

Fig. 2. Research design.

were two relational errors in scene pairs with two relations and two irrelevant matches in scene pairs without a distractor object. The same scene analogy stimuli were used in Experiments 1 and 2.

Results

Percentages of each participant's answer choices (i.e., relational match, relational error, featural match, and irrelevant match) were calculated for each block. The average percentages of each type of answer choice by block and country are reported in Table 2 and are further broken down by age group in Fig. 3. For the main analyses, the word 'proportion' is used to emphasize the relative distribution of each answer choice. We ran a second version of the analysis after randomly removing one one-relational problem without featural match from Block 1 to equate the number of items across blocks. The results are consistent with the main analyses, but tables with these data can be found in Tables S1 to S4 of the online supplementary material. Additional analyses were conducted on the effects of relational complexity, which showed that two-relational problems were generally harder than one-relational problems, although it did not systematically interact with our main variables of interests. The full analyses are reported in the supplementary material.

An overall factorial analysis of variance (ANOVA) with country, block, and response type as independent variables and proportion of responses as the dependent variable revealed a significant effect of block, $F(2, 15) = 7.26$, $p = .006$, $\eta_p^2 = .492$, and response type, $F(3, 15) = 21.25$, $p < .001$, $\eta_p^2 = .810$, but not of country, $F(1, 15) = 0.00$, $p = .999$, $\eta_p^2 = .000$. Overall, numerically, for all participants across all blocks, the most frequent selection was the featural match, followed by the relational match.

Table 2
Percentages (%) of answer types across blocks for U.S. and Chinese children in Experiment 1.

	United States			China		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
Relational match	26	44	32	21	53	25
Relational error	18	24	22	8	15	10
Featural match	44	–	38	67	–	63
Irrelevant match	12	32	8	4	32	2

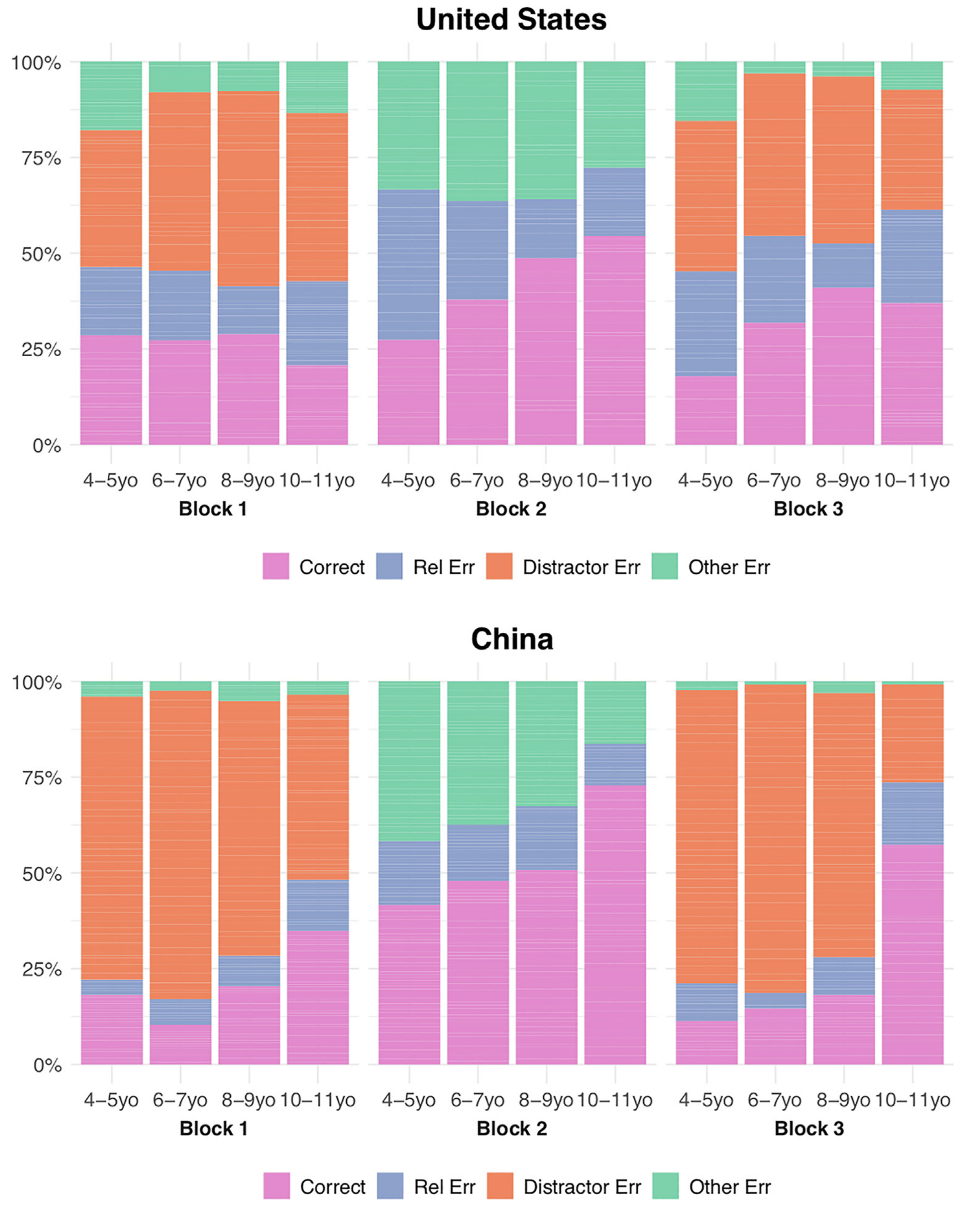

Fig. 3. Percentage of answer choices selected in each block by age and country. (Terms: yo, years old; Rel Match, relational match; Rel Err, relational error; Ft Match, featural match; Irr Match, irrelevant match).

To more directly assess the hypothesized effects of age and country, linear regressions were run for Blocks 1 and 2 with age (in years) and country (with China as the reference group) as predictors, and the proportions of each of the three response types (relational match, featural match, and relational error) as dependent variables. The results of the irrelevant match are not reported here because such an analysis would lack the independence given by the analyses of other response types (i.e., the score of irrelevant match is necessarily implied by the scores of the other three response types because they add up to 100%) and because our a priori hypotheses do not concern irrelevant matches. To examine the learning effect from the task-based constraint, we computed difference scores between Blocks 1 and 3 for each answer type. The scores were then regressed on age, country, and their interaction. Following the regressions, we conducted a planned focused analysis on changes in proportions of relational and featural matches by age group. Chance analyses for selection of relational match are included in the supplementary material.

Block 1 performance

Linear regressions revealed that, with age, children from both countries chose fewer featural matches. In addition, older children were more likely to select the relational errors when they did not select the relational match (e.g., mapping "source picture: *chaser*" to "target picture: *person being chased*" rather than to "target picture: *chaser*"). Older children also selected marginally more relational matches than younger children (Table 3).

Contrary to our expectations, we found no significant effects of country on selection of relational matches in Block 1, failing to support the hypothesis that Chinese children would respond more relationally at baseline. In fact, the Chinese children made more featural matches than the U.S. sample. When controlling for age, the U.S. children selected more relational errors than the Chinese children. These errors suggest an intention to reason relationally but failure to hold the relational roles correctly in mind, potentially due to the cognitive challenges of handling relational complexity.

Block 2 performance

When featural matches were removed from the scenes in Block 2, older children were more likely to select relational matches and less likely to select relational errors than younger children (Table 4). For country effects, Chinese children selected more relational matches despite having selected more featural responses in Block 1. U.S. children made more relational errors than Chinese children, suggesting that they were attending to relations but may have been less skilled at holding the relational role constant across contexts.

Learning effects across Blocks 1 and 3

To assess whether children inferred from Block 2 that the preferred match was a relational response, we computed difference scores between Blocks 1 and 3 for proportions of each answer choice. Here, a positive difference score indicates that an individual selected more of a response type in the third block than in the first block, and vice versa for a negative difference score.

Regression models predicting change in proportion of each answer type were created with age, country, and the interaction between age and country as predictors. Models revealed that older children in both countries demonstrated a relational shift by increasingly selecting relational matches rather than featural matches. Age had no significant relationship to proportion of relational errors. Moreover, change in all response types did not differ by country or by the interaction between age and country. In summary, older children across both countries attended more to relational matches

Table 3
Linear models predicting proportions of Block 1 answer types in Experiment 1.

		Relational match	Relational error	Featural match
Age	β (*SE*)	0.012† (0.006)	0.009* (0.004)	−0.018* (0.009)
	p (η_p^2)	.065 (.012)	.050 (.013)	.034 (.016)
Country	β (*SE*)	0.041 (0.031)	0.098*** (0.022)	−0.224*** (0.042)
	p (η_p^2)	.188 (.006)	<.001 (.068)	<.001 (.090)
R^2		.019	.084	.109

Note. Standard errors are in parentheses. China is the reference country in all linear regressions.
† $p < .10$.
* $p < .05$.
*** $p < .001$.

Table 4
Linear models predicting proportions of Block 2 answer types in Experiment 1.

		Relational match	Relational error
Age	β (*SE*)	0.041*** (0.007)	−0.171** (0.005)
	p (η_p^2)	<.001 (.098)	.001 (.036)
Country	β (*SE*)	−0.114** (0.036)	0.099*** (0.025)
	p (η_p^2)	.002 (.034)	<.001 (.051)
R^2		.118	.078

Note. Standard errors are in parentheses.
** $p < .01$.
*** $p < .001$.

and less to featural matches over the course of the experiment, but they noticeably shifted toward relational responding after Block 2, presumably due to their sensitivity to Block 2′s removal of a strong feature match as an indicator that object matching could not be a ubiquitous strategy for completing this task. This indicates that these participants sometimes engaged in an inference process regarding the intention of the task, although neither relational nor featural matches were described in the instructions (Table 5).

Learning effects by age group

To gain more specific insights into the age-related patterns of responding documented above, we further broke down changes by age group (Table 6). Based on our primary hypotheses, we focused only on changes in the proportions of relational matches and featural matches. A series of *t*-tests on age-group-specific difference scores revealed that only 10- and 11-year-olds selected more relational matches after Block 2. This pattern was significant for Chinese children, $t(42) = 3.91$, $p = .005$, $d = 0.60$, and marginal for U.S. children, $t(40) = 2.90$, $p = .097$, $d = 0.45$ (p values were Bonferroni corrected). The

Table 5
Linear models predicting changes in answer type proportions across Blocks 1 and 3 in Experiment 1.

		Relational match	Relational error	Featural match
Age	β (*SE*)	0.034** (0.010)	−0.004 (0.007)	−0.030** (0.010)
	p (η_p^2)	<.001 (.081)	.216 (.005)	.004 (.043)
Country	β (*SE*)	−0.066 (0.131)	0.083 (0.094)	−0.037 (0.139)
	p (η_p^2)	.821 (.000)	.452 (.002)	.911 (.000)
Age * Country	β (*SE*)	0.009 (0.015)	−0.008 (0.011)	0.004 (0.016)
	p (η_p^2)	.552 (.001)	.488 (.002)	.809 (.000)
R^2		.084	.009	.044

Note. Standard errors are in parentheses.
** $p < .01$.

Table 6
Percentage (%) changes in answer types between Blocks 1 and 3 by age group and country.

	United States			China		
	Relational match	Relational error	Featural match	Relational match	Relational error	Featural match
4–5 years	−10.7	9.5	3.6	−6.8	5.9	2.7
6–7 years	4.5	4.5	−4.2	4.3	−2.6	−0.0
8–9 years	12.2	−1.0	−7.4	−2.3	1.9	2.5
10–11 years	16.3†	2.4	−12.6	22.5*	2.9	−22.7*

† $p < .10$.
* $p < .05$.

10- and 11-year-old Chinese children also significantly decreased their selection of featural matches, $t(42) = -4.53$, $p = .001$, $d = -0.69$, whereas U.S. children did not show significant changes, $t(40) = -2.49$, $p = .272$, $d = -0.39$. These findings suggest that Chinese children may have been somewhat more sensitive to the task constraints. However, the degree of both changes did not differ by country when examined together [for increase in relational matches, $t(82) = 0.77$, $p = .441$, $d = 0.17$; for decrease in featural matches, $t(82) = -1.42$, $p = .161$, $d = -0.31$].

Discussion

Experiment 1 sought to identify potential cultural differences in spontaneous relational attention. Contrary to our hypothesis, we found that when first encountering questions with featural and relational matches in Block 1, there were no cultural differences in the selection of relational matches, given that both Chinese and U.S. children were significantly more likely to choose featural matches. In addition, when featural matches were removed in Block 2, children in both samples were more likely to select relational matches. This suggests that children from both cultures were more likely to pay attention to featural similarities when they were not prompted to attend to relations, supporting previous findings about spontaneous analogical reasoning (e.g., Gick & Holyoak, 1980, 1983). Importantly, the current task was designed such that even the youngest children in the study would be familiar with the relations and would be able to identify relations in the task if prompted (Richland et al., 2006). However, this study found that all children still initially relied on featural correspondences in spontaneous reasoning.

After featural matches were reinserted into Block 3, the majority of younger children returned to selecting the featural matches. Regardless of culture, only 10- and 11-year-old children showed significant increases in relational responding between Blocks 1 and 3. These findings suggest that older children from both cultures equally benefitted from the subtle task constraints of removing and reintroducing featural matches. In other words, the oldest age group was able to resist the lure of an object match in Block 3, seemingly having inferred information about what would be a consistent solution strategy to the task. For instance, one pilot participant stated, "Oh, I just realized I was doing it wrong before" during Block 2, suggesting the ability to exert a conscious shift in strategy and attention. It is also noteworthy that this shift was evident in both countries but was identified only in the older participants, suggesting that this shift may require some crucial aspects of maturation and/or other age-related factors.

Previous literature has suggested that children from Eastern cultures are more likely to attend to relations, whereas children from Western cultures focus on featural similarity. Supporting evidence comes from tasks of object recognition (Kuwabara & Smith, 2012, 2016), emotional judgment (Kuwabara et al., 2011; Lockhart et al., 2008), and prompted analogical reasoning (Richland et al., 2010) and also comes indirectly from adults' interaction with children (e.g. (Tardif et al., 1999)). Given the variety of tasks used and domains assessed to make this initial cultural claim, it is in some ways unexpected that the current study found no cross-cultural differences in spontaneous relational thinking within Blocks 1 and 3. We return to this point in the General Discussion.

Based on the results discussed above, children in both the U.S. and Chinese samples indicated a bias toward object similarity mapping that overwhelmed any differences by culture that could be captured by nationality. This could mean that children's biases are not easily changed. It could also mean, however, that nationality was not an adequately sensitive categorization of children's experiences with relations. Experiment 2, therefore, took a more direct approach and tested whether varying children's experiences with a relational generation task immediately prior to the scene-mapping task would affect children's selection of similarity alignments and their sensitivity to task constraints that implicitly favored a relational matching strategy.

Experiment 2 used a shortened version of a priming manipulation shown previously to affect young children's relational mindset (Simms & Richland, 2019) as a way to more directly examine the impact of children's reasoning context surrounding the scene-mapping task. Using the same scene-mapping task, we predicted that a prior relational priming task would facilitate children's adoption of a relational mindset and sensitivity to task-relevant constraints during the scene-mapping task itself, leading to more relational responding.

Experiment 2

Method

Participants

A sample of 247 U.S. children, aged 4 to 7 years and 10 and 11 years, participated in Experiment 2. Of the 247 children (54% female), 141 were recruited from a U.S. museum and assigned to a priming version of Experiment 1′s materials. We recruited only these two age groups to capture the range of developmental patterns identified in the results of Experiment 1. From this sample, 5 participants were excluded (4 participants with parental interference and 1 participant who was not able to complete the task). These data were then compared with Experiment 1′s U.S. data, which served as the control, to explore whether priming would lead to a pattern of performance that differed from the normative U.S. attentional patterns. The remaining 106 participants comprised the nonpriming sample and were from the U.S. sample in Experiment 1. Of these 106 participants, 87 aged 4 to 7 years and 10 and 11 years from the U.S. sample in Experiment 1 were included in the nonpriming condition sample (Table 7). In addition, because we were interested in the effects of priming on the general population regardless of potential cultural differences, the 19 participants originally excluded from Experiment 1 for having spent more than 6 months outside of the United States (n = 12) or for English not being the primary language (n = 7) were also included in the nonpriming sample. Informed consent was received from a parent or guardian of each participant, and all children in the experiment provided verbal assent.

Materials

Priming task. As shown in Fig. 2, a sample of children in Experiment 2 were assigned to a priming first condition. Children in the priming condition were asked to generate the relations that would allow them to complete a visual matrix task adapted from Simms and Richland (2019) immediately before completing the Scene Analogy Task. All participants were administered an abbreviated version of the "Active" condition in Simms and Richland (2019) that was shown to shift young children's attention to more relational similarities. Due to time constraints, participants were given four trials with matrices instead of the task's original six trials. Each matrix was constructed in an A:B::C:? format such that Objects A through C were pictured, and Object D was left blank (Fig. 4). The ? term could be solved by identifying the relationship shared between the A:B and C:D terms. The matrices were presented in one of four counterbalanced orders and were designed to be similar in level of abstraction. To complete the task, participants were first asked to identify the A:B relation ("How are these two things related?").

In the second part of the task, participants were asked to spontaneously produce an object that would complete the C:D relationship in an analogous manner to the A:B relationship ("What goes with [C] in the same way [as relationship A:B]?"). Unlike in the Simms and Richland (2019) Active protocol, children were not given objects to select between for Object D. If they were unsuccessful on their first attempt, the experimenter restated the A:B relationship and then asked participants, "What goes with [C] in the same way?" If participants were unsuccessful on the second attempt, researchers prompted participants again by explicitly stating the motion verb of interest for both the A:B and C:D relationships (e.g., "If caterpillars grow into butterflies, what grows into a sunflower?"). If children were not able to identify the relation even after the third attempt, the experimenter explicitly restated the

Table 7
Experiment 2 demographics.

		Total	4–5 years	6–7 years	10–11 years
No priming	n	106	36	26	44
	M_{age} (SD)		5.07 (0.54)	7.17 (0.57)	10.90 (0.59)
Priming	N	141	52	53	36
	M_{age} (SD)		5.06 (0.55)	6.87 (0.60)	10.93 (0.61)

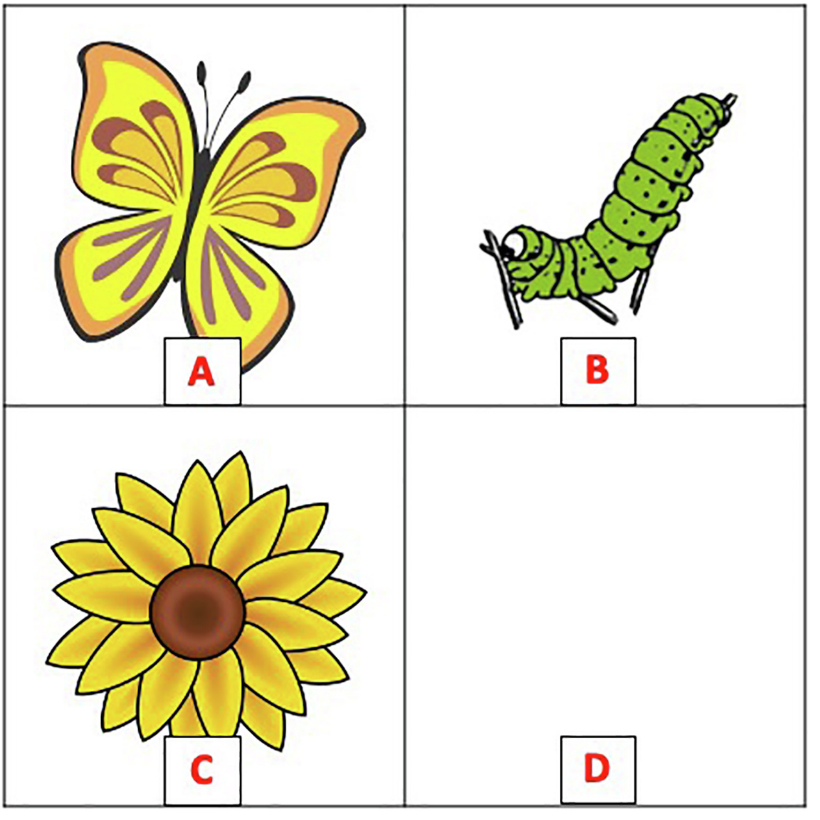

Fig. 4. Matrix priming task. See text for descriptions of objects in panels.

relationship between A:B and C:D using the answer provided ("Maybe seeds grow into flowers just like caterpillars grow into butterflies!"). Researchers recorded the number of attempts and accuracy for both the A:B and C:D relationships for all matrices. Participants in the priming condition were then immediately administered the Scene Analogy Task in an identical manner to Experiment 1.

Results

Table 8 and Fig. 5 detail the percentages of each answer choice selected in the Scene Analogy Task. An overall factorial ANOVA revealed that there were significant differences in the types of objects selected, $F(3, 15) = 13.51$, $p < .001$, $\eta_p^2 = .730$, that there were significant differences in patterns of selections across blocks, $F(2, 15) = 8.54$, $p = .003$, $\eta_p^2 = .532$, and that priming condition did not overall pre-

Table 8
Percentages (%) of answer types across blocks for children in the priming and no-priming conditions.

	No priming			Priming		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
Relational match	24	42	28	27	38	38
Relational error	19	26	24	22	30	26
Featural match	45	–	40	36	–	27
Irrelevant match	12	32	8	15	32	9

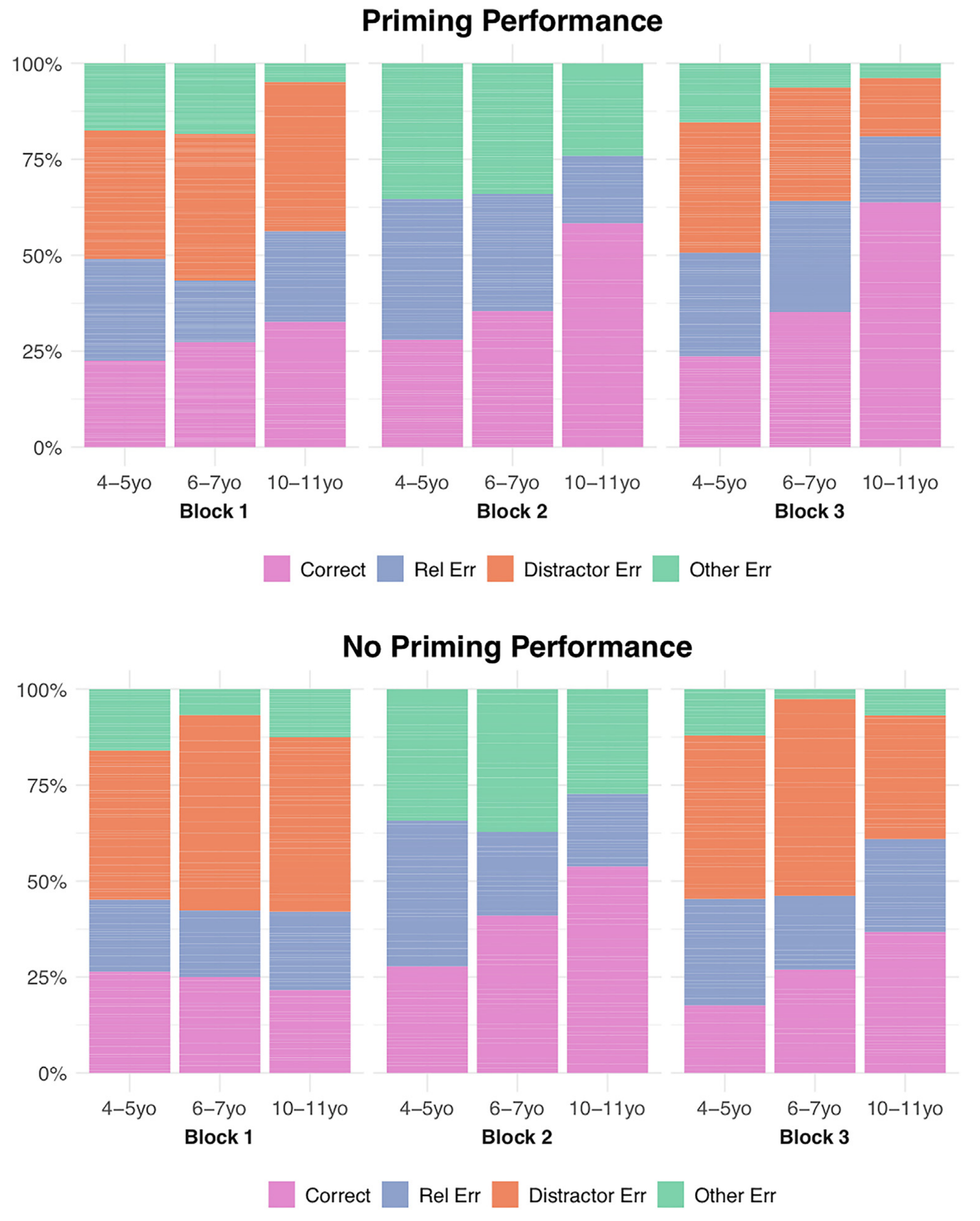

Fig. 5. Percentage of answer choices selected in each block by age and condition. (yo, years old; Rel Match, relational match; Rel Error, relational error; Ft Match, featural match; Irr Match, irrelevant match.)

dict differences in object selections, $F(1, 15) = 0.00$, $p = .999$, $\eta_p^2 = .000$. Overall, children tended to favor featural matches, followed by relational matches.

We next correlated performance within the matrix task, scored as the number of tries to generate the relevant relation between the A:B pair, to level of relational responding in the Scene Analogy Task for participants in the priming task. These were not correlated in Block 1 ($r = -.015$, $p = .067$), but there was a negative relationship to Block 2 ($r = -.26$, $p = .0014$) and Block 3 ($r = -.30$, $p = .001$), revealing that faster ease of generating the key relation in the generation task predicted more relational responding in the Scene Analogy Task in those blocks. This suggested that individual differences in relational skills might not override the object similarity bias and lead to a ubiquitous focus on relations over object similarity on new tasks (Block 1) but rather might lead to a greater sensitivity to the utility of relations in new tasks (Blocks 2 and 3).

To detail the relations among age, task constraints, and performance, we next ran regressions predicting proportions of each answer type in Blocks 1 and 2 with age and priming condition as predictors and with the no-priming condition as the reference group. We also assessed the learning effect from Blocks 1 to 3 by regressing difference scores with age, condition, and their interaction as predictors to test whether priming increases children's sensitivity toward the subtle task constraint changes in Block 2. Lastly, we conducted a focused analysis on age-group-specific results for relational and featural matches. As in Experiment 1, additional analyses addressed the impact of having unequal numbers of items in Block 1 by removing one scene pair for Block 1 to equate the task set sizes, and found the results unchanged\ (see Tables S5–S8 in supplementary material). We also report in the supplementary material the effects of relational complexity, which did not interact with our main variables, and chance analyses for selection of relational match.

Block 1 performance

Linear regressions predicting the proportion of each type of answer choice revealed that neither age nor priming condition had a significant impact on the proportion of relational matches or relational errors. On the other hand, the priming group chose marginally fewer featural matches than the no-priming group (Table 9). Overall, however, it seems that priming did not have a strong immediate effect on children's strategies in the unrelated scene-mapping task.

Block 2 performance

Regressions showed that throughout Block 2, age predicted an increase in relational matches and a decrease in relational errors (Table 10). However, priming showed no effect on any response type. Thus, children's performance in Block 2 seemed to be a function of age but not of priming condition.

Learning effects across Blocks 1 and 3

Difference scores between Blocks 1 and 3 were computed and regressed on age, condition, and their interaction. Regression models revealed significant effects of age on increasing relational match selection while decreasing featural match and relational error selection.

Importantly, consistent with our hypothesis, priming resulted in a significantly larger increase in relational match selection and a marginally larger decrease in featural matches after controlling for age. No main effect of priming was found for relational errors (Table 11).

In addition, none of the interactions were significant. Consistent with Experiment 1, older children benefitted more from the task constraints regardless of their priming condition. Moreover, when controlling for age, the initial generative priming task helped children to maintain attention to relations compared to the no priming condition.

Table 9
Linear models predicting proportion of Block 1 answer types in Experiment 2.

		Relational match	Relational error	Featural match
Age	β (*SE*)	0.006 (0.006)	−0.002 (0.006)	0.009 (0.009)
	p (η^2_p)	.294 (.005)	.772 (.000)	.319 (.004)
Priming	β (*SE*)	0.033 (0.031)	0.028 (0.028)	−0.075† (0.045)
	p (η^2_p)	.293 (.005)	.314 (.004)	.092 (.012)
R^2		.0078	.005	.0180

Note. Standard errors are in parentheses.
† $p < .10$.

Table 10
Linear models predicting proportions of Block 2 answer types in Experiment 2.

		Relational match	Relational error
Age	β (*SE*)	0.048*** (0.007)	−0.030*** (0.006)
	p (η_p^2)	<.001 (.152)	<.001 (.088)
Priming	β (*SE*)	0.002 (0.037)	0.013 (0.031)
	p (η_p^2)	.963 (.000)	.673 (.000)
R^2		.1550	.0930

Note. Standard errors are in parentheses.
*** $p < .001$.

Table 11
Linear models predicting changes in answer type proportions across Blocks 1 and 3 in Experiment 2.

		Relational match	Relational error	Featural match
Age	β (*SE*)	0.195*** (0.064)	−0.023* (0.055)	−0.155** (0.071)
	p (η_p^2)	<.001 (.096)	.048 (.016)	.001 (.054)
Priming	β (*SE*)	0.090** (0.052)	0.013 (0.045)	−0.067† (0.058)
	p (η_p^2)	.009 (.028)	.537 (.002)	.087 (.012)
Age * Priming	β (*SE*)	0.067 (0.090)	−0.107 (0.078)	−0.041 (0.100)
	p (η_p^2)	.460 (.002)	.170 (.008)	.683 (.001)
R^2		.1089	.0238	.0541

Note. Standard errors are in parentheses.
† $p < .10$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Learning effects by age group

The regression models did not rule out the possibility that even the youngest age group would be able to learn from the task-based constraint after receiving an initial priming task. A series of age-group-specific *t*-tests were run examining changes in proportions of relational matches and featural matches between Blocks 1 and 3 (Table 12). Once again, the results suggested that only 10- and 11-year-olds shifted their attention from featural similarities to relational similarities.

Importantly, children in the priming condition showed larger benefits than those in the no-priming condition. In particular, after Bonferroni correction, 10- and 11-year-olds in the no-priming condition showed a marginal increase in relational matches, $t(43) = 2.83$, $p = .084$, $d = 0.43$, whereas their peers in the priming condition showed both a significant increase in relational match selection, $t(35) = 4.85$, $p < .001$, $d = 0.81$, and a significant decrease in featural match selection, $t(35) = -3.61$, $p = .011$, $d = -0.60$. Comparing the performance of the oldest children, those in the priming group made marginally more relational matches across blocks than those in the no-priming group, $t(73) = 1.89$,

Table 12
Percentage (%) changes in answer types between Blocks 1 and 3 by age group and condition.

	No priming			Priming		
	Relational match	Relational error	Featural match	Relational match	Relational error	Featural match
4–5 years	−8.8	9.0	3.7	1.4	1.8	−0.2
6–7 years	1.9	1.9	0.3	7.9	12.9	−8.7
10–11 years	15.2†	3.8	−13.3	30.8***	−5.6	−24.1*

† $p < .10$.
* $p < .05$.
*** $p < .01$.

p = .063, d = 0.43, but performed equally on change in featural matches, $t(70) = -1.28$, p = .205, $d = -0.29$.

Discussion

This experiment aimed to examine whether completing a generative analogical reasoning priming task led to more relational responding on a scene-mapping task. The results supported our hypotheses but revealed nuanced effects. In Block 1, priming had no significant impact on proportion of relational matches when controlling for age, suggesting that the priming effect did not override children's tendency to select feature-based matches. It was in the last block that older children in the priming group were more relational than their peers in the no-priming group, suggesting that they had become more sensitive to the task cues in Block 2. In stronger versions of the generative priming task (Simms & Richland, 2019; Vendetti et al., 2014), children and adults showed more relational responding on scene mapping without a task cue, but (importantly) in this more subtle version we still see evidence for the shift in sensitivity to relational information. In a replication study, the effects of the subtle version of the priming task on older children (9- to 11-year-olds) replicated, but other priming-specific findings did not.[2] This suggests that this subtle priming mechanism needs to be further tested in larger sample sizes.

Another possibility for the delayed priming benefits could be due to task difficulty. Previous studies (Simms & Richland, 2019; Vendetti et al., 2014) used one-relation images with relational and featural matches. However, the current study used pairs of images containing both one- and two-relation images. As previous literature has shown, relational performance decreases as the number of relations depicted in an image increases (Richland et al., 2006). It might be the case that children require time to incorporate the benefits of the priming task and to transfer these benefits to more complex two-relation problems. Further research could examine whether the lack of an immediate priming effect was a result of increased complexity of the task.

We also found that age predicted an increase in relational matches and a decrease in featural matches between Blocks 1 and 3, suggesting that as kids get older, they are more likely to shift from attending to featural similarities to attending to relational similarities after the removal and reinsertion of featural matches. This replicates our findings in Experiment 1 and converges with previous research suggesting that children are more able to attend to relational similarities and to inhibit distraction from superficial featural similarities as they age (e.g., Daehler & Chen, 1993; Richland et al., 2006; Thibaut et al., 2010).

The finding that overall, children in the priming condition were more likely to attend to relational matches than children in the no-priming sample when controlling for age (Table 11) extends the current literature (Simms & Richland, 2019; Vendetti et al., 2014). It suggests that completion of a generative relational task prior to a structure-mapping task might increase spontaneous attention to structural similarities for all children, but effects may be most pronounced for older children. Thus, completion of a relational generation task could be a useful intervention to facilitate adopting a relational mindset in children.

The role of age in promoting learning from task constraints is less clear. Both Experiments 1 and 2 showed that only 10- and 11-year-old children were likely to spontaneously change to a relational mapping strategy after viewing a set of problems with no featural matches. Interestingly, no significant changes were seen between Blocks 1 and 3 for children in the 4- and 5-year-old age range. This suggests that younger children reverted back to attending to featural matches after the subtle changes in Block 2 in both the priming and no-priming conditions. Whereas previous research showed that 4-year-old children benefitted from an initial priming task (Simms & Richland, 2019), the current study was performed using a more minimal priming task and a more complex structure-mapping task

[2] The finding that older children in the priming condition showed a significant increase in relational matches between Blocks 1 and 3 was replicated in a third study where participants were randomly assigned to the priming or no-priming condition (p = .02 for children aged 9–11 years; 9-year-olds were combined with 10- and 11-year-olds given small sample sizes). However, other results did not replicate. This could be due to larger variation in ages with smaller sample size (priming: n = 70; no priming: n = 78) and the change in venue, which likely increased distraction (a more vibrant interactive children's museum exhibit).

(e.g., in Simms and Richland (2019), all the trials displayed one-relation images with a relational and featural match). This suggests that although young children benefit from a generative priming task before more straightforward tasks, priming may not create a relational mindset strong enough to change performance in young children when completing a complex relational task.

Further work could examine whether the development of a relational mindset is consrained by cognitive resources and thereby whether it is possible when 4-year-olds complete structure-mapping tasks containing stimuli with two relations and featural matches, or whether the lack of learning stemmed from mixing pairs of images with different degrees of difficulty. As shown in Richland and colleagues (2006), 3- and 4-year-olds show decreased performance on two-relation images with featural matches, so it is likely that the complexity of the two-relation problems interfered with the impact of the priming activity in creating a relational mindset.

General discussion

This study examined spontaneous attention and mapping decisions during an opportunity for relational or object-based similarity alignment and assessed whether these decisions were primarily dependent on age or maturation or whether culture and prior task experiences would shift children's focus. In Experiment 1, we examined the role of culture, with results suggesting that age and task context affected relational attention in both U.S. and Chinese children, although nationality did not have a clear effect. More specifically, 10- and 11-year-olds in both the U.S. and Chinese samples showed a learning effect after the removal and reinsertion of featural matches, suggesting that task-based priming could benefit older children across cultures when completing a complex reasoning task. In Experiment 2, we sought to delve into the priming effect and use a more explicit generative analogy task to see whether the development of a relational mindset could be extended to school-aged children. Our results suggest that the completion of a generative priming task before the complex Scene Analogy Task further enhanced the relational mindset in 10- and 11-year-olds, a result that we replicated in a follow-up study (see footnote 2).

These results are interesting on numerous fronts. First, contrary to our hypothesis, culture did not influence initial relational attention or the degree to which a learning effect was seen. However, Chinese children did show greater relational attention in Block 2 than U.S. children. This could suggest that Chinese children attend more to relations during more straightforward tasks (in this case when no featural matches were present), but relational attention does not differ on more complex reasoning tasks (e.g., in ambiguous tasks containing both featural and relational matches). Previous literature has generally used relatively simple reasoning tasks (i.e., one-relation tasks, less ambiguous tasks) in a single age group, and studies were mostly conducted in lab settings. Our study suggests that task constraints such as complexity and setting might play a larger role in relational attention than accounted for in previous studies. Thus, more research is needed to understand the nuances of relational attention between cultures and contexts.

The study also does not allow disentangling the effects of culture and socialization on the *ability* to reason relationally versus the *tendency* to do so. In this case, we found a relatively robust pattern suggesting that the tendency to notice and attend to relations develops with age but that, even so, most children across ages preferentially attended to featural matches regardless of country. This does not mean, however, that there might not be greater *ability* to do so in either of these regions. There are a few reasons from prior work to believe that this may be the case, including young Chinese children's ability to handle relational complexity more successfully than U.S. children (e.g., see Richland et al., 2010).

In addition, the priming literature has also mostly examined priming in straightforward tasks (e.g., one-relation tasks). Whereas previous findings have suggested that 4-year-old children benefit from the completion of a generative priming task (Simms & Richland, 2019), or a task inviting children to use relations to answer questions (Andrews et al., 2012), our findings suggest that older children particularly benefitted from this type of low-level priming task when completing complex reasoning tasks. Exploring the dosage and implementation of scaffolding interventions could be a useful target of future research to develop relational mindsets in children at different ages.

Overall, this study expands current literature by suggesting that context-dependent factors influence both spontaneous relational attention across cultures and relational attention following a generative priming task. These findings have important implications for educational settings for multiple reasons. First and foremost, this brings about the issue of the relevance of the tasks typically used in relational attention studies to real-world situations. In the current education context, children are asked to perform increasingly demanding tasks; they now must synthesize relationships and apply concepts to novel situations (National Research Council, 2013). Thus, tasks being used to examine relational attention must reflect the complexities that students see on a daily basis. For example, in mathematics settings, children must understand key mathematical principles, identify which principles to apply to novel problems, ignore irrelevant information, and adjust their procedure to best address the unique problem context. Very rarely will children simply be asked to identify the relationship between problems and apply a formulaic procedure. Thus, it is critical that research tasks mimic the rigor that children in educational contexts experience every day. Our study suggests that more attention must be given to the level of complexity of relational tasks being used to make conclusions about relational attention because using overly simplistic tasks could result in misleading conclusions that are not applicable to educational settings.

Furthermore, our study also suggests that priming interventions could be useful in shifting attention from superficial similarities to relational similarities in older children. However, given the importance of younger children developing this skill, further research is needed to determine the appropriate dosage and delivery necessary to best support younger children in increasing attention to relational similarities. Thus, more work is needed to understand the developmental trajectory of the benefits of priming and how context influences the efficacy of any intervention.

Limitations

Although these findings provide additional support for the development of a relational mindset after completion of a generative priming task, our study does present several limitations. First, due to timing restrictions at the study sites, only 10 trials were given for the Scene Analogy Task, whereas the protocol designed by Richland et al. (2006) consisted of 20 trials. In addition, only four matrices were used in the initial priming task in Experiment 2, whereas the protocol designed by Simms and Richland (2019) uses six images. Therefore, the current study might underestimate children's relational thinking ability because children were provided with only a limited number of trials and might not have had enough trials to orient themselves to the task. This underestimation could potentially affect U.S. and Chinese children to different degrees due to dissimilar experiment settings given that the museum setting in the United States had more distracting stimuli than the school setting in China.

Second, the study took place in public settings (i.e., in a museum and a school). These settings, in particular the museum, were often full of irrelevant sensory information that participants needed to inhibit in order to complete the study. Given that inhibition control has been shown to predict analogical reasoning ability (Simms et al., 2018), the cognitive demands of participants were being taxed. Because this study showed the impact of a generative reasoning task before a novel task, this suggests that the results could underestimate the development of a relational mindset of children in a quiet, less distracting environment. Further work is needed to measure the cultural impact on relational reasoning in more comparable experimental settings and the effect of priming on the development of a relational mindset in less cognitively taxing settings to fully examine the benefits of priming.

Third, the generative priming task was not completed with Chinese participants given that there were no overall differences seen between relational reasoning performance in U.S. and Chinese children. Thus, the impact of an generative priming task on Chinese participants, or in samples from other cultures, is uncertain.

Fourth, the term "goes with" that was used in the task instructions was translated into Chinese as "fu he" using a translation/back-translation procedure. However, research assistants who could fluently speak the two languages agreed that there was no direct translation for the English phrase "goes with." Although "fu he" also conveys correspondence that could be interpreted as both featural and relational similarity, young children might not share the same intuition as the adult translators. We note that even if this is the case, a lack of understanding cannot account for the strong preference for object matches among younger children as well as the developmental and cross-cultural patterns in Experiment 1. A further check would be ideal to examine whether changes in the instructions might bias U.S. and Chinese children's performance on this task.

Finally, this study operationalized culture at the level of nationality, drawing on theory and research suggesting broad differences in socialization between the United States and China as more individualistic and collectivistic countries, respectively (e.g., see Nisbett, 2003; Triandis, 1995). However, future research would benefit from a measure assessing children's home contexts rather than simply relying on nationality, which may have missed some important variability within the landscape of one's country. This type of study would benefit from adding a measure of individual children's socialization in either a collectivistic environment or an individualistic environment to assess whether traditional notions of culture are affecting children's attention and spontaneous reasoning patterns. For instance, several countries that were considered to be collectivistic, including China, have undergone rapid economic growth and are moving toward a more individualistic orientation (Greenfield, 2009). Greenfield (2009) proposed a multilevel causal model in which sociodemographic characteristics influence cultural values within a community, thereby affecting the learning environment and human development. Given that contexts are important for relational reasoning, the influence of changing sociodemographic variables across cultures could have the potential to alter children's analogical reasoning tendencies. In addition, previous cross-cultural studies used simple stimuli in a controlled lab setting and often prompted the use of a relational strategy to solve the tasks either implicitly or explicitly. Thus, little is known regarding cultural differences in spontaneous relational thinking in more naturalistic environments, although we note that a complete dichotomy between analogical abilities and tendencies might not be feasible and that any task performance results from a mixture of the two factors (Gray & Holyoak, 2020). Together with the potential changes in cultural and regional environments, the current finding of null cultural differences should not be seen as directly contrary to previous literature.

Conclusions

This study aimed to examine the effects of age, culture, context, and priming on children's relational attention. In Experiment 1, we compared U.S. and Chinese children's performance on an ambiguous structure-mapping task that contained an implicit prompt for relational attention. In Experiment 2, we examined the effects of a generative priming task on relational attention in a follow-up, ambiguous structure-mapping task in a sample of U.S. children. These experiments revealed no effect of culture but revealed effects of age and both implicit and explicit priming on children's attention toward relational similarities.

These findings provide new insights into the way in which age changes children's relational reasoning—not only by improving the ability to reason with relations but also in the tendency to notice the utility of relations to solving problems. These data also revealed a bias in children of all tested ages to match by object similarity over relational similarity despite age and knowledge to recognize the relations. Although there might not have been ubiquitous differences by nationality, the data do indicate the potential of the activities that children engage in outside of a particular task to influence how they engage with that task such that a generative priming task made children more sensitive to the relevance of relational information in the scene-mapping task.

CRediT authorship contribution statement

Ashley N. Murphy: Data curation, Formal analysis, Project administration, Investigation, Visualization, Writing - original draft, Writing - review & editing. **Yinyuan Zheng:** Conceptualization, Investigation, Methodology, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Apoorva Shivaram:** Methodology, Writing - review & editing. **Elayne Vollman:** Writing - review & editing. **Lindsey Engle Richland:** Supervision, Conceptualization, Methodology, Resources, Writing - review & editing.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2020.104981.

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