Using Structural Alignment to Facilitate Learning of Spatial Concepts in an Informal Setting

Dedre Gentner (gentner@northwestern.edu)
Department of Psychology, 2029 Sheridan Road
Evanston, IL 60208 USA
Susan Levine (s-levine@uchicago.edu)
Department of Psychology, 5848 South University Avenue
Chicago, IL, 60637 IL, USA
Sonica Dhillon
Department of Psychology, 2029 Sheridan Road
Evanston, IL 60208 USA
Ashley Poltermann
Department of Psychology, 2029 Sheridan Road
Evanston, IL 60208 USA

ABSTRACT

We tested whether analogical processes can be harnessed to help children learn in a complex, naturalistic learning situation. Specifically, we asked whether a brief analogical training experience could help children learn a key principle of stable construction—namely, the idea of using a diagonal brace to stabilize a structure. The context for this learning was a free construction activity in the Chicago Children's Museum, in which children and their families built a model skyscraper together. The results indicate that even a single brief analogical comparison can confer insight, and add to evidence that structural alignability processes underlie analogical comparison.

Keywords: Analogical learning; structural alignment; cognitive development; spatial learning

INTRODUCTION

Previous research has shown that analogical comparison can be a powerful process in helping both children and adults learn novel relations (Bassok, 1990; Chen & Daehler, 1989; Gentner & Namy, 1999; Gick & Holyoak, 1980, 1983; Kotovsky & Gentner, 1996; Reed, Dempster & Ettinger, 1985; Vosniadou, 1989). In this research, we ask whether analogical processes can be harnessed to help children learn a spatial concept in a complex interactive situation. Although there is abundant laboratory evidence that analogical processes can promote learning in children (See Gentner & Medina, 1998, Gentner & Namy, 2006, for reviews), there is little formal evidence that these gains can be achieved in learning environments such as classrooms and museums, which are far more complex, both socially and cognitively, than the typical conditions of a laboratory environment.

In this research we asked whether a brief analogical training experience, in which children were encouraged to make comparisons, could help them learn an important spatial principle—the use of a diagonal brace to achieve stable construction. The context for this learning was a participatory activity in the Chicago Children's Museum, in which children and their families constructed a building together using a custom-built Skyline small-scale construction kit system similar to an Erector set.

Our goal in this study was to test whether analogical comparison could effectively convey the idea of a diagonal brace—a subcase of the general principle that triangles confer stability in construction.[1] As Haden and

[1] The triangle is the only stable polyhedron. The shape of a triangle cannot be changed without changing the length of one or more sides. In

colleagues have shown (Wilkerson, Benjamin & Haden, 2007) have shown, the idea that triangles (and therefore diagonal braces) confer stability is typically not obvious to children (perhaps because buildings with only right angled horizontal and vertical beams look more tidy). Our goal was to test whether analogical comparison could give children insight into this principle. Because the context was a family activity, we aimed to create a learning activity that would require only two or three minutes. Thus the study serves to test whether even a very brief analogical comparison can lead to learning.

The basic idea of our intervention was to juxtapose two model buildings—one with a diagonal brace and the other without such a brace—and encourage children to compare them. This intervention was based on two principles of analogical processing derived from structure-mapping theory: (1) *abstraction*: analogical comparison reveals common structure (Gentner, 1983; Markman & Gentner, 1993a; Namy & Gentner, 2001; Gick & Holyoak, 1983); and (2) *contrast*: analogical comparison highlights alignable differences—differences along a common dimension or predicate that plays the same role in the common structure (Gentner & Markman, 1994; Markman & Gentner, 1993b).

These principles, taken together, predict that if children align two analogous but contrasting examples, the common structure will become more salient and any alignable differences will become more noticeable (Markman & Gentner, 1993). This prediction has been borne out in studies of relational mapping and transfer in adults (Catrambone & Holyoak, 1989; Gentner, Loewenstein & Thompson, 2003) and children (Gentner & Namy, 1999; Loewenstein & Gentner, 2001; Mutafchieva & Kokinov, 2007). For example, Gentner, Loewenstein and Hung (2007) found evidence that comparison can help young children learn the names for parts of animals. Specifically, when children were shown novel creatures that differed in one specific body part, children could use the alignment between them to focus on the distinctive part.

A third principle that is particularly relevant for developmental research is that alignment is easier and less error-prone for children when the items being compared are highly similar in their objects and parts as well as in their relational structure (Gentner & Rattermann, 1991; Gentner & Toupin, 1986; Paik & Mix, 2006; Richland, Morrison & Holyoak, 2006). For example, in the part-learning study just described, young children (3-year-olds) were far better at aligning the creatures and noticing the contrasting parts when the pairs were highly similar (making them easy to align). Older children (5-year-olds) were better able to deal with low-similarity pairs, presumably because their greater familiarity with the general bodily structure of animals allowed them to align the creatures even without surface similarities.

The study consisted of (1) a two-to-three minute individual *brace-training task* with the child, (2) a 12-15-minute *free construction session* for the child and his/her family, (3) a two-minute *brace placement task* with the child and (4) child *post-task assessments*. Children were randomly assigned to one of three conditions: High Alignability [HA], Low Alignability [LA], or No Training [NT]. In the first two conditions, children were taken aside just prior to the construction session and shown a pair of buildings (See Figure 1a and 1b). In both the High Alignability and Low Alignability training conditions, one building included a diagonal brace (which gave the structure stability) and the other had a horizontal crosspiece (which provided no structural support, but which looked very tidy). In the High Alignability condition, the two buildings differed only in this key feature of brace placement, and were readily alignable otherwise. In the Low Alignability condition, the buildings were perceptually different and

contrast, a rectangle (for example) can readily be distorted into a parallelogram by external forces.

therefore harder to align. Although the Low Alignability pair had the same key difference as the High Alignability pair (i.e., diagonal brace vs. horizontal crosspiece), we predicted that this difference was more likely to emerge in the High Alignability condition. The third group received no training and simply proceeded directly to the construction session. Following training, children built their own skyscraper along with family members.

METHOD

Participants

Participants were 138 children who were visiting the Chicago Children's Museum [CCM] with their families, of whom 19 were excluded due to failure to complete all the tasks. The criteria for requesting that a family participate were (a) a child in the appropriate age range; (b) no more than two children in the family,[2] with the participating child older than the sibling. The parents agreed to be a part of the study at the CCM Skyline exhibit and were given a return admission pass to the museum and a small gift. Forty-four 6-year-olds (range: 72-83 months; M = 78.5), forty-four 7-year-olds (range: 84-95 months; M = 89.6) and thirty-one 8-year-olds (range: 96-107; M = 101.5) participated. Approximately half of the children in each age group were female. Participants were randomly assigned to one of three training conditions: High Alignability, Low Alignability, and No Training.

Materials and Procedures

Brace training task. During training, children in the two alignability conditions—High Alignability (HA) and Low Alignability (LA)—were presented with two model buildings, each approximately 2 feet tall. Parents were not present for this task. One of the two buildings had a diagonal brace (and was therefore stable), while the other had a horizontal crosspiece instead (and was therefore unstable). In the High Alignability condition the two buildings were similar (*Figure 1a*); in the Low Alignability condition, they were dissimilar, with one narrower than the other (*Figure 1b*). Within the Low Alignability condition, which building had the diagonal brace—the narrow or the wide building—was counterbalanced. The same number of pieces was used in each of the buildings.

While the child viewed the two model buildings, the experimenter asked "Which one do you think is stronger[3]?" After the child answered, the experimenter invited them to test their prediction: "Let's find out – try to wiggle them and see which is stronger." When children did so, the non-braced building showed far greater distortion than the building with the diagonal brace. The experimenter then asked "Now which one do you think is stronger?" Then, regardless of the child's response, the experimenter gestured to the correct building and said, "Yes, this one is strong! See it doesn't wobble because it is stable". This completed the brace training portion of the study.

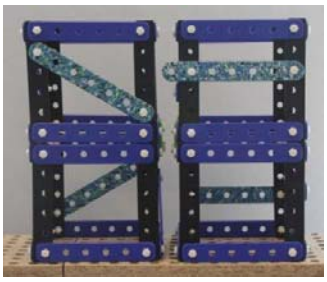

Figure 1a: High Alignability condition: stable (braced) model on left, unstable model on right

[2] Although we aimed to have two or fewer children, occasionally other siblings appeared later, in which case we continued with the study.

[3] Technically, the building with the diagonal brace is more *stable* than the other one, rather than stronger; but we judged that *stronger* would be more familiar to young children.

Figure 1b: Low Alignability condition: unstable model on left, stable (braced) model on right, showing the two counterbalanced versions

The predictions were (1) that children in the comparison conditions High Alignability and Low Alignability (HA and LA) would show more insight into the brace principle than those in the No Training (NT) condition; and (2) that children in the High Alignability condition would show more insight into the brace principle than those in the Low Alignability condition or No Training condition.

Construction session. After this brief initial training, children and their families engaged in a skyscraper-construction activity. The museum display invited the children and their families to work together to "brace their building so it won't fall down" and "see how close they can get to the clouds". They were asked to build within a marked-off square on the floor of their pavilion. See *Figure 2*. No other instructions were given. In accord with the museum's Skyline exhibit, the children and their families were free to design their buildings as they chose. The experimenters did not interact with families during the free construction session, although this task and all subsequent tasks were videotaped. (Those data will be analyzed later.) Families were provided with a large set of materials, including girders, two types of beams (one long and one short), triangle pieces, square mending plates, screws and nuts. They were given twelve minutes to complete their building, and an additional three minutes if they wanted more time. The computer screen provided a stopwatch indicating how much time they had left to build.

Figure 2. Construction area

Brace placement task. After completing the construction session, the target child was taken aside and asked to complete the key transfer task, the *brace placement* task, to test the child's ability to apply the diagonal brace principle. Children were presented with an unstable building frame (approximately 1 foot tall) that had no structural support. The experimenter wiggled the building for the children 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 beam and recorded whether the child placed the piece diagonally, horizontally, or vertically on the frame. A piece was coded as *horizontal* if it was attached to the building in two horizontally aligned holes across the structure. A piece was coded as *vertical* if it was attached to the building in two vertically aligned holes. (Such pieces were clearly detectable as horizontal or vertical, respectively.) A piece was scored as *diagonal* if it was attached at two non-aligned points in the frame.

RESULTS

Brace placement task. As predicted, performance on the brace placement task improved with training and with ease of alignment, as shown in *Figure 3*. As the two counterbalanced Low Alignability groups did not differ in performance, $t(38) = 1.57$, $p = .13$, their data were combined for all subsequent analyses. A 3 (Age: 6, 7, 8) x 3 (Condition: High Alignability, Low Alignability, No Training) x 2 (gender) ANOVA was conducted on the brace placement task. The main effect of condition is significant, $F(2, 101) = 5.03$, $p < .01$. Planned contrasts indicated that children in the High Alignability condition (M =.65, SD = .48) generated more diagonal braces than children in the Low Alignability condition (M =.48, SD = .51) and the No Training condition (M =.33, SD = .48), $p < .05$. The main effect of gender was significant, $F(1,101) = 7.08$, $p < .01$. Males (M =.61, SD = .49) generated more diagonal braces than females (M =.37, SD = .49) on the brace placement task, consistent with prior research (e.g., Newcombe & Huttenlocher, 2000). The effect of age did not reach significance, $F(2,101) = 2.66$, $p = .08$. There were no interactions.

We also examined whether there was a relation between the accuracy of children's initial guess as to which building was stronger in the brace training task and their subsequent performance in the brace placement task: that is, we asked whether children who answered accurately (i.e., who chose the diagonally braced building, M = .71) before wiggling the buildings performed differently than children that selected the unstable building (M =.29) initially in the subsequent task. We found no significant difference on the brace placement task between children who initially chose correctly ($M_{correct}$ =.54, SD = .50) and those who did not ($M_{correct}$ =.61, SD = .50), $t(78) = -.52$, $p = .60$.

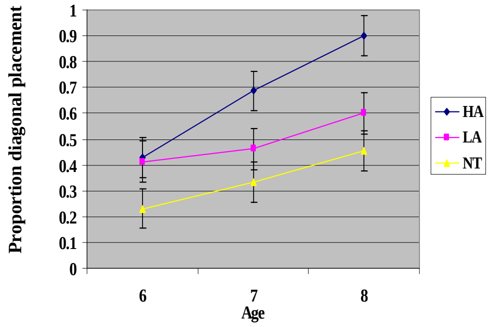

Figure 3: Proportion of diagonal beams generated in the brace placement task

Overall, the results confirm our prediction that performance is related to the ease of alignment, with children who were exposed to High Alignability training performing better than those that were exposed to Low Alignability training, and better than those receiving no training.

Construction session. Another way to assess the effects of our training is to examine the buildings created by participants in the three conditions. Because these buildings are a joint activity with the whole family, this measure is only a rough estimate of the effect of our training. Still, because the child was the only member of the family who was given training, if we do see an effect it will suggest that the children in our study not only learned from the training, but carried that insight into a complex interactive task. To assess the buildings, we counted the number of beams placed diagonally as well as the numbers of horizontal and vertical beams. We then computed the *diagonal proportion*: the proportion of diagonal beams and triangles over the total number of beams.

Children performed better in the construction session when they had analogical comparison training, as shown in Figure 4. As before, the two counterbalanced Low Alignability groups did not differ in performance, $t(38) = .81$, $p = .43$, and so their data were combined. A 3 (Age: 6, 7, 8) x 3 (Condition: High Alignability, Low Alignability, No Training) x 2 (gender) ANOVA was conducted on the diagonal proportion. The effect of condition was only of marginal significance, $F(2, 101) = 2.82$, $p = .06$. There was no effect of gender, $F(1,101) = 2.50$, $p = .12$, nor of age, $F(2,101) = 1.61$, $p = .21$.

We next asked whether the combined analogical training conditions would differ from the no-training condition. A 3 (Age: 6, 7, 8) x 2 (Condition: training [HA and LA], no training) x 2 (gender) ANOVA on the proportion of diagonals revealed a main effect of condition, $F(1, 107) = 5.73$, $p < .05$. Children who received analogical training ($M = .54$, $SD = .44$) generated a higher proportion of diagonal braces than those who did not ($M = .39$, $SD = .41$). Neither age, $F(2, 107) = 1.00$, $p = .37$, nor gender, $F(1, 107) = 1.62$, $p = .21$, were significant, and there were no interactions. Thus, we conclude that children who received analogical training used a higher proportion of diagonals in their construction sessions than those who did not.

As in the brace placement task, we also examined whether there was a relation between the accuracy of children's initial guess as to which building was stronger in the brace training task and their subsequent use of diagonal beams in the construction session: that is, we asked whether children's use of diagonals in the construction session could be accounted for by their initial understanding. We compared the diagonal proportion between children who initially selected the stable building ($M = .71$) and those who selected the unstable building ($M = .29$). There was no significant difference in use of diagonals during the construction session between children who initially chose the stable building ($M_{correct} = .57$, $SD = .44$) and those who did not ($M_{correct} = .48$, $SD = .43$), $t(78) = .83$, $p = .41$.

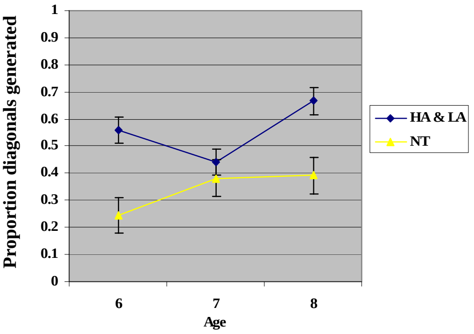

Figure 4: Proportion of diagonal beams used in construction session

DISCUSSION

This study provides evidence that the principles of structure-mapping can be used effectively in a naturalistic environment to promote children's learning of an important spatial concept. The children who received training were able to transfer their understanding of the brace principle to the final brace placement task. Further, these children carried the diagonal principle into their free construction activity with their families. Our results further show that ease of alignment can contribute to children's learning. Children who saw perceptually similar exemplars were better able to align them and notice the key alignable difference—diagonal versus horizontal beam.

These findings offer encouragement that analogical alignment could be used effectively in classrooms and other complex interactive contexts. In our study, detailed predictions from structure-mapping research were found to be useful in promoting children's spatial learning.

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, 1981, 2001; Nersessian, 1984; Thagard, 1992). Our findings join a growing body of research showing that laboratory findings on the power of analogy in learning can be scaled up to complex environments (Chen & Klahr, 1999; Loewenstein, Thompson & Gentner 1999; Richland, Zur & Holyoak, 2007). We suggest that the insights that have been gained by analogy researchers can be of immense benefit in accelerating learning.

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