Concreteness and Relational Matching in Preschoolers

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Abstract

This study investigated the effect of concreteness on preschool children's ability to recognize simple relations. Participants, age 3.0 to 5.0 years, were asked to make one-shot relational matches from a base to a target display. Two types of questions were posed: Generic in which the base display contained simple geometric shapes and Concrete in which the base display contained colorful familiar objects. Two between-subjects conditions varied the order in which the Concrete and Generic questions were asked. The results reveal relational matching on Concrete questions was significantly higher when preceded by Generic questions than when answered first, suggesting children transferred relational knowledge acquired through the Generic questions to answer the Concrete questions. However, there was no improvement on Generic questions when preceded by Concrete questions. These are novel findings suggesting that young children can better acquire and subsequently transfer relational knowledge from a generic format than from a concrete, perceptually rich format.

Keywords: Cognitive Science; Psychology; Transfer; Relations, Structure Recognition.

Introduction

The ability to recognize common relations across different situations is not always easy, but tends to improve through the course of development. Most researchers agree that some form of a relational shift occurs in development (e.g. Gentner, 1988; Gentner & Ratterman, 1991, see also Goswami, 1991); young children are more likely to attend to object-level similarities between systems or displays and overlook relations. Later in development, people become more likely to attend to relational similarities. For example, when given a simple metaphor such as a plant stem is like a straw, children's interpretation is often based on superficial attributes, such as both are thin and straight. Adults tend to interpret such metaphors through deeper relations; in this case, both can carry water (Gentner, 1988).

One category of theoretical accounts of relational development is that the relational shift is knowledge-driven (Brown, 1989, Brown & Kane, 1988; Gentner, 1988, Gentner & Ratterman, 1991, Vosniadou, 1989). By such accounts, domain-specific knowledge is the primary predictor of ability to attend to relations. In support of this position, there is considerable evidence that while young children may fail to reason analogically (i.e. based on relational structure) in many instances, they can reason analogically in contexts that are familiar to them (see Gentner, Ratterman, Markman, & Kotovsky, 1995 for discussion). For example, Gentner (1977a, 1977b) found that when 4-year-old children were shown a picture of a tree and asked, "If a tree had a knee, where would it be?", they interpreted the relational correspondence and responded as accurately as adults. Similarly, preschool children, aged 3 to 5 years, successfully transferred problem-solving strategies from contexts involving simple, familiar relations such as mimicry and camouflage (Brown & Kane, 1988). Additionally, 4-year-olds applied relational reasoning on tasks involving known relations, such as cutting and melting (Goswami & Brown, 1989). Taken together, there is ample evidence of successful relational reasoning by young children when the relations are known to them.

Yet, even in the context of simple relations and familiar objects, attention to relations can be diverted by interference of surface similarities across the base and target domains. For example, preschool children, age 3 and 4 years, were tested on their ability to make relational matches involving the relation of monotonic increase or decrease of three items (Gentner & Rattermann, 1991; see Gentner, et al., 1995 for summary). In the task, the experimenter and the participant each had sets of three items arranged in monotonically increasing or decreasing order. The child was asked to close his/ her eyes while the experimenter hid stickers under one object in each set. The stickers were always placed under items in the same relational roles across sets. When the child opened his/her eyes, the experimenter showed the child an object with sticker in the experimenter's set and asked the child to find the sticker was in the child's set. This study had a 2 x 2 design: literal similarity or cross-mapping by stimuli type. In the literal similarity condition, the correct item matched the target on both object appearance and relational location. In the cross-mapping condition, the correct item differed in appearance and matched the target only on relational location. Also, in the cross-mapped condition, an incorrect relational choice matched the target object in appearance. Hence, children could make either relational matches or appearance matches. The stimuli type varied the perceptual richness of the objects: either sparse,

such as clay pots or blue boxes, or rich, such as colorful toys or silk flowers.

It was found that children were more likely to choose relational responses in the literal condition than in the cross-mapped condition. Four-year-olds were very accurate on matching literal similarity for both rich and sparse material. However, 3-year-olds had difficulty with the sparse stimuli. In the cross-mapped condition, 3- and 4-year-olds generally matched on object appearance rather than on relational role. Furthermore, performance was much worse for perceptually rich objects than for perceptually sparse objects, suggesting that the richer objects were more likely to divert attention from relations than the more sparse objects.

Adults are also susceptible to interference from cross-mapped elements involved in complex relational tasks (Ross, 1987, 1989). When attempting to transfer mathematical solution strategies from one example problem to another, college students tend to align structure based on similarity of elements, placing similar elements in the same relational roles. This leads to incorrect solutions if the similar elements do not actually hold analogous roles.

The ability to perceive common relational structure underlies not only simple analogies, but also higher-order cognitive processes such as the acquisition and transfer of mathematical knowledge. This is because mathematical concepts are defined, not by surface features, but by their relational structure. Therefore, relational knowledge can potentially be transferred between situations that appear very different on the surface but have the same underlying structure. For example, the same probability principles can be applied to problems involving the number of ways computers can be assigned to offices or the number of ways toppings can be applied to pizza (e.g. Ross, 1987). Therefore, the study of factors that promote the recognition of common relations has importance to both the study of general cognition as well as practical importance for the potential improvement of acquisition of abstract concepts such as mathematical concepts.

One way of facilitating recognition of common relations is through explicit comparison (e.g. Catrambone & Holyoak, 1989; Loewenstein, Thompson, & Gentner, 1999; Gentner, Loewenstein, Thompson, 2003). Learners are more likely to recognize common relational structure between two instances when they explicitly compare them than when they encounter them sequentially. The process of comparison requires alignment that highlights common structure. Comparison appears to promote the formation of a schema which can in turn allow for successful transfer of relational knowledge to novel analogous situations (Gentner, et al., 2003; Gick & Holyoak, 1983).

Another factor that has been shown to affect the detection of common relations is the concreteness of the learning material. Concreteness of a given instantiation of an abstract concept can be construed as the amount of information communicated to an individual by that particular instantiation. By this interpretation concreteness can be in the form of perceptual richness or contextual richness including prior knowledge. In contrast to concrete instantiations, generic instantiations communicate little extraneous information. Concrete, perceptually rich objects and contexts can hinder performance on relational tasks in comparison to more abstract generic instantiations of the same concepts. This pattern is suggested by the performance of preschoolers on the relational matching task involving monotonic increase and decrease mentioned above (Gentner & Rattermann, 1991; see Gentner, et al., 1995). Children were more likely to make relational responses in the face of conflicting object matches when the task was conducted with perceptually sparse material than with perceptually rich material.

Other evidence for the hindering effects of concreteness is found from studies investigating the development of children's symbol use (DeLoache, 1995a, 1995b, 1997, 2000). Successful symbol use requires the detection of common relations. For example, to effectively use a map as a symbol for a real location, one must recognize the common relations between entities on the map and their real-world analogs. Young children have difficulty using concrete, perceptually rich objects as symbols. In a series of studies, 2½ to 3-year-old children were shown a 3-dimensional scaled model of a real room and told that a stuffed animal was hidden in the actual room. The experimenter then placed a miniature toy in the model telling the children that the location of the miniature toy in the model corresponded to the location of the actual toy in the real room. The children were then asked to retrieve the real toy. Only 16% of the children were able to make errorless retrieval of the actual toy. The children were then asked to retrieve the miniature toy. The accuracy of the miniature toy retrieval was 88% implying that the poor performance on the retrieval of the actual toy was not due to inability to remember the location, but an inability to realize that the model symbolically represented the actual room. In subsequent studies, the salience of the model was decreased by putting it behind a glass window. Under this condition, more than half of the participants accurately retrieved the toy. Similarly, when children were shown the location in a picture and not a 3-dimensional model, 80% of participants ably retrieved the real toy.

By 3 years of age, most children are successful in such a task. However, when the 3-year-old study participants were encouraged to play with the model first only 44% of them successfully retrieved the toy, compared to 78% of 3-year-olds who retrieved the object with no opportunity to play. The physical interaction with the model made it more difficult for the children to treat it as a symbol. In sum, decreasing the concreteness of the objects increased the ease of their symbolic use.

The hindering effects of concreteness demonstrated in the mentioned studies were found in the context of similarities between the base and target situations. In the Gentner and Ratterman study, object similarity was directly pitted against relational similarity. In the DeLoache et al. studies, there was some alignable similarity across base and target as

the model was intended to represent the real room. Little is known about the effects of concreteness on children's relational reasoning in absence of either relationally alignable or cross-mapped similarities between base and target.

There is some recent evidence for an advantage of generic material over more concrete material for children's relational reasoning in the absence of overt interdomain similarities. Kindergarteners were more likely to acquire the concept of proportion and correctly match displays of different objects based on proportion when training instantiated proportions using generic shapes than when proportions were instantiated with colorful, concrete objects (Kaminski & Sloutsky, 2009).

There is also evidence that concreteness can hinder the ability of adults to detect common relations (Kaminski, Sloutsky, & Heckler, 2006). Undergraduate students were less able, or often unable, to transfer complex relational knowledge to novel analogous when knowledge was acquired in a concrete format than when knowledge was acquired in a more generic format (Goldstone & Sakamoto, 2003; Goldstone & Son, 2005; Kaminski, Sloutsky, & Heckler, 2008; Sloutsky, Kaminski, & Heckler, 2005).

Taken together, prior research shows that adults are better able to recognize learned relations in novel contexts when they have initially acquired those relations through a more abstract, generic instantiation than through a more concrete, contextualized one. Generic instantiations also have advantages over concrete instantiations for children's ability to acquire novel relations such as proportion. It is unclear whether this advantage will hold for young children's ability to recognize simpler relations such as monotonic increase in the absence of surface similarities. It is possible that without competition of element similarity, children's attention can be focused on the underlying relation. At the same time, relations are less observable than elements and perhaps added perceptual richness of the elements will itself detract from relations.

The goal of the present study was to examine the effect of concreteness of elements on young children's ability to detect common relations. We considered the relations of monotonic increase, monotonic decrease, and symmetry involving three elements. These relations should be easier for children to recognize than proportion (Kaminski & Sloutsky, 2009) because they are built on the simple and familiar relation of "bigger than". Like previous research, we asked 3- and 4-year-old children to make one-shot relational matches across displays. This task prompts participants to compare two displays instantiating the same relation, therefore it allowed us to see whether or not generic instantiations can provide an advantage for recognition of relations beyond the comparison process alone.

Experiment

Method

Participants Participants were 100 preschool children from middle-class, suburban preschools and child care centers in the Columbus, Ohio area (51 girls and 49 boys). Participants' ages ranged from 3.0 to 5.0 years ($M = 3.72$ years, $SD = .47$ years).

Materials and Design Participants were shown two displays presented side by side involving a common relation. The task was to choose an item in the right display that was in the same relational role as an indicated item in the left display. Each display involved three objects. The relations considered in this experiment were monotonic increase, monotonic decrease, and symmetry. There were a total of 18 test questions (six increase, six decrease, six symmetry); half were Generic questions and half were Concrete. Generic questions presented simple colored, geometric shapes (circles, triangles, rectangle, or non-rectangluar parallelograms) in the base display. Concrete questions presented colorful perceptually rich objects (dogs, bugs, little girls, shoes, piggy banks, frogs, cats, jack-o-lanterns, and slices of cake) in the base display. The target display for all questions involved colorful perceptually rich objects (ducks, cats, fish, crayons, birds, flowers, ice cream, rocking horses, and ginger bread houses). Each of the target objects were used twice, once for a generic question and once for an analogous concrete question (see Figure 1). The color of the shapes for a generic question was the same as the predominant color of the perceptually rich objects in the analogous concrete question.

Participants were randomly assigned to one of two conditions (Generic-then-Concrete or Concrete-then-Generic). In the Generic-then-Concrete condition, participants were presented with the Generic questions first and then presented with the Concrete questions. The Concrete-then-Generic condition presented the Concrete questions first followed by the Generic questions. Prior to the test questions, participants were shown one example which illustrated the relation of bigger than. The base display of this example showed a bigger boy and a smaller boy in the Concrete-then-Generic condition and a bigger triangle and a smaller triangle in the Generic-then-Concrete condition. For both conditions, the target display showed a bigger teddy bear and a smaller teddy bear.

For the example and all test questions, the elements were identical except in size within each display. For example, in the questions shown in Figure 1, the triangles, dogs, and fish are identical except in size. There were no variations between elements in any other surface features.
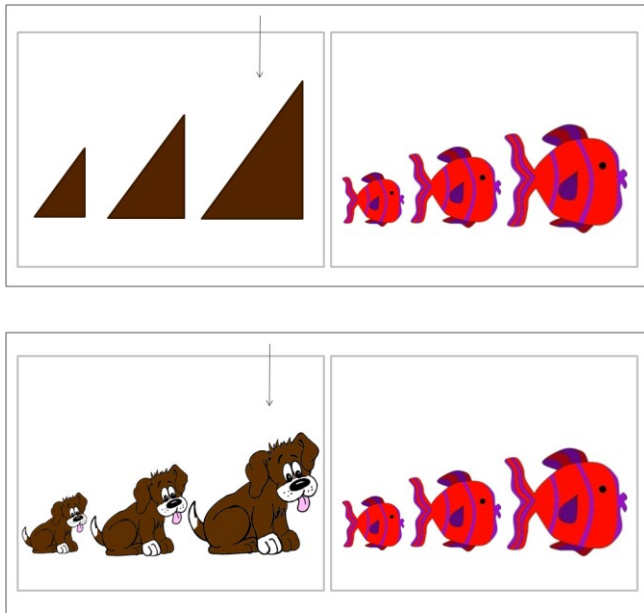
Figure 1: Example of a Generic question (upper) and its analogous Concrete question (lower).

Procedure Participants were asked to play a matching game with the experimenter. All questions were presented on the computer.

The experimenter told the child that he/she would see two pictures and showed the child the example of "bigger than". The experimenter explained that one picture had a certain pattern in it and the same patter was in the other picture, but it looked different. The following is the script:

"See, in the top picture, there are a bigger boy and a smaller boy. This is the bigger boy, and this is the smaller boy (*the experimenter pointed to each as described*). Now in the bottom picture, there is a bigger bear and a smaller bear (*the experimenter pointed to each as described*). See, the same pattern happens in both, but it looks different. Now, in this game, first you have to figure out what the pattern is that happens in both pictures. Okay? Then I am going to point to one thing in one picture, and your job is to tell me what is in the same part of the pattern in the other picture."

"So here, we have a bigger boy and a smaller boy, and a bigger bear and a smaller bear. Now I am going to point to the smaller boy (*the experimenter pointed*). Which one is like the smaller boy in the bottom picture according to the pattern? Which one is in the *same part* of the pattern in the bottom picture?"

The Generic condition presented an analogous script which replaced the word "boy" with the word "triangle". The experimenter gave corrective feedback to this example.

Test questions first presented the base display alone on the left side of the computer screen and participants were told to "look for the pattern between things in this picture".

The next slide showed the original base display and a new target display on the right side of the screen. In addition an arrow appeared over one of the objects in the base (left) display. The experimenter asked the child, "According to the pattern, what in this picture (*the experimenter gestured to the right picture*) is like this?" *(the experimenter pointed to the object with the arrow)*. The experimenter recorded the child's response on a paper. Then feedback which explicitly stated the relation was given after both correct and incorrect responses. For example, the feedback to the Concrete question that appears in Figure 1 was: "Right *or* No, actually… because in this picture (*the experimenter pointed to the left picture*), these dogs are getting bigger and bigger (*the experimenter gestured*) and I pointed to the biggest one. And in this picture (*the experimenter pointed to the right picture*), these fish are also getting bigger and bigger and this is the biggest one. So, you should point to this one (*the experimenter pointed*).

Results and Discussion

In both the Generic-then-Concrete and Concrete-then-Generic conditions, children were successful at relational matching on both the Generic and Concrete questions. Mean test scores are presented in Figure 2. Scores were above a chance score of 33% (3 out of 9 correct), one-sample t-tests, ts > 8.1, ps < 0.001. However, there was a significant difference in performance as a function of the order in which participants received the Generic and Concrete questions. Test scores were submitted to a two-way analysis of variance with order of the test question type as a between-subjects factor, age as a covariate, and test question type as a repeated measure. The analysis indicated a significant order x question type interaction, $F(1,91) = 11.09$, $p < .001$, $\eta_p^2 = .11$. There were no differences in scores on the Generic questions between the Generic-then-Concrete condition and the Concrete-then-Generic condition, independent samples t-test, $t(92) = .079$, $p > .93$. At the same time, there were differences in scores on the Concrete questions, participants in the Generic-then-Concrete condition scored significantly higher than participants in the Concrete-then-Generic condition, independent samples t-test, $t(92) = 3.16$, $p < .003$. These findings suggest that children who first answered the Generic questions acquired knowledge of the relevant relations that they were able to transfer to the Concrete questions. The reverse was not the case, answering the Concrete questions first did not improve scores on the Generic test. Therefore, experience answering the Generic questions offered an advantage for subsequent transfer that answering the Concrete questions did not.

Additionally, there were improvements with age in test scores on both question types, ANCOVA $F(1,91) = 21.66$, $p < .001$, $\eta_p^2 = .19$. Figures 3 and 4 present accuracy for the Concrete and Generic questions respectively split across the participant age range. Figure 3 illustrates that the differences in accuracy on Concrete questions is present across the age range. Therefore, while development leads to better
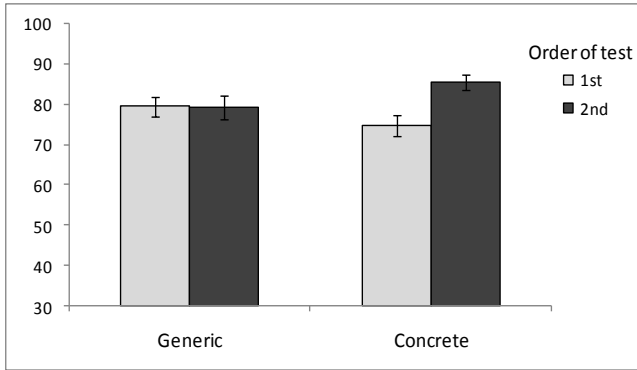
Figure 2: Mean test scores (% correct) by order of test. Error bars represent standard error of mean. Chance score is 33%.
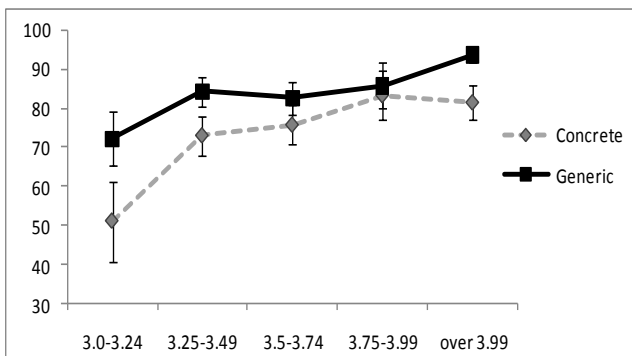

Figure 3: Mean test scores (% correct) on Concrete questions by age of participant in years. Error bars represent standard error of mean.
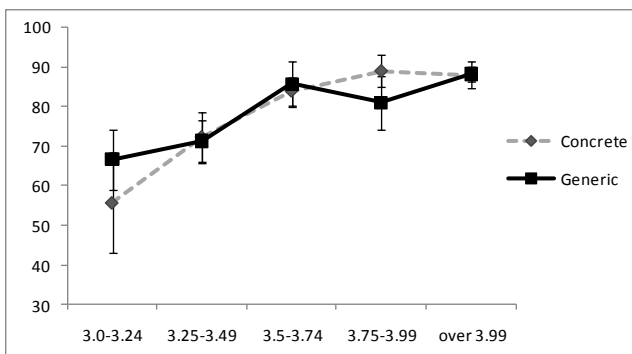

Figure 4: Mean test scores (% correct) on Generic questions by age of participant in year. Error bars represent standard error of mean.

recognition of relations, there is a consistent transfer advantage when first answering the Generic questions.

General Discussion

Previous research has demonstrated the difficulty young children have attending to common relations across displays particularly in the face of competing surface similarities (e.g. Gentner & Ratterman, 1991; Gentner et al, 1995,

Richland, Morrison, & Holyoak, 2006). Explicit comparisons, as well as the use of relational language, have been shown to increase relational reasoning (e.g. Gelman, Raman, & Gentner, 2009). There is also evidence that learning a generic instantiation of an abstract concept can facilitate subsequent relational transfer for adults (Goldstone & Sakamoto, 2003; Goldstone & Son, 2005; Kaminski, Sloutsky, & Heckler, 2008; Sloutsky, Kaminski, & Heckler, 2005). However, little research has considered what types of learning instantiations might help promote young children's relational reasoning in the absence of competing surface similarity.

The present study considered preschool children's ability to recognize the relations of symmetry and monotonic increase and decrease. Preschool children were asked to make one-shot mappings across displays of three items. This task encourages participants to make comparisons between instantiations of the same relations. Participants were given generic questions in which relations were mapped from displays of generic shapes to displays of colorful, concrete items. They also answered concrete question in which the mapping was between two displays of different colorful, concrete objects. The results found that when participants first answered the generic questions they scored markedly higher on the subsequent concrete questions than when the concrete questions were answered first. This suggests that by answering the generic questions, participants acquired solid knowledge of the relations which they ably transferred to the concrete questions. At the same time, there were no differences in scores on the generic questions as a function of when they were answered. Therefore, answering the concrete questions provided no benefit for subsequent transfer of relations.

In order to successfully recognize common relations in two different instantiations, the learner must focus attention on the relations between the objects and not directly on the objects themselves. Perceptually rich, concrete objects communicate much more information than perceptually sparse objects. Consider how much more information is communicated by the dogs versus the triangles in the base displays of Figure 1. This abundance of extraneous information may divert the learner's attention from relevant relations making it difficult to recognize these relations. In addition, the present findings suggest that when acquiring relations in the presence of extraneous concrete information, learners may form a weaker representation of the relational knowledge that can hinder future transfer.

Simple generic objects likely have less potential to capture attention, allowing more attentional resources to be focused on relevant relations. Therefore, instantiating relations with generic elements may provide an advantage for later transfer even for very young children.

While it is well accepted that the process of comparison can facilitate abstraction of relations and transfer, these findings suggest that comparisons between some types of instantiations may be more beneficial than comparison between other types of instantiations. Furthermore, this

advantage may not be detectable in immediate performance, but in later tasks involving the same relations.

Acknowledgments

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