Bias and Sensitivity to Task Constraints in Spontaneous Relational Attention

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Abstract

Two studies examined factors that predicted children's tendencies to match objects versus relations across scenes when no instruction was given. Study 1 examined a) age and b) nationality as a proxy for cultural differences in experiences with relations. The results showed that Chinese and U.S. children across ages all 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 relational matches were a more reliable solution and shifted their responding toward relations over time. Study 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. Before the main scene mapping task children did a relation-generation task known to prime attention to relations (Simms & Richland, 2019). This did not override the initial bias toward object mapping, but magnified the role of age, making older children increasingly sensitive to task features that prompted relational matches, further shifting their responding toward relations over time.

Bias and Sensitivity to Task Constraints in Spontaneous Relational Attention

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; 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), and 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 et al., 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 *ability* to successfully reason analogically when opportunities present themselves, and *tendencies* to notice and use relational similarities in those situations when it's not explicitly required. Most developmental studies have focused on *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 aims 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 those thresholds of knowledge and cognitive ability would mean that children will automatically reason relationally, or whether there are other factors that systematically impact this likelihood. 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 (though see Simms & Richland, 2019; Walker et al, 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 became more relational. We specifically examined children's choices in a task to match objects across scenes where relational and object similarity were competing, but children of all ages would understand the core relations depicted in the scenes. 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 given an opportunity to draw on 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, Morrison & Holyoak, 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 & Toupin, 1986; Gentner & Ratterman, 1991; Rattermann & Gentner, 1998; Richland, Morrison & Holyoak, 2006; Thibaut, French, & Vezneva, 2010). This change in focus from featural similarities to relational similarities has been described as the *relational shift* (Gentner, 1988; Gentner & Rattermann, 1991; Gentner & Toupin, 1986).

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 individuals with low-domain knowledge tend to focus on similarities between objects and/or object properties (Gentner & Ratternann, 1991; Goswami, 2002; 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, Frausel, & Richland, 2018; Thibaut, French, & Vezneva, 2010). Analogical reasoning relies upon both working memory and the inhibitory control systems within

Executive Functions (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, Frausel & Richland, 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 WM is required to handle greater complexity of relations that will be mapped structurally (see Halford, 1993; Bunch & Andrews, 2012; Todd, Andrews, & Conlon, 2019), meaning that as one'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" executive function, "hot" EF involving affective reward systems may potentiate earlier ability to handle more complex relations. Bunch and Andrews (2012), find that 4- and 5-year-olds performed better on ternary-relational items in hot than cool tasks matched on complexity, presumably because of the differential rates of maturation in the underlying neural regions responsible for hot and cool executive functions. 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, 2005; Richland et al., 2007). Both ability to handle distraction and relational complexity increase as children mature (Richland et al, 2006; Halford, Andrews, & Wilson, 2014) and decline as older adults age (Todd, Andrews, & Conlon, 2019), mirroring the rise and decline of EFs, providing further support for the argument that executive function 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, there are rarely individuals stating that the goal of the moment is relational reasoning, and so spontaneous noticing of opportunities to draw on one's prior knowledge or make inferences about relational similarity is quite important (Alexander, 2016). Spontaneous attention refers to what people naturally attend to without being prompted explicitly to seek relational similarity, and is often a function of experience, maturation, and context. 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 (Simms & Richland, 2015) or to improve relational reasoning skills themselves (Tzuriel & George, 2009), with the educational goal being to support youth 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; Masuda & Nisbett, 2001; Kuwabara & Smith, 2016), 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 Japanese peers when identifying objects, suggesting 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 towards relations has also been documented in other tasks. In a relational abstraction task, Carstensen and colleagues (2019) found that Chinese three-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, while Japanese children described the large fish in relation to other objects in the scene. In judging emotions, when four-year-old Japanese and U.S. children were asked to match facial expressions to emotions, the Japanese children were influenced by the surrounding context while 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). Further, Richland and colleagues (2010) found that Chinese children were able to handle relational complexity better than their US peers, though these preschoolers were equally distracted by object matches, suggesting that skill with relations may 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. While children of the same ages 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. While this study would not provide insight into specific aspects of culture that influence reasoning practice, 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 is growing reason 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 children (Andrews, Halford & Boyce, 2012; Simms & Richland, 2019; Walker et al., 2018) and adults (Andrews & Bohadana, 2018; Goldwater & Markman, 2011; Vendetti, Wu & Holyoak, 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 impacted by task demands and cues, such as in Goldwater and Markman (2011), who 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, Vu & Holyoak (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 non-relational responses and instead focus on the relevance of relational responding.

Current Study

In the current study, we examined children's spontaneous relational responding – 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. Study 1 examined the roles of a) children's age and b) 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. Study 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 1) greater presumed experience generating relations through socialization in China versus the U.S., and 2) with greater manipulated experience via the 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 measured which object in the bottom scene they selected as the one that "goes with" that object the best. There were two primary sorts of 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. the chaser – if the top scene had a cat chasing a mouse, and the bottom scene had 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 that indicated 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 a child was sensitive to noticing this difference as an indicator that object-based similarity may 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 allow for a more nuanced understanding of how age and experiences both before and during a task can impact 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

Methods

Participants

The sample consisted of 117 children from the United States with English as a primary language (48% female; M = 8.41, SD = 2.37) and 172 children from a large city-center in China (51% female; M = 7.99, SD = 2.39) aged 4- to 11-years-old. Data from 21 additional participants were excluded from the United States sample to provide a more stringent cultural comparison (seven participants whose primary language was not English, twelve participants who spent over six months outside of the United States, and two participants who received interference from parents). 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: 4-5, 6-7, 8-9 and 10-11-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
U.S.	n	117	28	22	26	41
	M_{age} (SD)		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)		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 3-year-old children and above, previously tested in the U.S. and in Hong Kong (Figure 1, see Richland, Chan, Morrison & Au, 2010; and Richland, Morrison & Holyoak, 2006). For each trial, participants were shown the pair of two 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

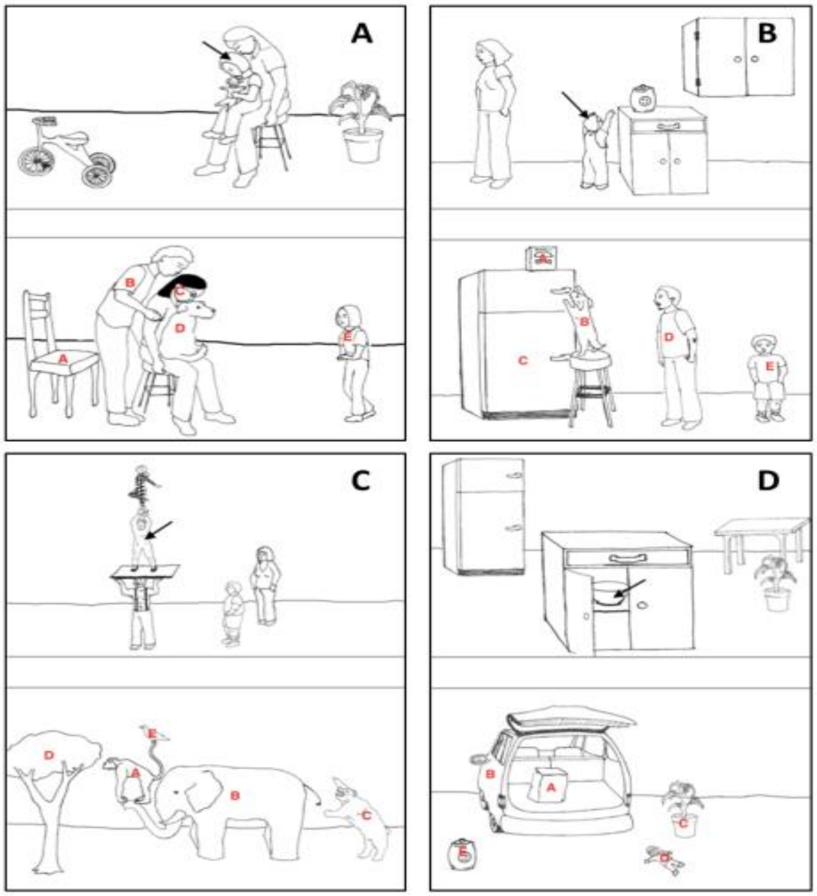
Figure 1). Seven out of ten pairs of scenes had bottom scenes with both a relational match as an option (an object in the same relational role as the key object in the source image), and a featural match as an option (an object that is featurally similar to the key object but does not play the same relational role). The number of objects per scene were 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, and thereby providing subtle information that could be used for inferring the utility of relational responding.

In total, the ten scene analogy problems consisted of four different types of problems (4 two-relation problems with featural matches [2RD, Figure 1A], 3 one-relation problems with featural matches [1RD, Figure 1B], 2 two-relation problems without featural matches, [2RND, Figure 1C], and 1 one-relation problem without a featural match [1RND, Figure 1D]).

Figure 1

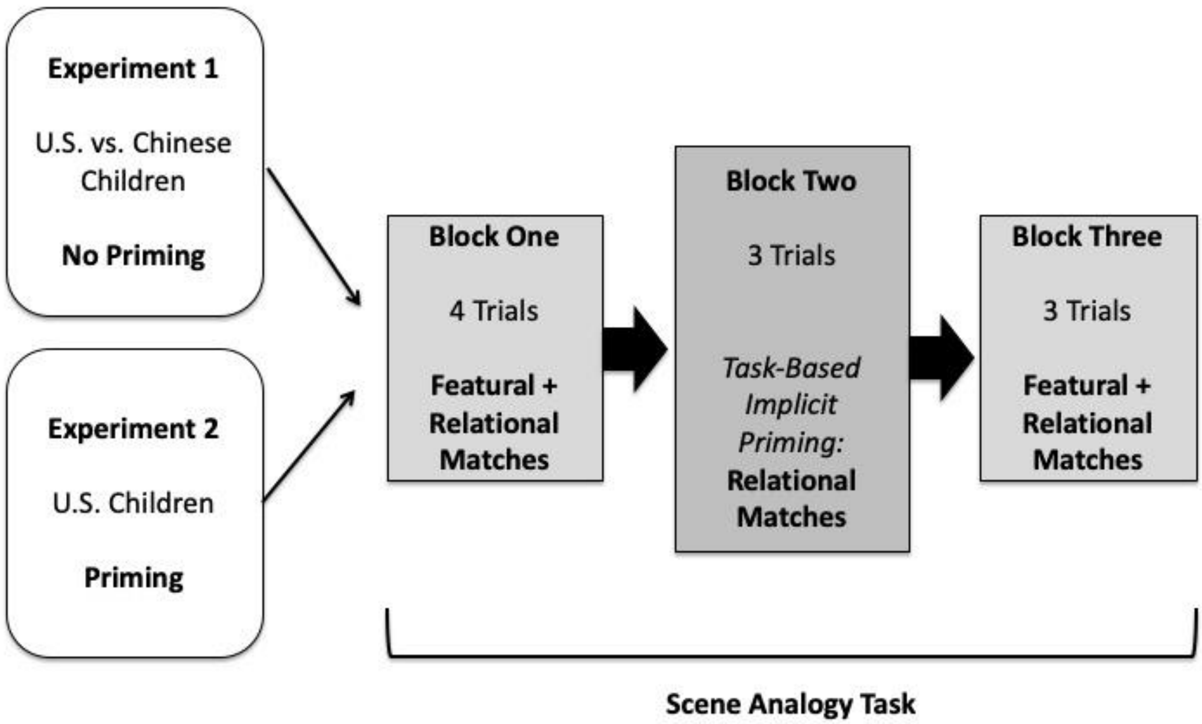
Four Examples Scenes from Scene Analogy Task. 1A: Two relations, "kissing," with girl as an object similarity match; 1B: One relation, "Reaching" with boy as an object similarity match; 1C: 2 relations, "lifting," with no object similarity match; 1D: 1 relation, "inside," with no object similarity match.



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 Figure 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.

Figure 2

Research Design



Procedure

The Scene Analogy Task was administered on an iPad through the Qualtrics offline app and took approximately five minutes to complete. Children were informed 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 Figure 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 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 participants’ 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 Figure 3. For the main analyses, the word proportion is used to emphasize on the relative distribution of each answer choice. We ran a second version of the analysis having removed one 1-R problem from block one to equate the numbers of items. The results are unchanged, but tables with these data can be found in the supplemental materials, Table S1–S4. Additional analyses were conducted on the effects of relational complexity, which showed that two-relational problems were in general harder than the one-relational ones, although it did not systematically interact with our main variables of interests. The full analyses are reported in the supplemental materials.

An overall factorial ANOVA (independent variables: country, block, and response type; dependent variables: proportion of each response type) 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 country [$F(1, 15) = 0.00$, $p = .999$, $\eta_p^2 = .000$]. Overall, for all participants across all blocks, the most frequent selection was the featural match, followed by the relational match.

To assess the hypothesized effects of age and country, linear regressions were first run for Blocks 1 and 2, with age (in years) and country (with China as the reference group) as predictors and 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., score of irrelevant match is necessarily implied by the scores of 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 materials.

Table 2

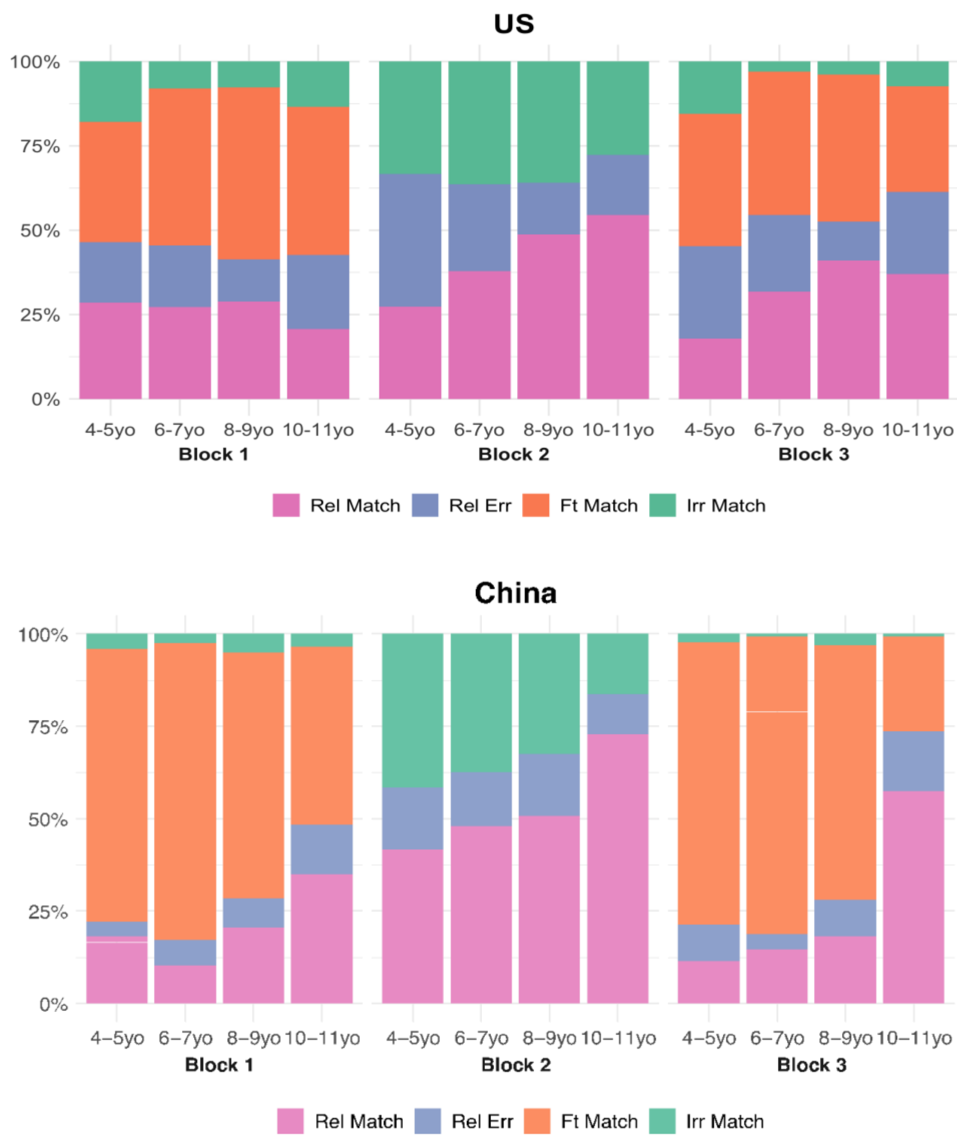
Percentages of Answer Types across Blocks for U.S. and Chinese Children in Experiment 1

	US			CN		
	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%

Figure 3

Percentage of Answer Choices Selected in Each Block by Age and Country



Block One 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.

Contrary to our expectations, we found no significant effects of country on selection of relational matches in Block one, 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, often due to the cognitive challenges of handling relational complexity.

Table 3

Linear Models Predicting Proportions of Block One 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		0.019	0.084	0.109

Note: [†]*p < .1; *p < .05; **p < .01; ***p < .001. Numbers in parentheses indicate standard errors. China is the reference country in all linear regressions.*

Block Two Performance

When featural matches were removed from the scenes in Block Two, 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 they were attending to relations but may have been less skilled at holding the relational role constant across contexts.

Table 4

Linear Models Predicting Proportions of Block Two 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		0.118	0.078

Note: †*p < .1; *p < .05; **p < .01; ***p < .001. Numbers in parentheses indicate standard errors.*

Learning Effects across Blocks 1 and 3

To assess whether children inferred from Block Two 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 demonstrate 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 nor by the interaction between age and country. In summary, older children across both countries attended more to relational matches and less to featural matches over the course of the experiment, but noticeably shifted towards 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 these participants sometimes engaged in an inference process regarding the intention of the task, though neither relational nor featural matches were described in the instructions.

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		0.084	0.009	0.044

Note: $^{\dagger}p < .1$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. Numbers in parentheses indicate standard errors.

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 only focused 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 10-11 year-old children 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 10-11 year-old Chinese children also significantly decreased the selection of featural matches ($t(42) = -4.53$, $p = .001$, $d = -0.69$) while U.S. children did not show significant changes ($t(40) = -2.49$, $p = .272$, $d = -0.39$), suggesting the Chinese children may have been somewhat more sensitive to 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, $t(82) = -1.42$, $p = .161$, $d = -0.31$).

Table 6

Percent Change in Answer Types Between Blocks 1 And 3 By Age Group and Country

	US			China		
	Relational Match	Relational Error	Featural Match	Relational Match	Relational Error	Featural Match
4-5 yo	-10.7%	9.5%	3.6%	-6.8%	5.9%	2.7%
6-7 yo	4.5%	4.5%	-4.2%	4.3%	-2.6%	-0.0%
8-9 yo	12.2%	-1.0%	-7.4%	-2.3%	1.9%	2.5%
10-11 yo	16.3%†	2.4%	-12.6%	**22.5%***	2.9%	**-22.7% ***

Note: $^{\dagger}p < .1$; $^{*}p < .05$; $^{**}p < .01$.

Experiment 1 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 as 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 have been shown to be able to solve them relationally if prompted (Richland, Morrison & Holyoak, 2006), but in this study we found that all children still relied on featural correspondences in spontaneous reasoning.

After featural matches were re-inserted in Block 3, the majority of younger children returned to selecting the featural matches. Regardless of culture, only 10- to 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 benefited from the subtle task constraints of removing and re-introducing 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. One pilot subject 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 only identified 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, Son & Smith, 2011; Lockhart et al., 2008), prompted analogical reasoning (Richland et al., 2010), and indirectly from adults' interaction with children (Richland, 2015; Tardif, Gelman & Xu, 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 will 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 impact 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 impact 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

Methods

Participants

A sample of 247 U.S. children, ages 4-7 and 10-11, were analyzed in Experiment 2. Of the 247 children (134 Female), 141 children were recruited from a U.S. museum and assigned to a priming version of Study 1's materials. We recruited only these two age groups to capture the range of developmental patterns identified in the Study 1 data. Five participants were excluded from this sample (four participants who received help from a parent and one participant who was not able to complete the task). These data were then compared to Study 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 non-priming sample and were from the U.S. sample in Experiment 1. Of these 106 participants, 87 participants, ages 4-7 and 10-11, from the U.S. sample in Experiment 1 were included in the non-priming condition sample. In addition, since 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 both spent greater than six months outside of the U.S. (12) or for English not being the primary language (7) were also included in the non-priming sample. Informed consent was received from the parents or guardians of each participant, and all children in the experiment assented to participation.

Table 7

Experiment 2 Demographics

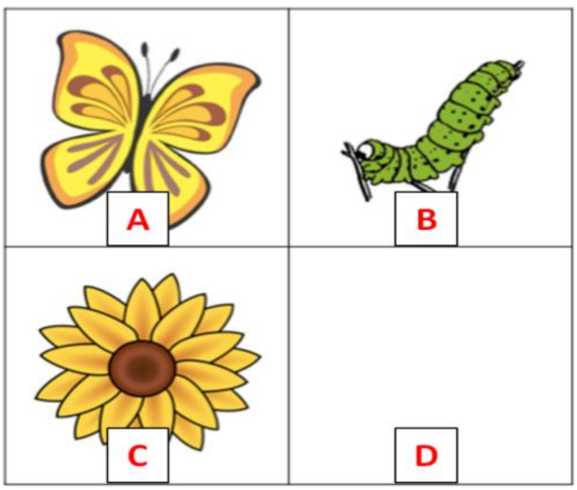
		Total	4-5 years	6-7 years	10-11 years
No Priming	n	106	36	26	44
	M_{age} (SD)		5.07 (0.54)	7.17 (0.57)	10.90 (0.59)
Priming	n	141	52	53	36
	M_{age} (SD)		5.06 (0.55)	6.87 (0.60)	10.93 (0.61)

Materials

Priming Task. As shown in Figure 2, in Experiment 2, a sample of children were randomly 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 & 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. Each matrix was constructed in an A : B :: C : ? format, such that objects A-C were pictured, and object D was left blank (Figure 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?").

Figure 4

Matrix Priming Task



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 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 A:B and C:D relationships (ex: "If caterpillars grow into butterflies, what grows into a sunflower?"). If children were not able to identify the relation by the third attempt, the experimenter explicitly restated the relationship between A:B and C:D using the correct answer ("Maybe seeds grow into flowers just like caterpillars grow into butterflies!"). Researchers recorded the number of attempts and accuracy for both 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 Figure 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 ($F(3, 15) = 13.51$, $p < .001$, $\eta_p^2 = .730$), and 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 predict 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 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 Blocks 2 (r = -.26, p = .0014) and 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 may 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 between age, task constraints, and performance, we next ran regressions predicting proportion of each answer type in Blocks 1 and 2 with age and priming condition as predictors, with 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 towards 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 for Experiment 1, additional analyses addressed the impact of having unequal numbers of items in Block 1 and found the results unchanged (see supplementary materials, Table S5-S8). We also reported in the supplementary materials the effects of relational complexity, which did not interact with our main variables, and chances analyses for selection of relational match.

Table 8

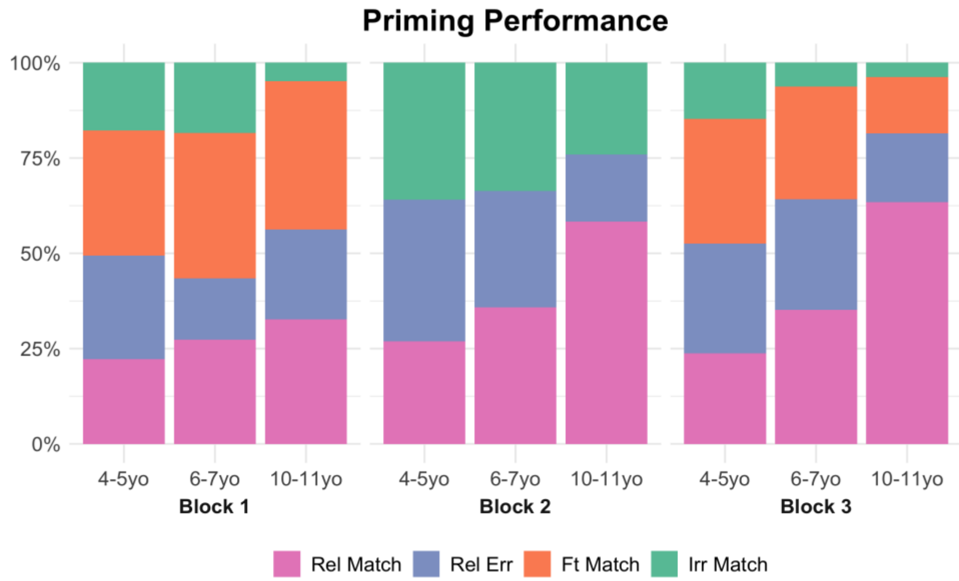
Percentages of Answer Types across Blocks for Children in the Priming and No Priming Conditions

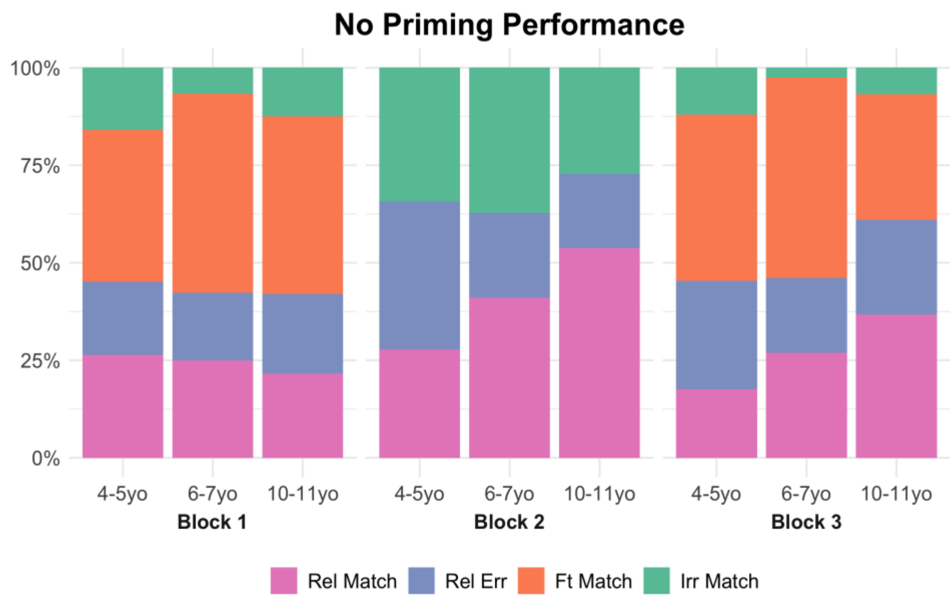
	No Priming			Priming		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3

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%

Figure 5

Percentage of Answer Choices Selected in Each Block by Age and Condition





Block One 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, though, it seems that priming did not have a strong immediate effect on children's strategies in the unrelated scene mapping task.

Table 9

Linear Models Predicting Proportion of Block One 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_p^2)	.294 (.005)	.772 (.000)	.319 (.004)
Priming	*β (SE)*	0.033 (0.031)	0.028 (0.028)	-0.075† (0.045)
	p (η_p^2)	.293 (.005)	.314 (.004)	.092 (.012)
R^2		0.0078	0.005	0.0180

Note: †$p < .1$; *$p < .05$; **$p < .01$; ***$p < .001$. Numbers in parentheses indicate standard errors.

Block Two 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.

Table 10

Linear Models Predicting Proportions of Block Two 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		0.1550	0.0930

Note: †p < .1; *p < .05; **p < .01; ***p < .001. Numbers in parentheses indicate standard errors.

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 was found for relational errors.

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 maintain attention to relations, as compared to no priming.

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		0.1089	0.0238	0.0541

Note: †*p* < .1; **p* < .05; ***p* < .01; ****p* < .001. Numbers in parentheses indicate standard errors.

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). The results again suggested that only 10-11-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, 10-11 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, ($t(35) = -3.61$, $p = .011$, $d = -0.60$). However, comparing their performance, the oldest children in the priming group made marginally more relational matches across blocks than those in the no priming group, $t(73) = 1.89$, $p = .063$, $d = 0.43$, but performed equally on change in featural matches, $t(70) = -1.28$, $p = .205$, $d = -0.29$.

Table 12

Percent Change 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
4-5yo	-8.8%	9.0%	3.7%	1.4%	1.8%	-0.2%
6-7yo	1.9%	1.9%	0.3%	7.9%	12.9%	-8.7%
10-11yo	15.2%†	3.8%	-13.3%	**30.8%****	-5.6%	**-24.1%***

Note: $^{\dagger}p < .1$; $^{*}p < .05$; $^{**}p < .01$.

Experiment 2 Discussion

This study 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 they had become more sensitive to the task cues in Block 2. In stronger versions of the generative priming task (Vendetti, Wu, Holyoak, 2014; Simms & Richland, 2019) 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 (ages

9-11) replicated, but other priming-specific findings did not[1]. 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 (Vendetti et al, 2014; Simms & Richland, 2019) utilized one-relation images with relational and featural matches. However, this current study utilized 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, Morrison, Holyoak, 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 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 inhibit distraction from superficial, featural similarities as they age (e.g. Daehler & Chen, 1993; Richland, Morrison & Holyoak, 2006; Thibaut, French, & Vezneva, 2010).

[1] 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 conditions ($p = 0.02$ for children 9-11; 9 year olds were combined with 10-11 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).

The finding that 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 12), extends the current literature (Vendetti, Wu, & Holyoak, 2014; Simms & Richland, 2019) suggesting that completion of a generative relational task prior to the 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 children in adopting a relational mindset.

The role of age in promoting learning from task constraints is less clear. Both Experiment 1 and 2 showed that only 10-11 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 4-5-year-old age range. This suggests younger children reverted back to attending to featural matches after the subtle changes in Block 2 in both the priming and no priming condition. While previous research showed that 4-year-old children benefited from an initial priming task (Simms & Richland, 2019), the current study was performed using a much simpler structure-mapping task (e.g. all of the trials displayed one-relation images with a relational and featural match). This suggests that while young children benefit from a generative priming task before more straightforward tasks, priming does not create a relational mindset in young children when completing a complex relational task.

Further work could examine if the development of a relational mindset is possible when 4-year-olds complete structure-mapping tasks containing stimuli with two relations and featural matches, or if the lack of learning results from mixing pairs of images with different degrees of difficulty. As shown in Richland, Morrison, and Holyoak (2006), 3-4-year-old children 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 impacted relational attention in both U.S. and Chinese children, though nationality did not have a clear effect. More specifically, 10-11-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 if 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 enhances the relational mindset in 10-11-year-old children, a result that we replicated in a follow-up study (see footnote 1).

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 for fully separating effects of culture and socialization on *ability* to reason relationally, versus *tendency* to do so. In this case we found a relatively robust pattern suggesting that 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 doesn't mean, however, that there may not be greater *ability* to do so in either of these regions. There are some reasons from other work to think 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, Chan et al, 2010).

Additionally, the priming literature has also mostly examined priming in straightforward tasks (e.g. one-relation tasks). While previous findings have suggested that four-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, Halford, & Boyce, 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 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 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, as 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

While 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. In addition, only 4 matrices were used in the initial priming task, whereas the protocol designed by Simms & Richland (2019) utilizes 6 images. Therefore, the current study might underestimate children's relational thinking ability because children were only provided with a limited number of trials and might not have had enough trials to orient themselves to the task. This underestimation could potentially impact U.S. and Chinese children to different degrees due to dissimilar experiment settings, given that the museum setting in the U.S. 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 had to inhibit in order to complete the study. Given that inhibition control has shown to predict analogical reasoning ability (Simms, Frausel, & Richland, 2018), the cognitive demands of participants were being taxed. Since 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 effortful priming task was not completed with Chinese participants given that there were no overall differences were seen between relational reasoning performance in U.S. and Chinese children. Thus, the impact of an effortful 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 translation/back translation procedure. However, research assistants who could fluently speak the two languages agreed that there was no direct translation for the English verb “goes with”. Although “fu he” also conveys correspondence that could be interpreted both as featural and relational similarity, young children may not share the same intuition as the adult translators. We would like to note that even if this is the case, a lack of understanding cannot account for the strong developmental patterns and null effects of country in Experiment 1. A further check is ideal to examine whether changes in instructions bias English and Chinese children’s performance in this task.

Finally, this study operational culture at the level of nationality, drawing on theory and research suggesting broad differences in socialization between the U.S. 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 collectivistic/individualistic environments to assess whether traditional notions of culture are affecting children’s attention and spontaneous reasoning patterns. For instance, several countries, such as China, that were considered to be collectivistic have undergone rapid economic growth and are moving towards a more individualistic orientation (Greenfield, 2009). Greenfield (2009) also 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 utilized 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 may not be feasible and 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.

Conclusion

This study aimed to examine the effects of age, 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 effect of a generative priming task in a sample of U.S. children. These experiments revealed no effect of culture but effects of age and both implicit and explicit priming on children's attention towards relational similarities.

These findings provide new insights into the way that age changes children's relational reasoning – not only by improving ability to reason with relations, but also in 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 the age and knowledge to recognize the relations, and while there may not have been ubiquitous differences by nationality, they 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.

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References

Alexander, P.A. (2016). Relational thinking and relational reasoning: harnessing the power of patterning, *npj Science of Learning*, vol 1, 16004.

Andrews, G., Bohadana, R.G. (2018). Does solving distant analogies facilitate relational integration? *Journal of Cognitive Psychology, 30*(3), 270-280.

Andrews, G., Halford, G.S., Boyce, J. (2012). Conditional discrimination in young children: The roles of associative and relational processing. *Journal of Experimental Child Psychology, 112*, 84-101.

Bain R. (2008). Into the breach: Using research and theory to shape history instruction. In: Stearns PN, Seixas P, Wineburg S, eds. Knowing, Teaching and Learning History: National and International Perspectives. New York: New York University Press; 2000, 331–352.

Blanchette, I., Dunbar, K. (2001). Analogy use in naturalistic settings: The influence of audience, emotion, and goals. *Memory and Cognition, 29*, 730-735.

Blums, A., Belsky, J., Grimm, K., Chen, Z. (2017). Building links between early socioeconomic status, cognitive ability, and math and science achievement. *Journal of Cognition and Development*, *18*(1), 16-40.

Brown, A. L. (1989). Analogical learning and transfer: What develops? In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (p. 369–412). Cambridge University Press.

Brown, A.L., Kane, M.J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology, 20*(4), 493-523.

Bunch, K. M., & Andrews, G. (2012). Development of relational processing in hot and cool tasks. *Developmental Neuropsychology*, *37*(2), 134-152.

Carstensen, A., Zhang, J., Heyman, G.D., Fu, G., Lee, K., Walker, C.M. (2019). Context shapes early diversity in abstract thought. *Proceedings of the National Academy of Sciences*, 1-6.

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*(2), 121-152.

Daehler, M. W., & Chen, Z. (1993). Protagonist, theme, and goal object: Effects of surface features on analogical transfer. *Cognitive Development*, *8*(2), 211-229.

Gentner, D. (1978). On relational meaning: The acquisition of verb meaning. *Child Development*, *48*, 988-998.

Gentner, D. (1988). Metaphor as structure mapping: The relational shift. *Child Development*, 59, 47-59.

Gentner, D. (2003) Why we're so smart. In: Language in mind: Advances in the study of language and thought, ed. Gentner, D. & Goldin-Meadow, S., pp. 195–235. MIT Press.

Gentner, D., & Clement, C. (1988). Evidence for Relational Selectivity in the Interpretation of Analogy and Metaphor. *Psychology of Learning and Motivation - Advances in Research and Theory*, *22*(C), 307-358. https://doi.org/10.1016/S0079-7421(08)60044-4

Gentner, D., & Rattermann, M. J. (1991). Language and the career of similarity. In S. A. Gelman & J. P. Byrnes (Eds.), *Perspective on Language and Thought: Interrelations in Development* (pp. 225–277). London, England: Cambridge University Press.

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

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306-355.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, *15*, 1-38.

Goldwater, M. B., Markman, A. B. (2011). Categorizing entities by common role. *Psychonomic Bulliten Review, 18*, 406-413.

Goldwater, M. B., & Schalk, L. (2016). Relational categories as a bridge between cognitive and educational research. *Psychological Bulletin*, *142*(7), 729.

Golinkoff, R. M., Hirsh-Pasek, K., Mervis, C. B., Frawley, W., & Parillo, M. (1995). Lexical principles can be extended to the acquisition of verbs. *Beyond Names for Things: Young Children's Acquisition of Verbs*, 185-222.

Golinkoff, R. M., Jacquet, R. C., Hirsh-Pasek, K., & Nandakumar, R. (1996). Lexical principles may underlie the learning of verbs. *Child Development*, *67*(6), 3101-3119.

Goswami, U. (1992). *Essays in developmental psychology. Analogical reasoning in children.* Lawrence Erlbaum Associates, Inc.

Goswami, U., Brown, A.L. (1990). Melting chocolate and melting snowmen: Analogical reasoning and causal relations. *Cognition*, *35*(1), 69-95.

Gray, M. E., & Holyoak, K. J. (2020). Individual differences in relational reasoning. *Memory & Cognition*, *48*(1), 96-110.

Greenfield, P. M. (2009). Linking social change and developmental change: shifting pathways of human development. *Developmental Psychology*, *45*(2), 401.

Halford, G. S. (1993) Children's understanding: The development of mental models. Erlbaum.

Halford, G. S., Andrews, G., & Wilson, W. H. (2014). Relational processing in reasoning: The role of working memory. In *Reasoning as memory* (pp. 48-66). Psychology Press.

Holyoak, K.J., & Thagard, P. (1995). Mental leaps: Analogy in creative thought. Cambridge, MA: MIT Press.

Ji, L. J. (2008). The leopard cannot change his spots, or can he? Culture and the development of lay theories of change. *Personality and Social Psychology Bulletin*, *34*(5), 613-622.

Kuwabara, M., & Smith, L. B. (2012). Cross-cultural differences in cognitive development: Attention to relations and objects. *Journal of Experimental Child Psychology*, *113*(1), 20-35.

Kuwabara, M., & Smith, L. B. (2016). Cultural differences in visual object recognition in 3-year-old children. J*ournal of Experimental Child Psychology*, *147*, 22-38.

Kuwabara, M., Son, J. Y., & Smith, L. B. (2011). Attention to context: US and Japanese children's emotional judgments. *Journal of Cognition and Development*, *12*(4), 502-517.

Lockhart, K. L., Nakashima, N., Inagaki, K., & Keil, F. C. (2008). From ugly duckling to swan?: Japanese and American beliefs about the stability and origins of traits. *Cognitive Development*, *23*(1), 155-179.

Loewenstein, J., Thompson, L., & Gentner, D. (1999). Analogical encoding facilitates knowledge transfer in negotiation. *Psychonomic Bulletin and Review*, *6*(4), 586- 597.

Luciana, M., Nelson, C.A. (1998). The functional emergence of prefrontally-guided working memory systems in four-to eight-year-old children. *Neuropsychologia*, *36*(3), 273-293.

Markman, A. B., & Gentner, D. (1993). Structural alignment during similarity comparisons. *Cognitive Psychology*, *25*, 431-467.

Masuda, T., & Nisbett, R. E. (2001). Attending holistically versus analytically: comparing the context sensitivity of Japanese and Americans. *Journal of Personality and Social Psychology*, *81*(5), 922.

Morrison, R.G. (2005). Thinking in working memory. In K.J. Holyoak, & R.G. Morrison (Eds.). *The Cambridge Handbook of Thinking and Reasoning* (pp. 457-473). New York: Cambridge University Press.

Morrison, R.G., Krawczyk, D., Holyoak, K.J., Hummel, J.E., Chow, T., Miller, B., & Knowlton, B.J. (2004). A neurocomputational model of analogical reasoning and its breakdown in frontotemporal dementia. *Journal of Cognitive Neuroscience*, *16*, 260-271.

National Research Council. (2013). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Academies Press.

Nisbett, R. (2003), *The Geography of Thought: How Asians and Westerners think differently ... and why*. Free Press.

Rattermann, M. J., & Gentner, D. (1998). More evidence for a relational shift in the development of analogy: Children's performance on a causal-mapping task. *Cognitive Development*, *13*(4), 453-478.

Richland, L. E. (2015). Linking gestures: Cross-cultural variation during instructional analogies. *Cognition and Instruction*, *33*(4), 295-321.

Richland, L. E., & Begolli, K. N. (2016). Analogy and higher order thinking: learning mathematics as an example. *Policy Insights from the Behavioral and Brain Sciences*, *3*(2), 160-168.

Richland, L.E., Burchinal, M.R. (2013). Early executive function predicts reasoning development. *Psychological Science, 24*(1), 87-92.

Richland, L. E., Chan, T. K., Morrison, R. G., & Au, T. K. F. (2010). Young children’s analogical reasoning across cultures: Similarities and differences. *Journal of Experimental Child Psychology*, *105*(1-2), 146-153.

Richland, L. E., Morrison, R. G., & Holyoak, K. J. (2006). Children's development of analogical reasoning: Insights from scene analogy problems. *Journal of Experimental Child Psychology*, *94*(3), 249-273.

Richland, L. E., & Simms, N. (2015). Analogy, higher order thinking, and education. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(2), 177-192.

Simms, N. K., Frausel, R. R., & Richland, L. E. (2018). Working memory predicts children's analogical reasoning. *Journal of Experimental Child Psychology, 166,* 160-177.

Simms, N. & Richland, L.E. (2019). Generating relations elicits a relational mindset in children. *Cognitive Science, 43*(10), 1-13.

Spellman, B.A. & Holyoak, K. J. (1992). If Saddam is Hitler then who is George Bush? Analogical mapping between systems of social roles. *Journal of Personality and Social Psychology, 62*(6), 913-933.

Tardif, T., Gelman, S. A., & Xu, F. (1999). Putting the "noun bias" in context: A comparison of English and Mandarin. *Child Development*, *70*(3), 620-635.

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

Todd, J.M., Andrews, G., Conlon, E. G. (2019). Relational thinking in later adulthood. *Psychology and Aging, 34*(4), 486-501.

Treagust, D. F., Duit, R., Joslin, P., Lindauer, I. (1992). Science teachers' use of analogies: Observations from classroom practice. *International Journal of Science Education, 14*(4), 413-422.

Triandis, H. C. (1995). *New directions in social psychology. Individualism & collectivism.* Westview Press.

Tzuriel, D., & George, T. (2009). Improvement of analogical reasoning and academic achievement by the Analogical Reasoning Programme (ARP). *Educational and Child Psychology*, *26*(3), 71.

Vendetti, M.S., Wu, A., Holyoak, K.J. (2014). Far-out thinking: Generating solutions to distant analogies promotes relational thinking. *Psychological Science, 25*(4), 928-933.

Walker, C.M., Hubachek, S.Q., & Vendetti, M.S. (2018). Achieving abstraction: Generating far analogies promotes relational reasoning in children. *Developmental Psychology, 54(*10), 1833-1841.

Waltz, J.A., Lau, A., Gewal, S.K., & Holyoak, K. J. (2000). The role of working memory in analogical mapping. *Memory & Cognition, 28(7),* 1205-1212.