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Rapid Learning in a Children's Museum via Analogical Comparison

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Abstract

We tested whether analogical training could help children learn a key principle of elementary engineering—namely, the use of a diagonal brace to stabilize a structure. The context for this learning was a construction activity at the Chicago Children's Museum, in which children and their families build a model skyscraper together. The results indicate that even a single brief analogical comparison can confer insight. The results also reveal conditions that support analogical learning.

Keywords: Analogical learning; STEM learning in museums; Spatial learning

1. Introduction

Improving education in mathematics and science is a national priority in the United States, both because of workforce demands in our increasingly technological society and because American students lag behind their international peers in these domains (Gonzales et al., 2000). Moreover, increasing STEM achievement is essential to creating a citizenry that understands scientific data and the policy decisions that are informed by these data. Thus, finding effective ways to promote STEM learning is of considerable interest. In our research, we tested whether a method drawn from basic research on analogical

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processing promotes learning of a spatial engineering principle—the diagonal brace principle—in an informal museum setting. Enhancing children's science understanding in such settings through their own active participation is an important goal in cognitive science and education (Callanan, 2012). But it can be challenging to design experiences that result in actual science learning, and not just having fun with the displays. We suggest that general learning principles that emerge from cognitive science can encourage and support active science learning even in informal learning contexts such as museums.

The context of our study was an activity at the Chicago Children's Museum (CCM) in which children and their families constructed a skyscraper together. At the museum's Skyline activity, each family had its own building pavilion and a custom-built Skyline construction kit system (similar to an Erector set) (see Fig. 1). They were encouraged to build a very tall skyscraper. Children and their families enjoyed this activity and were eager to participate. But their buildings were often unstable—as they grew taller, they tended to tilt or collapse.

It appeared that children were missing an important principle of elementary physics and engineering—the use of a *diagonal brace* to achieve a stable construction[1] (Wilkerson, Benjamin, & Haden, 2007). The idea of using diagonals to increase stability in a construction is not at all obvious to young children, who instead tend to create vertical and horizontal structures (e.g., Frye, Clark, Watt, & Watkins, 1986). This preference for horizontal and vertical structures in the building context is consistent with Olson (1970) classic studies, which showed that preschool children have trouble even copying a diagonal line of checkers on a board, although they easily reproduced a vertical or horizontal line.

Our goal here was to test whether analogical comparison could give children insight into the idea that diagonal braces are critical to making structures stable. Analogical processing is a powerful learning mechanism. We know from many laboratory studies that analogical mapping can promote learning in science, mathematics, and engineering

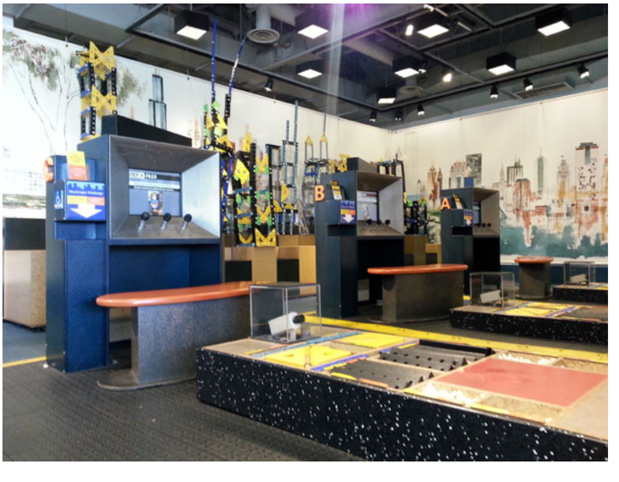

Fig. 1. Construction area with sample model buildings.

(Bassok & Holyoak, 1989; Goldstone & Son, 2005; Jee et al., 2013; Reed, Dempster, & Ettinger, 1985; Ross & Kilbane, 1997; Schwartz, Chase, Oppezzo, & Chin, 2011; Vosniadou, 1989). There is also evidence that analogical processes can support STEM learning in the classroom (Jee et al., 2010; Richland, Zur, & Holyoak, 2007; Rittle-Johnson & Star, 2007; Rivet & Kastens, 2013; Schunn, Richey, & Alfieri, 2011). Indeed, a recent meta-analysis shows widespread benefits of analogical comparison in science classrooms (Alfieri, Nokes-Malach, & Schunn, 2013). But the use of analogy in the context of more informal learning contexts where distractions abound has not yet been investigated.

The essence of an analogical comparison is finding a *structural alignment*—a set of correspondences between like relations and their arguments (Falkenhainer, Forbus, & Gentner, 1989; Gentner, 1983, 2010; Gentner & Markman, 1997). Such an alignment promotes learning in at least three ways: It renders the common structure more salient, thus promoting abstraction and transfer (Catrambone & Holyoak, 1989; Christie & Gentner, 2010; Gentner, Loewenstein, & Thompson, 2003; Gick & Holyoak, 1983); it promotes noticing *alignable differences*—differences connected to the common structure (Gentner & Gunn, 2001; Gentner & Markman, 1994; Markman & Gentner, 1993; Sagi, Gentner, & Lovett, 2012); and it invites the projection of inferences from the base (or source) domain to the target domain.

Fruitful use of analogies in learning requires that the student be able to align the two analogs. This can sometimes require considerable effort on the part of instructors and/or students. For example, studies of analogy use in mathematics classrooms have found that learning benefits when instructors take steps to ensure that students fully understand the correspondences between the analogs—for example, by juxtaposing the analogs and clearly pointing out the correspondences (Richland, Holyoak, & Stigler, 2004; Richland et al., 2007). Even when the analog is physically present, lengthy exploration may be needed. Rivet, Lyons, Miller, Schmalstig, and Kastens (2013) found that it took middle-school science students several sessions to understand a physical analogy for the phases of the moon.

But although careful explication and/or lengthy exploration of analogical mappings can be extremely valuable, they are not always feasible. In the informal museum setting, we needed a different kind of analogical intervention—one that would capture children's interest, that was brief enough not to interfere with the flow of family activities, and—most important—that would induce children to derive the correct insight. For this purpose, we drew on recent laboratory research showing that young children often learn best from highly similar, spatially juxtaposed analogies, such as the pair in Fig. 2a (Christie & Gentner, 2010; 2014; Loewenstein & Gentner, 2001). Such pairs are "self-aligning": Because of their surface similarity they can be readily aligned even by children with little prior domain knowledge. Once the pair is aligned, the common relational structure and any associated differences become more salient and easier to notice (Gentner & Namy, 1999; Gentner, 2010).

This brings us to another somewhat distinctive aspect of the present research. Many prior studies have used comparison as a way to highlight common structure and thereby reveal non-obvious relational patterns (e.g., Christie & Gentner, 2010; Gentner, Anggoro,

(a) (b)

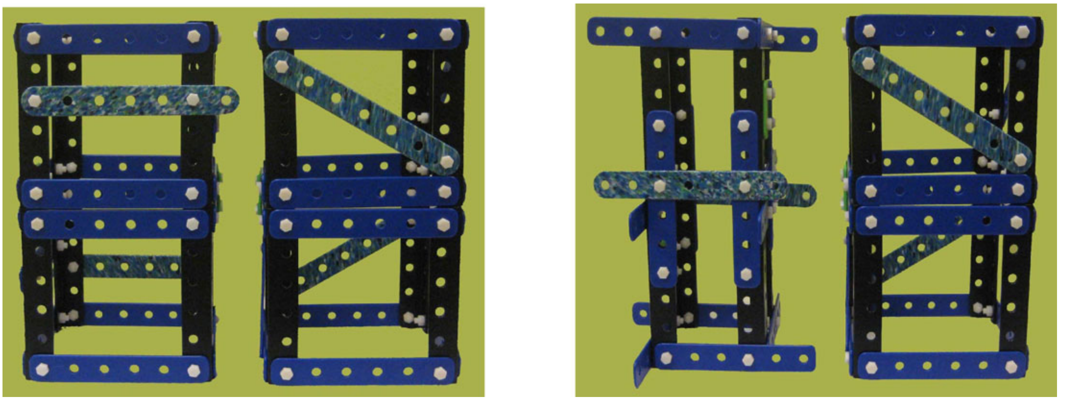

Fig. 2. Models used in comparison training, showing high alignment (HA, a) and low alignment (LA, b). Within each photo, the stable (braced) model is on the right, and the unstable (non-braced) model is on the left.

& Klibanoff, 2011) or low-salient dimensions (Graham, Namy, Gentner, & Meagher, 2010). Here, we capitalize on the fact that structural alignment can also reveal key contrasts: once two examples are aligned, alignable differences—differences connected to the common system—stand out (Gentner & Gunn, 2001; Gentner & Markman, 1994; Markman & Gentner, 1993, 1996; Rittle-Johnson & Star, 2009; Sagi et al., 2012).

Specifically, we used analogical comparison to highlight the difference between a diagonal beam and a horizontal beam. We presented children with two spatially juxtaposed model buildings to compare, as shown in Fig. 2. One building had a diagonal cross-piece —which served as a brace—and the other had an extra horizontal piece in the same vicinity. The central hypothesis is that if children are able to structurally align the two buildings, the diagonal versus horizontal contrast will stand out, making it more likely that children will notice this key contrast. This leads to two specific predictions. First, children who compare braced and unbraced buildings will make more use of diagonal braces in subsequent tasks than those not given the comparison. Second, this advantage will be greater for children who compare highly similar buildings (Fig. 2a) than for those who compare different-looking buildings (Fig. 2b). This is because high-similarity pairs are easier to align than low-similarity pairs,[2] for both adults (Sagi et al., 2012) and children (Gentner, Loewenstein, & Hung, 2007; Gentner & Toupin, 1986; Kotovsky & Gentner, 1996).

2. Overview

Upon arriving at the exhibit, children whose families had agreed to participate in the study were randomly assigned to one of three conditions: high-alignment comparison (HA), low-alignment comparison (LA), or no training (NT). Children in the HA and LA conditions participated in a brief comparison experience at the beginning of the study;

children in the NT condition did not. All children then engaged in a 12–15-min free construction session with their families (the Construction Task), in which their goal was to build a very tall skyscraper. Consenting families were videotaped during this session. After completing the Construction Task, children were taken aside from their family and asked to repair a wobbly building (the Repair Task). The main dependent measures were whether the child used a diagonal brace (a) during the Construction Task and (b) during the Repair Task. We also transcribed all spatial language by children and parents during the Construction Task. Finally, we tested for effects of age and/or sex.

Our design involves both an experimental manipulation—the training conditions and the Repair Task—and a naturalistic activity with parents (the Construction Task). The Repair Task provides a purer assessment of the child's knowledge about diagonals, because it involves the child alone whereas the Construction Task is done collaboratively with the family. However, the Construction Task allowed us to investigate the benefit of analogical instruction in a naturally occurring interaction. Our primary goal was to discover whether and how our brief analogical comparison would affect children's performance on these two tasks. The prediction is that children in the two comparison conditions would outperform those in the No Training condition, and those in the high-alignment condition would outperform those in the LA condition.

3. Method

3.1. Participants

Participants were 139 children who were visiting the CCM with their families. Families were approached to participate in the study if (a) there was a child who appeared to be in the appropriate age range (6–8 years of age), (b) there was at most one other sibling, and (c) the target child was older than his or her sibling. Of these 139 families, 29 were excluded from all analyses; eight for the child's failure to attend to the demonstration and 21 for failure to complete the entire procedure. The remaining participants (n = 110) included 39 6-year-olds (M = 78.4 months, range: 6;1–6;11; 16 male), 38 7-year-olds (M = 89.5 months; range: 7;1-7;11; 21 male), and 33 8-year-olds (M = 101.6 months; range: 8;1-8;11; 14 male).

During the Construction Task, children and their families were videotaped if the parents consented. There were 91 participant families who gave consent to be recorded and whose videos were codeable (i.e., the target children were visible and audible throughout). All participating families were compensated for their time with a small gift and a return admission pass to the museum.

3.2. Materials

The building materials for the Comparison Training, Construction Task, and Repair Task included girders, long and short beams, triangle pieces, square mending plates, screws, and nuts. In the Comparison Training activity, children in the HA and LA conditions were shown two model buildings, each approximately 2 feet tall. One of the buildings had a diagonal brace (and was therefore stable), whereas the other had a horizontal crosspiece instead (and was therefore unstable) (Fig. 2). In the HA condition the two buildings were identical in overall structure (including height and width) and had mostly corresponding pieces; their only difference was that one building (the *braced* building) had two diagonal interior pieces, whereas the other had two horizontal crosspieces in corresponding locations (Fig. 2a). In the LA condition, the buildings differed in several ways: they were of different widths,[3] and some beams protruded from one of the buildings. Here too, the braced building had diagonal crosspieces and the non-braced building did not; but because the buildings were more difficult to align, we predicted that children in this condition would be less likely to notice the diagonal versus horizontal contrast (Fig. 2b). Each family had its own pavilion in the Construction Task, with the set of pieces described above.

3.3. Comparison training

Children in the LA and HA conditions were taken aside at the start of the study for a brief demonstration. Each child was presented with two model buildings (see Fig. 2). The child was asked to predict which building was stronger, and then to test this prediction by wiggling the two buildings. This revealed that the non-braced building was easy to distort, whereas the building with the diagonal brace retained its shape. When we then asked "Now which do you think is stronger,?" 94% of the children answered correctly. The eight children who failed to answer correctly after wiggling the buildings were excluded from further analyses. The experimenter then confirmed (or corrected) this guess, pointing to the correct building and saying, "Yes, this one is strong! See, it doesn't wobble because it is stable." Children in the NT condition did not receive this training.

To ensure that parents did not observe their child's training, one experimenter had the parents fill out a questionnaire at a table near the pavilion, whereas another experimenter took the child to a station roughly 15 feet away. The child had her back to her parents during the session, and both experimenters positioned themselves between the child and the parents.[4] Following the comparison activity, the children rejoined their families for the Construction Task.

4. Construction task

Each family had its own pavilion (Fig. 1) and a large set of materials, as described above. A computer display invited them to "See how close you can get to the clouds" and to "Brace your building so it won't fall down." No other instructions were given, and the term "brace" was not explained in the video. The experimenters did not interact with families during the Construction Task. Families were given 12 min to complete the task, with an additional 3 min if they wished. Then they went on the Repair Task, described later. Both the construction task and the repair task were videotaped with the consent of the parents.

4.1. Construction task scoring

Videos of the Construction Task were coded by independent coders, blind to the child's condition, for (a) parent and child contributions to the construction, and (b) parent and child spatial language. To avoid possible contamination effects, the construction activities were coded by a separate set of coders from those who transcribed and scored the language. Language transcription and coding were done using ELAN.[5]

For the construction activity, we coded each individual action by parent or child, including the type of piece, the orientation of the piece, who initiated the placement, and whether the placement was completed. We then focused more selectively on the child's activities. We coded the child's placement of interior pieces—pieces that were added to the frame of the structure, excluding pieces used solely for decoration. There were two criteria for inclusion. First, the pieces had to be placed by the child independently, with no help or only minor help (such as helping to attach a piece placed by the child) from a parent. Instances in which the child imitated another family member or was directed to place a piece in a certain position or orientation were excluded. Second, the action had to be completed. We excluded actions that were abandoned by the child. Actions that met the inclusion criteria were coded as to their orientation: horizontal, vertical, or diagonal. A *brace* was defined as a diagonal beam connected on both ends to the existing frame of the building such that the piece created a triangle. The measure of interest was the number of diagonal braces placed primarily by the child.

A second independent coder, also blind to condition, scored the child's placements for all events that met the inclusion criteria, for a randomly selected 20 percent of the videotapes (n = 18) Agreement was 100 percent for child's placement of the piece (horizontal, vertical, or diagonal).

Language coders watched the videos of the construction sessions and transcribed all utterances by target children and their parents that contained spatial language. (See the Cannon, Levine, and Huttenlocher [2007] coding manual.) Although our main interest was the use of terms that could refer to diagonal bracing (e.g., *angle, brace, criss-cross, X, cross beam, crossbar, diagonal,* and *tilt*), we also transcribed and analyzed all uses of spatial terms (e.g., *on top, next to, higher*). (See the Cannon et al. [2007] coding manual.)

4.2. Results—Construction task

Only the 91 children with video data are included in analyses of the Construction Task (and all analyses involving language)—30 in the NT condition, 31 in LA, and 30 in HA. The central question is whether our brief analogical comparison training affected children's understanding of the brace principle. We also examined whether there were effects of parental spatial language as well as of child age and sex.

Of the 56 (of 91) children who placed interior pieces on their own, the majority (34) placed pieces horizontally or vertically (thus failing to brace the building). Of the 22 children who did spontaneously place a diagonal brace, 20 were in the comparison conditions (8 in HA, 12 in LA, and 2 in NT). To test whether comparison increased the likelihood that children would use diagonal braces, a binary value was created (1 = child placed at least one diagonal, 0 = child placed no diagonals). A logistic regression model predicting performance from comparison condition, age, and sex showed that analogical comparison training was indeed a significant predictor of spontaneous use of diagonal braces: Children in the HA and LA conditions were more likely to place a diagonal brace than were those in the NT condition (HA compared to NT: *coefficient* = 1.89, *SE* = 0.87, *Wald* $Z = 2.167$, $p < .05$); LA compared to NT: *coefficient* = 2.36, *SE* = 0.85, *Wald* $Z = 2.790$, $p < .01$)[6]. HA and LA did not differ significantly from one another. We conclude that receiving analogical comparison helped children gain insight into the idea of bracing.

We next asked whether parental use of diagonal language influenced children's performance in addition to, or instead of, the analogical training. When parent diagonal language was added as a binary variable to the model predicting whether children would use at least one diagonal in the Construction Task (in addition to sex, comparison condition, and age as presented above), we found that it was not a significant predictor of children's use of diagonal braces[7] (*coefficient* = −0.06*, SE* = 0.59, *ns*). There were no significant interactions.

5. Repair task

Following the Construction Task, children in all three conditions were taken aside from their families whereas their parents completed further questionnaires. Each child was shown a one-story building frame lacking a brace. The experimenter wiggled the building and said, "My friend made this building, but it still wobbles. Can you help me make it more stable? Can you make it so it doesn't wobble?" The experimenter offered the child a long beam and recorded whether the child placed the piece diagonally, horizontally, or vertically in the frame (Fig. 3).

5.1. Results—Repair task

All 110 children who completed the study were included in the Repair Task. We scored whether the child placed the piece diagonally (correct) or horizontally or vertically (incorrect). We then built a series of logistic regression models (R Development Core Team, 2012). We first used condition, age, and sex as predictors of children's likelihood of solving the Repair Task correctly.

In the best-fit model (Residual deviance: 135.23 on 105 *df*, $n = 110$), comparison training was a significant predictor of success on the Repair Task. Children in the HA condition were more likely to succeed than were those in the LA or NT conditions (LA compared to HA: *coefficient* = −0.99, *SE* = 0.50, *Wald* $Z = -1.972$, $p < .05$; NT compared to HA: *coefficient* = −1.48, *SE* = 0.53, *Wald* $Z = -2.774$, $p < .01$). There was no difference in likelihood of Repair Task success between the LA and NT conditions. Gender was a significant predictor of success (males were more likely to solve the task correctly than were females, *coefficient* = 0.99, *SE* = 0.42, *Wald Z* = 2.372, $p < .05$), and age was a marginally significant predictor (*coefficient* = 0.03, *SE* = 0.02, *Wald Z* = 1.791, $p < .08$). Although Fig. 4 suggests the possibility of an Age × Training condition interaction, this interaction was not a significant predictor of success (all $p > .40$).

We next asked whether the language used during the preceding Construction Task predicted children's performance in the Repair Task. We found no effect of children's spatial language nor of overall parental spatial language. However, parental use of diagonal terms

Fig. 3. A child places a diagonal brace to stabilize a non-sturdy building during the repair task.

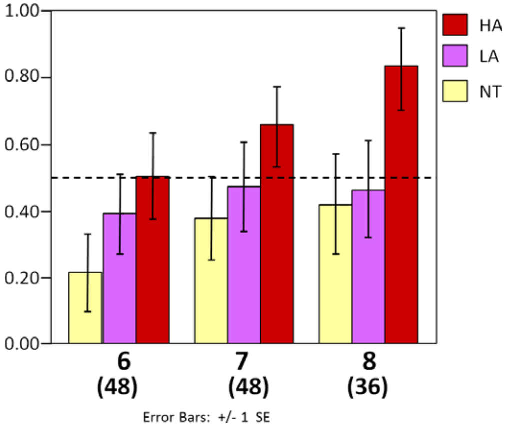

Fig. 4. Proportion of children at each age who used a diagonal brace to stabilize a wobbly building during the repair task. Although age was included as a covariate in the ANOVA, it is presented here as a categorical variable for ease of interpretation. Error bars are SEM. The dashed line represents chance performance (0.5, as there were two possible diagonals as well as horizontal and vertical placements).

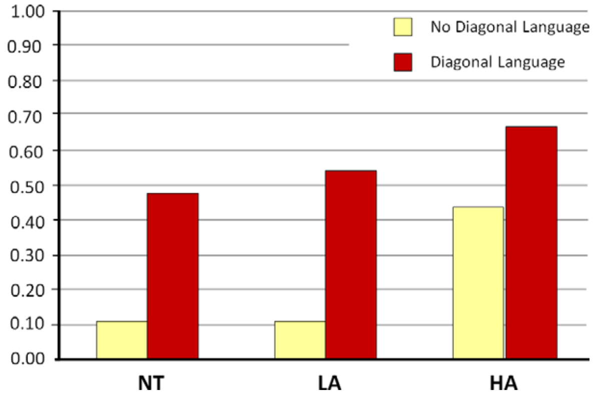

Fig. 5. Proportion of children who successfully used diagonal braces (as opposed to horizontal or vertical placement) to stabilize a wobbly building during the repair task, grouped by comparison condition and parental use of diagonal language.

did influence children's performance. As noted earlier, of the 91 participants for whom we had Construction Task videos, 64 parents used at least one word related to diagonal bracing during the Construction Task. Adding parent use of diagonal language as a binary variable to a model predicting Repair Task performance to the variables of sex, condition, and age improved the fit of the model for this subset of 91 children (Residual Error = 85.48 on 76 *df*, compared to 96.48 on 75 *df*, $\chi^2(1) = 11.00$, $p < .001$). Children whose parents had used language about diagonals during the Construction Task were more likely to succeed on the subsequent Repair Task (*coefficient* = 1.94, *SE* = 0.64, *Wald Z* = 3.02, $p < .01$; see Fig. 5 for a depiction). However, adding language to the model did not change the basic condition effects: Children in the HA condition still outperformed those in the LA (*coefficient* = −1.40, *SE* = 0.68, *Wald Z* = −2.06, $p < .05$) and NT (*coefficient* = −1.63, *SE* = 0.69, *Wald Z* = −2.38, $p < .05$) conditions. There were no interactions among factors.

6. General discussion

In this research, we asked whether analogical comparison could help children gain knowledge of an important engineering principle—the idea that a diagonal brace provides stability in a construction. There are three main findings. First, even a brief analogical comparison experience can help children gain insight into an important engineering principle. Children who received the spatial analogy were able to register the idea of a diagonal brace and to transfer it to the free-form Construction Task. Second, the specific nature of the comparison mattered: Children who received highly alignable comparisons performed better on the Repair Task (our purest measure of the child's knowledge) than those who received comparisons that were harder to align (as well as those who received no training). Third, spatial language input mattered. Children whose parents used terms referring to diagonals during the Construction Task performed better on the subsequent Repair Task than those whose parents did not.

We also found that males performed significantly better than females on the Repair Task, possibly based on differential spatial play experiences including construction activities (e.g., Baenninger & Newcombe, 1989; Connor & Serbin, 1977; Saracho, 1994, 1995; Tracy, 1987). However, both sexes showed significant benefits of comparison training, and both performed better on the Repair Task when given high-alignment comparison than when given low-alignment comparison. This suggests that the principles of analogical learning apply across a broad range of prior skills.

At the theoretical level, a possible concern is that the advantage of high-similarity pairs over low-similarity pairs stemmed not from their greater alignability, but from there being fewer potential differences between the pairs. Sagi et al. (2012) considered this issue in adult studies of difference detection, and showed that the advantage of high alignability does not depend on there being few differences in the high-alignment pairs, and that it persists even when the choice of which difference to attend to is removed. Thus, while we cannot rule out an effect of number of potential differences, we think that the ability to align the two analogs is critical to the learning effect.

Two features of the study make the findings particularly relevant for early STEM instruction. First, the intervention was extremely brief—just 2 or 3 min. This is a key factor in informal learning contexts such as museums, but it is also a factor in children's classroom learning, where sustained attention can be hard to maintain. Second, the study took place in a complex, highly interactive context, involving parents and sometimes another sibling, and with other families in the vicinity. Yet children were able to learn from it and to transfer that learning to two different building contexts.

Our findings connect to a growing body of work showing that early spatial learning provides a foundation for mathematics and science understanding (Cheng & Mix, in press; Gunderson, Ramirez, Beilock, & Levine, 2012; Newcombe et al., 2009; Pruden, Levine, & Huttenlocher, 2011) and that spatial processes contribute to success in mathematics and science courses and STEM career paths (Casey, Nuttall, & Pezaris, 2001; Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2009).

Of course, we are not claiming that the children in our study fully understood the brace principle. On the contrary, our data leave open the possibility that children had only a very limited, context-specific sense of the importance of a diagonal piece in bracing a model building. But even if children's initial insight is limited, it still constitutes a beginning—one that could pave the way for deeper, more durable understanding.

6.1. Spatial language and spatial cognition

Our findings are consistent with studies showing that spatial language input can influence children's spatial thinking (Gentner, Özyürek, Gürcanli, & Goldin-Meadow, 2013; Hermer-Vasquez, Moffet, & Munkholm, 2001; Pruden et al., 2011; Pyers, Shusterman, Senghas, Spelke, & Emmorey, 2010). Specifically, children whose parents referred to diagonals during the Construction task were more likely to use a diagonal brace in the subsequent Repair Task (for which parents were not present) than those who did not hear such language. It appears that hearing language about diagonals influenced children's conceptual focus during (and after) the task. This is consistent with the idea that adult language can influence children's construal of objects and events (Loewenstein & Gentner, 2005) and their ability to remember and transfer these elements to new contexts (Benjamin, Haden, & Wilkerson, 2010; Haden, Ornstein, Eckerman, & Didow, 2001).

6.2. Designing optimal comparisons

Our findings contribute to the goal of developing optimal instructional practices for effective use of comparisons (Alfieri et al., 2013; Goldstone & Son, 2005; Richland et al., 2004, 2007; Rittle-Johnson & Star, 2007, 2009). Whereas most prior work has been done at the high school and college level, we focused on learning in the early school years—a foundational period for math and science understanding. Two features of the comparison training stand out. First, the pairs were spatially and temporally juxtaposed, making comparison easy. The importance of juxtaposition for promoting comparison in young children has been demonstrated in laboratory studies (Christie & Gentner, 2010; Spencer, Perone, Smith, & Samuelson, 2011). A second feature of optimal comparison is using readily alignable exemplars. Children who saw perceptually similar examples, for which the corresponding elements could be readily aligned, were more likely to notice and use the key alignable difference between the two examples (i.e., a diagonal vs. a horizontal beam). This fits with evidence from laboratory studies showing that early in learning, children are more likely to achieve a relational alignment if they receive readily alignable pairs—pairs in which the matches between corresponding features of the two analogs are perceptually obvious—than if they receive pairs that lack such surface similarity (Gentner & Toupin, 1986; Gentner et al., 2007; Loewenstein & Gentner, 2001; Paik & Mix, 2006).

High similarity can matter to older learners as well, particularly when they are novices in the domain. For example, Richland et al. (2004) found that instructors of eighth-grade mathematics classes were most likely to use analogies with high surface-similarity when students seemed to be having trouble. Goldstone and Son (2005) find that even college students benefit from close similarity early in learning. Furthermore, they find that a learning sequence that shifts from close concrete similarity pairs to more abstract structural alignments leads to better transfer. A similar pattern (often called *progressive alignment*) has been found for young children, who often show greater insight into abstract analogical matches after having experienced closely similar pairs (e.g., Gentner et al., 2011; Kotovsky & Gentner, 1996).

6.3. Summary

Analogical learning has been intensely studied in cognitive science—in laboratory experiments, in cognitive simulations, and in case studies of scientific discovery (Dunbar, 1999; Gentner, 2002; Nersessian, 1984; Thagard, 1992). Our findings join a growing body of research showing that analogical comparison can be effective in imparting the principles of science, engineering, and mathematics. Importantly, we showed that analogical learning can take place even in a complex, informal environment—a busy museum, with a very popular exhibit—and that even a very brief analogical experience can be enough to spur learning. Finally, our findings provide ideas for how to design optimal comparisons to support early science learning.

There remain many open questions. For example, how deep is the insight children are deriving; how durable is this learning; and what further experiences should children get to capitalize on this initial insight. The answers to these questions can be of immense benefit in supporting children's learning.

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Notes

1. The use of a diagonal brace in construction follows from the fact that the triangle is a stable polygon; that is, its shape cannot be changed without changing the lengths of one or more sides. In contrast, the angles of a four-sided figure can change even if the length of the sides is fixed—for example, a square can become a rhombus. In a rectangular structure such as a building, diagonal braces incorporate triangles into the construction and thereby provide stability.
2. An alternate explanation could be that there are more potential differences in the LA condition, making it harder to select one. We return to this issue in the discussion.
3. The LA condition had two subconditions, each given to half the LA children. One group received the pair shown here, and another group received a pair in which the narrow building had the diagonal brace. As these two LA subconditions did not differ significantly from one another on any measure, they were collapsed in all subsequent analyses.
4. As a check on whether parents had observed their children's training, we coded the number of diagonals placed by parents in the Construction Task. There were eight in HA, 12 in LA, and eight in NT, a nonsignificant difference ($\chi^2 = 1.39$, $p = .499$). Parental use of diagonal language also did not differ across conditions: there were 21 instances in HA, 22 in LA, and 21 in NT.

5. Source: http://tla.mpi.nl/tools/tla-tools/elan/citing_elan/.
6. Age (coefficient = 0.04, SE = 0.03, Wald Z = 1.645, $p > .10$) and sex (=male: coefficient = 0.63, SE = 0.54, Wald Z = 1.173, $p > .10$) were maintained as factors in the best-fit model despite the fact that they are not significant predictors. Competing analyses with these factors removed were not significantly better or worse at predicting performance when compared to the model outlined here.
7. However, there was an intriguing hint that parent diagonal language might have influenced Construction Task performance among the LA group. Among children who put in a diagonal, the number who put in diagonals *after* hearing parent diagonal terms versus *before or without* hearing such terms was 2 versus 6 in HA, 10 versus 2 in LA, and 1 versus 1 in NT. This pattern suggests that hearing diagonal language may have helped the LA children take advantage of their less-than-ideal alignment condition. In contrast, it appears that the HA group put in diagonals relatively often and the NT group, vary rarely, regardless of parental language.

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