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Structure Mapping and Relational Language Support Children's Learning of Relational Categories

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Learning relational categories—whose membership is defined not by intrinsic properties but by extrinsic relations with other entities—poses a challenge to young children. The current work showed 3-, 4- to 5-, and 6-year-olds pairs of cards exemplifying familiar relations (e.g., a nest and a bird exemplifying *home for*) and then tested whether they could extend the relational concept to another category (e.g., choose the barn as a *home for* a horse). It found that children benefited from (a) hearing a (novel) category name in a relational construction and (b) comparing category members. The youngest group—3-year-olds—learned the category only when given a combination of relational language and a series of comparisons in a progressive alignment sequence.

Relational categories are those whose membership is determined by a common relational structure rather than by common properties. For example, an exemplar of the *barrier* category must block some object or actor from its goal. Members of a relational category can differ widely in their intrinsic properties; for example, the *barrier* category can include a fence, a river, a canyon, or a mountain, or even poverty or lack of education (Asmuth & Gentner, 2005; Gentner & Kurtz, 2005; Goldwater, Goodman, Wechsler, & Murphy, 2009; Markman & Stilwell, 2001). Relational categories thus contrast with entity categories such as *tulip* or *camel*, whose members share many intrinsic properties.

Relational categories play a key role in abstract thought. They occur frequently in everyday life (*pet*, *parent*, *winner*, *accident*); for example, Asmuth and Gentner (2005) estimated that relational nouns made up nearly half of the nouns in a representative corpus of adult vocabulary. They are especially prominent in mathematics and science (e.g., *result*, *carnivore*, *pressure*, *equilibrium*). Given the importance of relational categories, it is natural to ask when and how they are learned by children.

There is a reason to expect relational categories to be relatively late in acquisition. In general, relational tasks and concepts are more difficult for children than are object concepts; for example, children solve object-matching tasks at an earlier age than relation-matching tasks (Gentner & Rattermann, 1991; Smith, 1984), and when given relation-matching tasks, children often match objects instead (Gentner & Toupin, 1986; Rattermann & Gentner, 1998; Richland, Morrison, & Holyoak, 2006). Further, children's early word learning appears geared toward object-based categories (e.g., Gentner, 1982, 2006; Golinkoff & Hirsh-Pasek, 1990, 2008; Markman, 1989; Waxman & Markow, 1995). Finally, there is indirect evidence that relational nouns are acquired later than entity nouns: In the MacArthur Communicative Developmental Inventory, which serves as a reasonable upper-bound estimate of what children might know at a given age, entity nouns are plentiful even for the 8- to 16-month range, whereas relational nouns do not appear until the 17- to 30-month range.

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Given the challenge of learning relational categories, what might contribute to children's learning? We investigate two likely candidates: relational language and comparison across instances. We first review evidence concerning relational language and then turn to comparison.

Relational Language

The first question is whether receiving a noun label will help children learn a relational category such as *container* or *barrier*. Prior work offers evidence for and against this possibility. There is abundant evidence that hearing a noun label invites children to form categories of like objects (Markman, 1989; Waxman, 1990). For example, Markman and Hutchinson (1984) found that in a triad test, young children tended to group the standard with a strong associate (e.g., spider with web) when asked ''which one does it go with,'' but they grouped according to likeness (e.g., spider with fly) when asked to extend a label: ''This is a dax—put it with the other dax.'' Waxman and Markow (1995) found a facilitative effect of nouns, but not adjectives, on category formation even in 12-month-old infants. Thus, noun labels facilitate the formation of basic-level taxonomic categories.

However, the very facility young children bring to connecting nouns with basic-level categories may undermine their ability to learn relational categories. For example, a preschool child who hears the word *taxi* is likely to think that *taxi* means a yellow car (Keil & Batterman, 1984). The child's belief that nouns name object categories makes it difficult to discard the object properties and focus only on relational information, such as that a taxi is a car that can be hired. But this is what is required for learning relational categories. Further, early in acquisition, children often rely on perceptual features in extending categories (Gershkoff-Stowe & Smith, 2004; Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988). In learning relational categories, children are challenged to cast aside this helpful guide and abstract the relational system from its concrete context.

Indeed, there is evidence that noun labels can lead children in the wrong direction—that when young children encounter relational nouns, they initially take them to refer to entity categories, defined by intrinsic properties (Gentner, 2005; Gentner & Rattermann, 1991). A striking example comes from a study by Hall and Waxman (1993) in which they attempted to teach 3½-year-olds ''situation-specific nouns,'' including relational nouns such as *passenger*. Even when children were explicitly told ''This one is a 'blicket' BECAUSE IT IS RIDING IN A CAR,'' children chose as another ''blicket'' a similar-looking doll, rather than another doll riding in a car. They interpreted the new word as referring to a concrete object category instead of to the intended relational category. It seems that ''This is an X'' does not suggest a relational category, at least for young children.

But word labels are not the only linguistic signal. Another kind of linguistic information that influences acquisition is the construction in which a word is embedded (Cameron-Faulkner, Lieven, & Tomasello, 2003; Fisher, 1994; Gleitman & Gleitman, 1992). The importance of the syntactic and semantic context is most apparent for words such as verbs and adjectives that do not name simple basic-level categories or individuals—that is, for words whose concepts are not preindividuated or ''naturally partitioned'' in the perceptual world (Gentner, 1982, 2006; Gentner & Boroditsky, 2001). For example, Gleitman and colleagues found that if adults are shown silent videos of parents interacting with children and asked to either guess the nouns or the verbs (with the word in question indicated by a beep), their identification rate was far lower for verbs (15%) than for nouns (45%; Gillette, Gleitman, Gleitman, & Lederer, 1999). However, when people were given nonsense syntactic frames (e.g., ''Gorp the fendex'') as well as the nouns used in the sentence, the percentage of correct verb guesses rose to 90%—evidence of a strong role for syntactic–semantic frames in deriving verb meanings (Fisher, 1996; Gleitman & Gleitman, 1992).

There is reason to believe that relational nouns, like verbs, may benefit from syntactic support. Like verbs, relational nouns do not refer to naturally individuable entities (Gentner, 2005, 2006), and so may require more linguistic guidance. Also like verbs, relational nouns typically take arguments, often linked to the noun by case markers (Barker & Dowty, 1993; Partee & Borschev, 2000; see Asmuth & Gentner, 2005, for discussion), for example, ''the *brother of* X'' or ''A *barrier to* Y.'' Thus, a syntactic frame that makes the argument structure clear—such as ''This is the *barrier to* the river'' or ''This is the *home of* the bird'' may clarify the relational status of the noun.

In sum, we hypothesize that children's learning of a relational concept such as *container for* or *food product of* will be aided by hearing a relational label in an informative construction. Experiment 1a examined the role of relational language—that is, a noun label in a supportive syntactic context—in children's learning of a relational concept. Specifically, we asked whether hearing relational language led to an improvement in learning over receiving the same exemplar without relational language. Experiment 1b used the same design but asked whether a noun label *without* the supportive syntactic context would also promote relational learning. Subsequent studies explored the role of comparison and structural alignment in learning relational concepts.

Comparison in Relational Learning

Comparison across exemplars plays an important role in children's acquisition of word meaning (Childers, 2008; Gentner & Namy, 2004). For example, Gentner and Namy (1999; Namy & Gentner, 2002) found that children were more likely to extend a new word on the basis of conceptual commonalities (as opposed to purely perceptual commonalities) when they compared two instances of the standard than when they saw only one. Likewise, Liu, Golinkoff, and Sak (2001) found that when given two exemplars of different basic-level categories instead of one, 4- to 5-year-olds were able to make a superordinate extension of a novel word.

Comparison is particularly effective at highlighting relational information (Christie & Gentner, in press; Namy & Gentner, 2002). According to structure-mapping theory (Gentner, 1983, 2003, 2010), this is because comparison entails a structural alignment process that promotes a focus on common relational structure (Gentner & Clement, 1988; Gentner & Medina, 1998; Markman & Gentner, 1993). For example, Christie and Gentner (in press) taught 3- and 4-year-old children names for novel spatial configurations and asked them to extend the name to another instance. Children given one standard chose on the basis of matching objects, disregarding the spatial configuration, but those who had compared two standards were far more likely to choose the same relational configuration (even with new objects). We hypothesize that this aspect of comparison—that structural alignment draws attention to shared relational structure—is important in the early acquisition of relational categories, both because for young children, nouns may strongly signal entity concepts and because young children may be less able to derive a relational concept from a single example. This line of reasoning leads us to predict (a) that comparing two instances of a relational concept should promote learning the relational meaning and (b) that comparison should be more important for younger than for older children. These predictions were tested in Experiments 2 and 3.

Experiment 1a

In Experiment 1a, we gave children an instance of a relational concept using two pictured objects to exemplify its arguments. For example, the relation *cutter for* (X, Y) was illustrated by a watermelon card (the *entity*) and a knife card (the *operator*). Half the children (RelLang condition) heard a novel noun in a relational construction (e.g., ''The knife is the *dax* for the watermelon''). The other half (NoLabel condition) received the exemplar without a specific label (e.g., ''The knife goes with the watermelon''). Then children were asked to complete another example: For example, given a piece of paper, the child had to choose which item bore the same relation to the paper as the knife did to the watermelon. There were three alternatives: a relational match (scissors—correct), a thematic associate (pencil), and an object or taxonomic match (pieces of paper). If the relational noun helps children to form a relational category, there will be more relational responding in the RelLang condition than in the NoLabel condition. But if children interpret the novel label as an object term, then adding the label may lead them to choose the object match, thus decreasing the likelihood of correct relational choice.

Method

Participants. Participants were twenty-four 3-year-olds (range = 3;0–3;6, M = 3;3), twenty-four 4- to 5-year-olds (range = 4;7–5;5, M = 5;0), and twenty-four 6-year-olds (range = 6;0–6;6, M = 6;3). At each age, children were randomly assigned to either the NoLabel or RelLang condition.

Materials. Materials were five sets of colored line drawings, each consisting of six cards (30 in total). Each set included two example cards and four test cards. The example cards consisted of an *entity* card (e.g., a watermelon) and an *operator* card (e.g., a knife). The test cards consisted of an entity card (e.g., paper) and three choice cards: a relational choice (e.g., scissors), a thematic choice (e.g., pencil), and a taxonomic choice (e.g., pieces of paper). See Figure 1 for this example and online supporting information Appendix S1 for a complete list.

Procedure. In the RelLang condition, the experimenter explained to the child that they were going

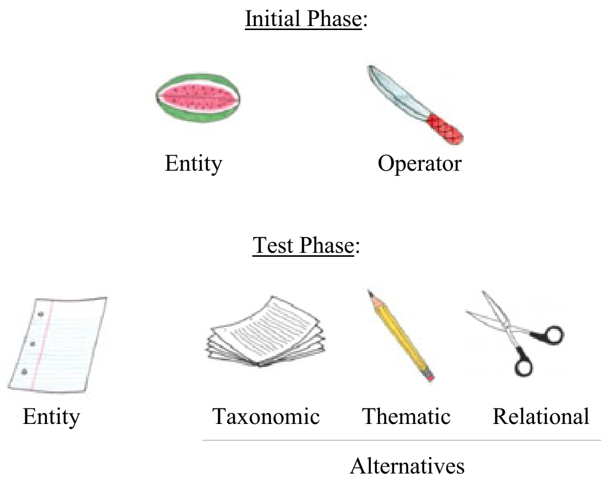

Figure 1. Sample set depicting a cutter for relation from Experiment 1a.

to play a game ''about figuring out what funny words mean.'' She presented the example cards and said, ''The first word is *dax*. The knife is the *dax* for the watermelon.'' Then at test, she put down the test cards and said, ''Now it's your turn. Which one of these is the *dax* for the paper?'' A similar procedure was used in the NoLabel condition, except for the language used. When the experimenter pointed to the example cards, she said, ''The knife *goes with* the watermelon.'' Then at test, she put down the test cards and said, ''Now it's your turn. Which one of these *goes with the paper in the same way*?'' In both conditions, children then chose among the three cards.

Results

The key question was whether hearing relational language would help children to notice and retain the relation. The results support this possibility for the 4- to 5-year-olds but not for the youngest children (see Figure 2). The proportion of trials on which children made the relational choice was submitted to a 3 × 2 ANOVA with age (3-, 4- to 5-, and 6-year-olds) and condition (RelLang, NoLabel) as between-subject factors. There was a main effect of condition, $F(1, 66) = 6.43$, $MSE = 0.32$, $p < .05$, $\eta_p^2 = 0.09$: Children in the RelLang condition made more relational choices than those in the NoLabel condition. There was also a main effect of age, $F(2, 66) = 14.46$, $MSE = 0.72$, $p < .001$, $\eta_p^2 = 0.31$. Tukey's post hoc tests indicated that 6-year-olds ($M = 0.72$, $SD = 0.20$) made more relational choices than 4- to 5-year-olds ($M = 0.42$, $SD = 0.26$) and 3-year-olds ($M = 0.42$, $SD = 0.22$; ps < .001).

Further planned comparisons revealed a significant language advantage only for the 4- to 5-year-olds. Among 4- to 5-year-olds, those in the RelLang condition made more relational responses than those in the NoLabel condition, $t(22) = 1.98$, $p < .05$ (one-tailed), $d = 0.84$; neither of the other age groups showed such a difference. Chance comparisons show the same pattern: The 4- to 5-year-olds were above chance in the RelLang condition, $t(11) = 2.61$, $p < .05$, $d = 1.57$, but not in the NoLabel condition, $t(11) = 0.19$, *ns*. In contrast, the 6-year-olds made the relational choice at above-chance (.33) rates in both the RelLang and NoLabel conditions (ts > 5.74, ps < .001, ds > 3.46), and the 3-year-olds were at chance in both conditions (ts < 1.83, *ns*). Thus, it appears that for 4- to 5-year-olds, relational language facilitates the encoding of a common relation; for 6-year-olds, a single example is sufficient, and for 3-year-olds, the concept was not learned in either condition. Interestingly, none of the age groups selected the taxonomic response at greater than chance levels, although 3-year-olds made more taxonomic choices than 6-year-olds, $t(46) = 3.21$, $p < .01$, $d = 0.95$.

Discussion

Our goal in this article is to understand how children acquire relational categories. Experiment 1a asked whether relational language would aid in this learning. The answer is yes for 4- to 5-year-olds. This group learned the relational concept *only* when it was labeled with a relational term. The oldest group, 6-year-olds, could derive the relational concept from a single exemplar with or without relational language, and the youngest group, the 3-year-olds, failed to learn the relational concept in either condition.

These findings are consistent with our prediction that relational language—specifically a novel label in an informative construction—would aid children in learning relational concepts. But before proceeding further, we must take up the question of how children in Experiment 1a interpreted the label in the relational language condition. We suggested that children induced a relational category. But perhaps instead children in the relational language condition construed the terms as referring to abstract superordinates, analogous to taxonomic categories such as *reptiles* or *vegetables*. For example, perhaps children who heard the term *blicket* applied to a closet were able to abstract the notion of *container*. We would argue that (regardless of whether the category is subordinate or

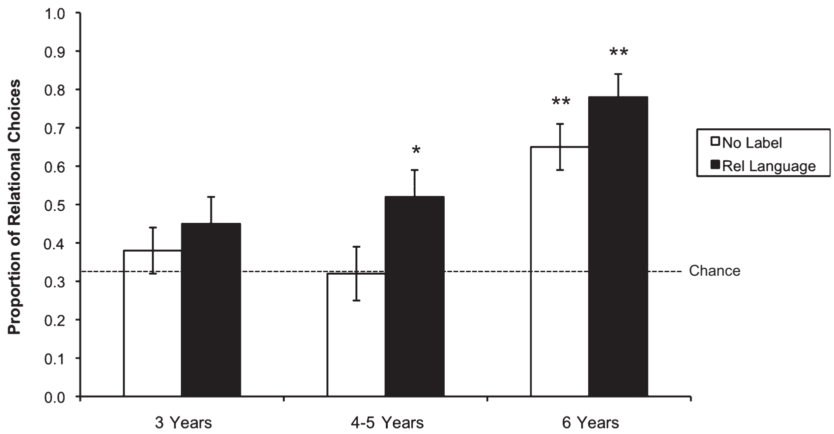

Figure 2. Results from Experiment 1a: 6-year-olds in both conditions and 4- to 5-year-olds in the RelLang condition made relational responses at above chance (.33) rates.

superordinate), there is a semantic distinction between relational categories like *container*, whose membership is determined by common participation in a relational structure, and abstract entity categories like *reptile*, whose membership is determined by intrinsic features. If so, then (as for verbs and other relational terms), syntax such as ''the dax *for* the melon'' that makes the relational status of the concept apparent should aid in acquisition.

We can test this claim by giving children the novel labels without the full relational construction—that is, by using a normal referential construction. If the effect of language in Experiment 1a was to invite a standard superordinate category like *reptile*, then the relational construction should not be necessary; hearing ''This is a dax'' should yield the same result. In contrast, if the language prompted children to form a relational category, then relational syntax should be crucial in achieving this result.

Experiment 1b was designed to test whether it is the *label-plus-relational-syntax* or the label itself that facilitates relational response for 4- to 5-year-olds, the group for whom the relational language conferred an advantage. We added a LabelSuperord condition, in which we presented the novel term as a superordinate noun. Pointing to the operator card, we said, ''Do you know what this is? This is a knife. This knife is a *dax*.'' By first naming the operator at the basic level, we signaled that *dax* was a superordinate, as is standard in presenting a superordinate noun. By showing only the operator cards (and not the entity cards), we eliminated all relevant relational information. (We considered keeping the entity card present, as in Experiment 1a, and simply ignoring it, but pilot studies suggested that children found this extraneous object confusing.) We also added a card at test—a perceptual match for the operator—to give children an attractive alternative in case they failed to derive an abstract category. Because of the additional card at test, we also retested the NoLabel and RelLang conditions from Experiment 1 to ensure that the results were stable. The only change for these two conditions was the addition of a perceptual match (to the operator card) at test. Based on prior research (Imai et al., 1994; Landau et al., 1988), we expected this alternative to appeal to children who were given a label but who failed to grasp the intended relational meaning of the term.

Based on our predictions and on the results of Experiment 1a, we expected that children in the RelLang condition would be more likely to choose the relational alternative than those in the NoLabel condition. The key question concerns the LabelSuperord condition. If children are deriving abstract superordinate category just from the novel word, then children in the LabelSuperord condition should choose the same correct match as children in the RelLang condition. However, if the superordinate label is insufficient to arrive at the correct category—in other words, if children need the support of the relational construction—then they should fail to grasp the relational match.

Experiment 1b

Method

Participants. Participants were fifty-six 4- to 5-year-olds (range = 4;4–5;6, *M* = 4;11) randomly assigned to the NoLabel, LabelSuperord, or RelLang condition.

Materials. Materials were identical to Experiment 1a with the exception of an additional card at test: a perceptual match choice (e.g., a baseball bat with the same color and basic shape as the knife). See Figure 3 for this example and online supporting information Appendix S2 for a complete list.

Procedure. The procedure for the RelLang and NoLabel conditions was as in Experiment 1a with the exception of an additional alternative at test. The LabelSuperord condition was like the other two conditions, except for the absence of the entity card in the initial phase and the wording in both phases. In the initial phase, the experimenter pointed to the operator card and said, ''Do you know what this is? This is a knife. This knife is a *dax*,'' and at test, she asked ''Which one of these is also a *dax*?'' The test array was identical for the three conditions: The four choice cards were spread out with the entity card above them (see Figure 3). For the LabelSuperord condition, no mention was made of the test entity card.

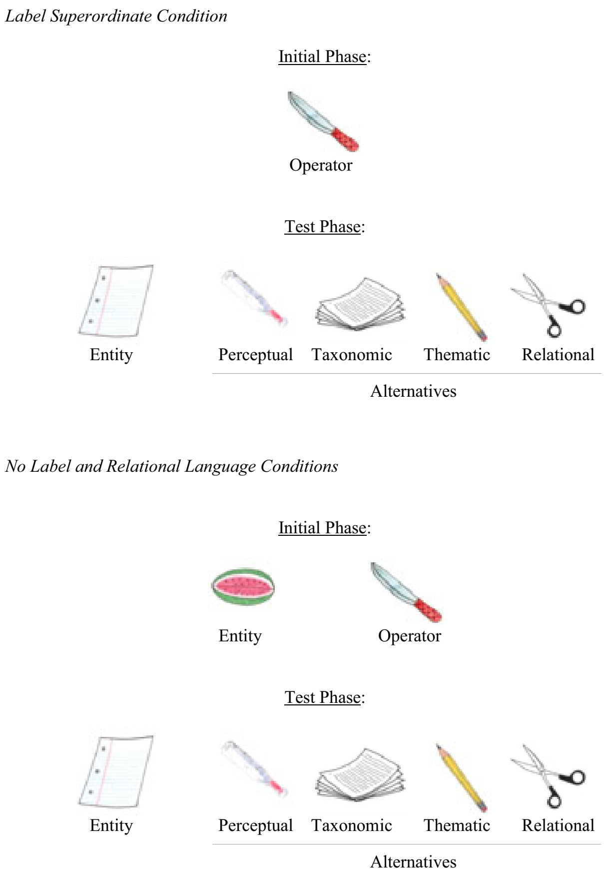

Figure 3. Sample set depicting a cutter for relation from Experiment 1b.

Results

As predicted, children made many more relational responses when they received a label in a relational construction than when they received the label only (i.e., in a simple category sentence) or no label at all (see Figure 4). An ANOVA on the proportion of trials on which children made the relational choice with condition (NoLabel, LabelSuperord, RelLang) as the between-subject factor revealed a main effect of condition, $F(2, 53) = 12.94$, $MSE = 0.60$, $p < .001$, $\eta_p^2 = 0.33$. Consistent with the findings of Experiment 1a, 4- to 5-year-olds in the RelLang condition made more relational responses than those in the other two conditions (ts > 2.11, ps < .05, ds > 0.70). Relational responding was above chance (.25) only in the RelLang condition, $t(18) = 4.95$, $p < .001$, $d = 2.33$. Children in the LabelSuperord condition were *less* likely to choose the relational match (ts > 2.84, ps < .01, ds > 0.92) and *more* likely to choose the perceptual match (ts > 32.36, ps < .001, ds > 10.60) than those in the other two groups.

Discussion

This study operates on two levels. At one level, it asks what kinds of cognitive and linguistic support is needed for children to learn relational categories. At another level, it bears on the theoretical claim that relational categories are a distinct class of superordinate categories, and cannot simply be treated as standard superordinates (Asmuth & Gentner, 2005; Gentner, 2005; Gentner & Kurtz, 2005; Goldwater et al., 2009; Markman & Stilwell, 2001).

These results demonstrate the specific importance of relational information in young children's learning of relational concepts. When given a new noun in a relational construction, with an available relation to apply the noun to, 4- to 5-year-olds can arrive at a relational meaning. In contrast, simply hearing a superordinate category label renders children *less* likely to infer a relational meaning. This underscores the semantic distinction between relational categories and standard taxonomic superordinate categories. Unlike standard taxonomic superordinates like *feline* or *mammal*, relational categories like *carnivore* cannot simply be characterized as more abstract (in the sense of having fewer properties) than their subcategories; rather, their members cohere on the basis of common relational structure.

Turning to the developmental pattern, the findings of Experiments 1a and 1b suggest that by

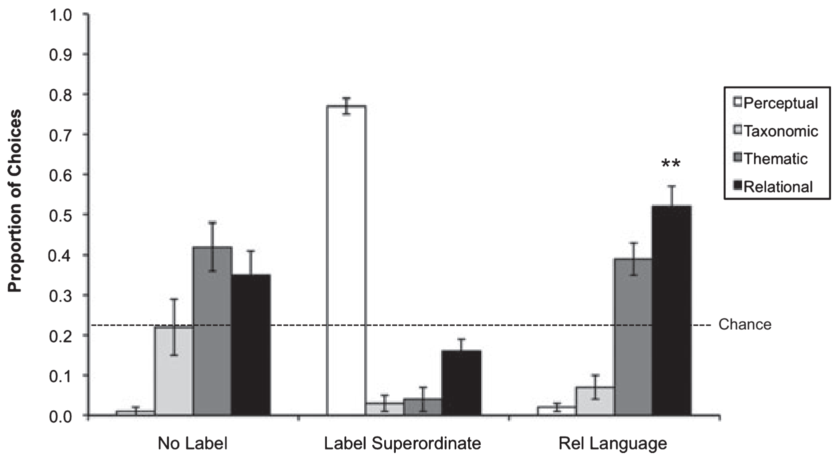

Figure 4. Results from Experiment 1b: Children's relational responses were above chance (.25) only in the RelLang condition.

6 years of age, children can infer a relational category simply by seeing an example of the relation, even without the support of language. The 4- to 5-year-olds can derive the relation from an example if they receive relational language (though not if they simply hear a referential label). However, we saw no evidence of relational learning in 3-year-olds, even with relational language.

This raises the question of whether and how 3-year-olds *can* learn nominal relational concepts. To answer this question, we turn to our second major theme: comparison processes. There is considerable evidence that comparison can facilitate relational learning (Christie & Gentner, in press; Gentner, 2003, 2010; Gentner & Medina, 1998). This is because comparison entails a process of structural alignment that acts to render commonalities—especially interconnected relational commonalities—more salient and more likely to be used in further reasoning (Gentner & Namy, 1999, 2006; Gick & Holyoak, 1983; Loewenstein & Gentner, 2001; Markman & Gentner, 1993).

In Experiment 2, we asked whether comparing instances would foster learning a relational concept. We showed children two instances of a relation, each illustrated by a pair of cards. For example, the relation *cutter for* (X, Y) was illustrated by watermelon–knife and by evergreen tree–ax. We also asked whether comparison and relational language would combine to increase relational learning, as suggested by prior findings that hearing a common label provides a strong ''invitation to compare'' (Gentner & Medina, 1998; Gentner & Namy, 1999).

As in Experiment 1a, half the children heard a novel noun label in a relational construction applied to each exemplar of the relational category. The other half was encouraged to compare the same two exemplars, but was not given relational language. At test, children were asked to complete another example of the same relation. To increase the generality of the study, we increased the number of sets from five to nine.

Experiment 2

Method

Participants. Participants were thirty-two 3-year-olds (range = 3;0–3;6, *M* = 3;2), thirty-two 4- to 5-year-olds (range = 4;6–5;3, *M* = 4;10), and twenty-four 6-year-olds (range = 6;0–6;6, *M* = 6;2) randomly assigned to either the NoLabel or RelLang condition.

Materials. Materials were nine sets of colored line drawings of objects, each consisting of eight cards (72 in total), displayed on laminated cards. Each set included two example pairs (four cards) and four test cards. The example cards consisted of two *entity–operator* pairs (e.g., a watermelon and a knife, an evergreen tree and an ax); the test cards were as in Experiment 1a. See Figure 5 for this example and online supporting information Appendix S3 for a complete list.

Procedure. The procedure for each example set was similar to that of Experiment 1a. Children were told (for example), ''The knife {is the *dax* for; goes with} the watermelon. And the ax {is the *dax* for; goes with} the tree.'' In both conditions, they were explicitly prompted to compare the example pairs after the second example was shown: ''You see how these (gesturing across the operators) {are *daxes* for these; go with these in the same way} (gesturing across the entities)?'' The test phase was as in Experiment 1a.

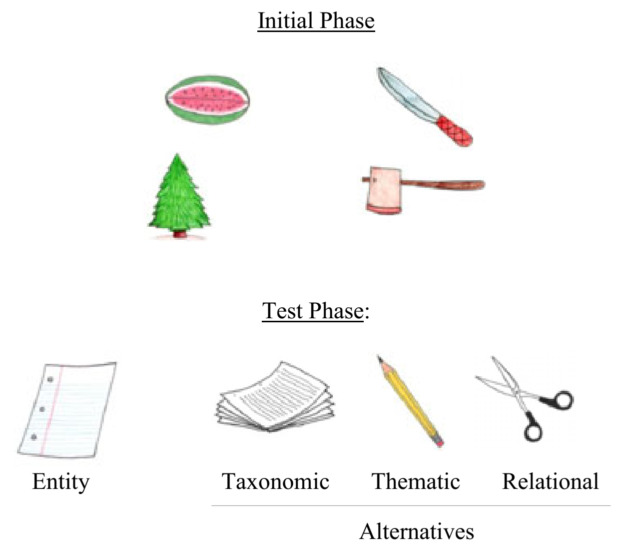

Figure 5. Sample set depicting a cutter for relation from Experiment 2.

Results

The key questions were (a) whether comparison would promote the learning of relational concepts and, if so, (b) whether adding relational language would increase the relational learning. That is, if, as predicted, we find that comparison renders the common structure more available, is there added value in common relational language? The answer to both is yes for the older two groups (see Figure 6).

A 3 × 2 ANOVA on the proportion of relational choices with age (3-, 4- to 5-, and 6-year-olds) and condition (NoLabel, RelLang) as between-subjects factors revealed a main effect of condition, $F(1, 82) = 10.26$, $MSE = 0.37$, $p < .01$, $\eta_p^2 = 0.11$: Children in the RelLang condition made more relational choices than those in the NoLabel condition. There was also a main effect of age, $F(2, 82) = 38.48$, $MSE = 1.38$, $p < .001$, $\eta_p^2 = 0.48$. Tukey's post hoc tests indicated that 6-year-olds made more relational choices than 4- to 5-year-olds, who in turn made more relational choices than 3-year-olds (ps < .01). Planned comparisons revealed a significant language advantage for 6-year-olds, $t(22) = 3.09$, $p < .01$, $d = 1.32$, and 4- to 5-year-olds, $t(30) = 2.63$, $p < .05$, $d = 0.96$, but not for 3-year-olds ($t < 0.21$, *ns*).

Further analyses revealed that the older groups made the relational choice at above-chance (.33) rates in both the RelLang and NoLabel conditions (ts > 2.89, ps < .05, ds > 1.49). Thus, for the 4- to 5-year-olds, comparison alone—even without relational language—was sufficient to invite relational responding. However, as in Experiment 1a, 3-year-olds were at chance in both conditions (ts < 0.81, *ns*). Their responses did not appear to show any systematicity: Regardless of condition, only 37.5% of the 3-year-olds made the relational choice on at least four of nine trials, and the remaining responses were roughly evenly distributed over the thematic and taxonomic alternatives. The trials for which relational choices were made also varied across children.

Discussion

These results bear out the prediction that structural alignment can help children arrive at relational meanings. For children with 4 years of age and older, carrying out a relational comparison, even without relational language, was sufficient to prompt encoding the common relation. Relational language heightened this relational focus, replicating the finding of Experiment 1 that relational language helps children as young as 4 years of age to interpret a novel word as a relational term. Combining the findings from Experiments 1 and 2, it appears that by 4–5 years of age, *either* comparison *or* relational language is sufficient to invite relational responding.

We also considered the adverse possibility that the children who succeeded did so simply by translating the novel terms into familiar terms such as *home* rather than by learning them as new relational terms. However, we found no evidence that children performed better on relations that are translatable into familiar words (e.g., *home*) than on those that are not (e.g., *food product of*) (see online supporting information Appendix S4).

For 3-year-olds, neither relational comparison nor relational language nor both was sufficient to prompt relational encoding. This failure to show relational learning could stem from a maturational limitation, such as insufficient processing capacity to encode the relational structure (Halford, 1992) or insufficient executive capacity to inhibit object matches (Richland et al., 2006). However, another possibility, suggested by Gentner and Rattermann (1991) is that their limitation is a lack of knowledge (Gentner & Rattermann, 1991; Goswami & Brown, 1990; Rattermann & Gentner, 1998). On this account, what the 3-year-olds lack is a sufficiently firm encoding of the domain relations to be able to align and extract the common relational structure.

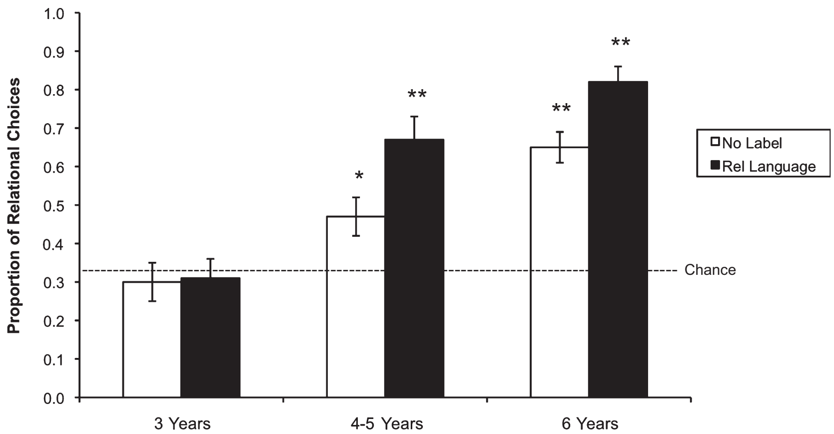

Figure 6. Results from Experiment 2: 4- to 5- and 6-year-old children in both conditions made relational responses at above-chance (.33) rates.

One way to bootstrap relational encoding in a domain is by progressive alignment from close, concrete comparisons to more abstract purely relational comparisons (Gentner, Loewenstein, & Hung, 2007; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001; Namy & Gentner, 2002; Thompson & Opfer, 2010; Waxman & Klibanoff, 2000). In a close similarity comparison, the object matches—which are easy for the child to grasp—support the correct structural alignment. Because the structure-mapping process favors common relations over common object attributes, achieving a structural alignment, even between overall similar pairs, will increase the salience of the common relational structure somewhat, increasing the likelihood of alignment with a further example of the same relational structure (Gentner & Namy, 1999). For example, Loewenstein and Gentner (2001) found that 3-year-olds who compared two highly similar model rooms were subsequently better at mapping between one of the rooms and a very dissimilar room (with the same relational structure) than were children who interacted with the same two initial rooms separately. Applying this logic to the present case, we hypothesize that a child who cannot see the match between watermelon–knife and log–ax may nonetheless be able to match watermelon–knife1 with orange–knife2. Carrying out this concrete alignment can help the child begin to notice the common relation *cutter for*. Once this relation is made salient, the child may be able to achieve the more abstract alignment between evergreen tree–ax and log–saw, despite the lack of object similarity.

In Experiment 3, we tested whether progressive alignment can help 3-year-olds grasp relational categories. To do this, we created new high-similarity pairs that shared the same relational structure as the low-similarity pairs used in Experiment 2. We began with these high-similarity pairs and then progressed to the low-similarity pairs like those used in Experiment 2. We predicted that making concrete alignments would highlight relational commonalities and foster children's ability to perceive the relation in the subsequent low-similarity analogs. If so, this will be evidence that progressive alignment can help children grasp a new relational category.

Experiment 3

Method

Participants. Participants were fifty-eight 3-year-olds (range = 3;0–3;8, *M* = 3;2) randomly assigned to the NoLabel or RelLang condition.

Materials. For each of the initial pairs, we created two close pairs instantiating the same relation. In order to keep the task length manageable despite having two additional pairs in each set, we reduced the number of item sets from the nine used in Experiment 2 to five sets (see online supporting information Appendix S5; some minor changes were made to permit designing the two new pairs). Specifically, the materials were five sets of colored line drawings of objects, displayed on laminated cards. Each set included four example pairs (eight cards) and four test cards. As in Experiments 1a and 2, each example pair consisted of an *entity* (e.g., watermelon) and an *operator* (e.g., knife). The corresponding objects in the first two pairs (close pairs) were highly similar (e.g., entity: watermelon–orange; operator: knife1–knife2); the corresponding objects in the second two pairs (far pairs) were less similar (e.g., entity: evergreen tree–log; operator:

ax–saw). Independent ratings from 48 adults validated this distinction between close and far (see online supporting information Appendix S6). The test cards were as in Experiments 1a and 2 (see Figure 7 for an example).

Procedure. The procedure was similar to that of the prior studies, except that a puppet was used to help make the task more accessible for these younger children. In the RelLang condition, the experimenter said, ''In this game we are going to teach Sammy (a puppet sitting on the table) the word *dax.* We're going to show him what *dax* means.'' The remaining procedure was similar to that of Experiment 2 for each close and far pair, with the addition of another explicit comparison across all four example pairs after the last pair was shown: ''Now let's look at all of them. You see how these (gesturing across all four operators) {are *daxes* for these; go with these in the same way} (gesturing across all four entities)?'' The test phase was identical to that of Experiments 1a and 2.

Results and Discussion

The key question was whether progressive alignment, with or without relational language, would help 3-year-olds abstract a common relation. The answer is yes, but only for the combination of progressive alignment and relational language. Children in the RelLang condition performed above chance (.33), $t(28) = 4.25$, $p < .001$, $d = 1.61$. However, progressive alignment by itself was not sufficient to induce the relational concept: Children in the NoLabel condition performed at chance ($t < 0.67$, *ns*; see Figure 8). Accordingly, the proportion of relational choices in the RelLang condition was greater than that in the NoLabel condition, $F(1, 56) = 5.85$, $MSE = 0.37$, $p < .05$, $\eta_p^2 = 0.10$.

To examine the effect of progressive alignment over a single comparison, we compared 3-year-olds' performance with and without progressive alignment (Experiments 3 and 2, respectively) on the five sets of materials used in both experiments. Children who received progressive alignment (Experiment 3, $M = 0.44$, $SD = 0.26$) made more relational choices than those who did not (Experiment 2, $M = 0.28$, $SD = 0.21$), $t(88) = 2.99$, $p < .01$, $d = 0.64$. The facilitative effect of progressive alignment held in the RelLang condition, $t(43) = 3.27$, $p < .01$, $d = 1.00$, but not in the NoLabel condition ($t < 1.03$, *ns*).

We conclude that 3-year-olds can learn a relational category when given a progressive-alignment sequence from closely similar to purely relationally similar pairs. Further, the finding that only children in the RelLang condition learned the relation is evidence that relational language supports the formation of relational concepts.

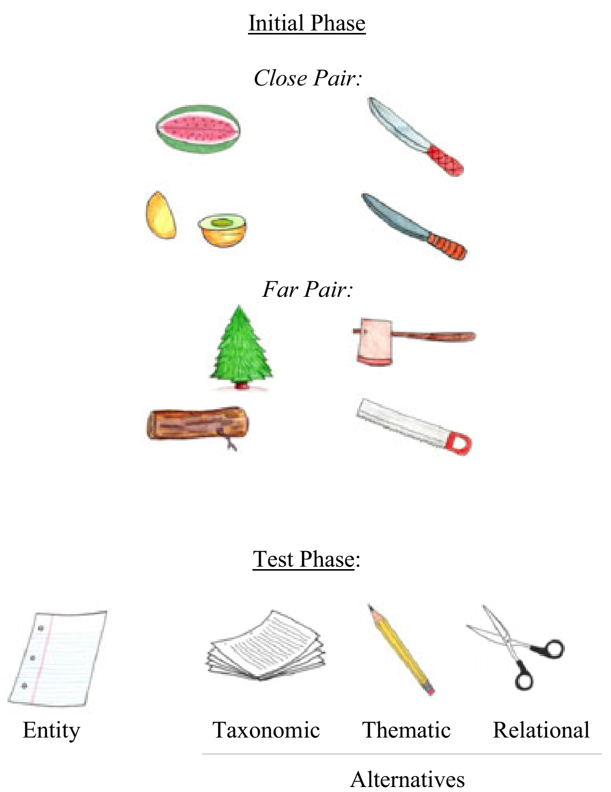

Figure 7. Sample set depicting a cutter for relation from Experiment 3.

General Discussion

Learning nominal relational categories poses a substantial challenge to young children, yet by around 3 years of age, children are beginning to acquire a stock of such concepts. In this work, we sought to discover which internal and external factors enable 3-year-olds to learn these kinds of categories. We found support for three hypotheses: (a) relational language—specifically, the use of a noun in a relational construction—invites a relational category, (b) comparison across different instances helps children abstract a relational category, and (c) progressive alignment—a particularly effective form of early comparison-based learning—in conjunction with relational language can bootstrap the initial learning of relational categories. These findings are consistent with Gentner's (2003, 2010) claim that structural alignment and relational language act to bootstrap relational learning.

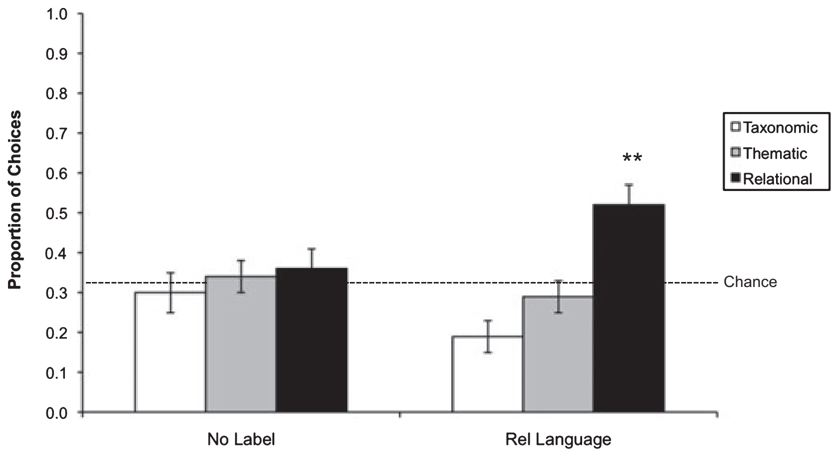

Figure 8. Results from Experiment 3: Children's relational responses were above chance (.33) only in the RelLang condition.

Experiments 1a and 1b tested the role of relational language. In Experiment 1a, children received a single exemplar of the relational category, with or without relational language. The results revealed a developmental progression in children's ability to apply the relation to a new exemplar: Six-year-olds could derive the relation from one example, with or without relational language; 4- to 5-year-olds could do so only if they received relational language; and 3-year-olds were at chance in both conditions. Thus, language played a key role for the 4- to 5-year-olds. More specifically, Experiment 1b revealed that relational syntax (e.g., ''This is the dax *for the watermelon*'') was crucial in supporting this insight: When given a novel label without relational syntax, 4- to-5-year-olds failed to learn the relational category.

In Experiment 2, we turned to our second hypothesis: that structural alignment processes are instrumental in children's learning of relational categories. We gave children two instances of a relation to compare, with or without relational language. As predicted, comparison helped children learn the relational category: Four- to 5-year-olds (and 6-year-olds) were able to learn and transfer the relation, with or without relational language. We also found effects of relational language: Both 4- to 5-year-olds and 6-year-olds performed better with relational language. Thus, the two older groups were aided both by comparison and by relational language. However, 3-year-olds again failed to learn the relation in either condition.

In Experiment 3, we asked whether 3-year-olds could learn a relational category if given a more powerful comparison experience, namely, progressive alignment (Gentner & Namy, 1999; Gentner et al., 2007; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001). That is, we asked whether 3-year-olds could achieve a relational abstraction if given an optimal learning sequence (from close to far pairs), and whether relational language would aid in this learning. We found evidence for both hypotheses: Only those 3-year-olds who received *both* relational language and progressive alignment were able to learn and apply the relational category. This suggests that by 3 years of age, relational language invites a relational construal, but at this early stage, children need to compare easily aligned exemplars to begin to discern the specific relational structure.

Table 1 shows the three studies organized in terms of the degree of support they provide for structural alignment: a single standard (Experiment 1), a moderately dissimilar pair of standards (Experiment 2), and finally a progressive alignment sequence from highly similar to moderately dissimilar pairs (Experiment 3). Only the 6-year-olds were able to abstract and transfer a relation when given a single exemplar (with or without relational language; Experiments 1a and 1b). The 4- to 5-year-olds succeeded if they *either* were given two exemplars to compare (Experiment 2) or received one exemplar with relational language (Experiment 1a). The 3-year-olds succeeded only when given *both* relational language and a progressive alignment sequence from a highly similar ''fail-safe'' pairs to less similar pairs (Experiment 3).

Relational Language

Our finding that relational constructions can aid in the acquisition of relational nouns is consistent with work by Saylor, Sabbagh, and Baldwin (2002; Saylor & Sabbagh, 2004) on children's acquisition of

Table 1
Analogical Structure Used in the Studies, Showing Increasing Opportunities to Compare and Align the Study Exemplars From Experiment 1 to Experiment 3.

	Analogical pattern	Example (food for)
Experiment 1	A:B :: X: ?	Rabbit:Carrot :: Horse: ?
Experiment 2	A:B :: C:D :: X: ?	Rabbit:Carrot :: Robin:Worm :: Horse: ?
Experiment 3	A:B :: A′:B′:: C:D :: E:F :: X: ?	Rabbit:Carrot :: Mouse:Cheese :: Robin:Worm :: Penguin:Fish :: Horse: ?

part terms, a particular class of relational nouns (Partee & Borschev, 2000). Like other relational nouns, part terms are difficult to learn when presented in a bare referential sentence such as ''This is an X.'' Saylor and colleagues showed that constructions such as ''This has an X'' facilitate children's acquisition of part labels (Saylor & Sabbagh, 2004; Saylor et al., 2002).

Our findings are consistent with prior findings that relational labels can support the learning of relational concepts (Casasola, 2005). For example, children who are reminded of relational language such as *Daddy*, *Mommy*, *Baby* (Gentner & Rattermann, 1991) or *top*, *middle*, *bottom* (Loewenstein & Gentner, 2005) perform better on relational mapping tasks than those not so reminded (see also Son & Goldstone, 2005). Likewise, children given an event-mapping task are more likely to match on the basis of relational roles if they are reminded of the verb that expresses the relational pattern (Gentner, Simms, & Flusberg, 2009). There is also evidence that novel terms can support relational learning (Childers, 2011; Gentner & Namy, 2004, 2006). Christie and Gentner (2007) found that young children are more likely to attend to the simple relation of identity—matching AA with BB instead of with CD—when a novel label is applied to the standard. The current work provides further evidence that novel relational terms can contribute to relational learning.

Structural Alignment in Language Learning

Our findings highlight the importance of structural alignment in early learning. The 4- to-5-year-old children who were led to compare two relationally similar situations (Experiment 2) were able to align them and extract the common relation for use in a new situation. These findings are consistent with much prior research showing the importance of comparison in learning the meanings of relational terms (Childers, 2011; Childers & Paik, 2008; Gentner & Namy, 2004; Pruden, Hirsh-Pasek, Maguire, & Meyer, 2004; Scott & Fisher, 2009). For example, Childers (2011) found that 2½-year-olds were better at learning novel verbs if they compared multiple instances that varied in their specific details. As in our studies, the comparison effect was increased by the use of common language across presentations.

However, our findings also show that early in learning, the ability to carry out structural alignment is limited; 3-year-olds were able to learn the relation only when given a combination of relational language and a particularly supportive comparison sequence—progressive alignment from highly similar ''fail-safe'' pairs to less similar pairs (Experiment 3). The pattern of results fits a large body of prior research that finds that younger children are highly dependent on close comparison in deriving a new relational meaning.

Progressive Alignment or Multiple Exemplars?

Although we have interpreted the 3-year-olds' success in Experiment 3 as due to progressive alignment, we cannot rule out the possibility that the gain resulted simply from seeing four examples rather than two, rather than from the sequence of close-to-far pairs. However, prior findings in which number of exemplars was equated are strongly suggestive that progressive alignment could have been operative here (Christie, Gentner, Vosniadou, & Kayser, 2007; Gentner et al., 2007; Haryu, Imai, & Okada, 2011; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001; Thompson & Opfer, 2010; Waxman & Klibanoff, 2000). For example, Haryu et al. (2011) found that Japanese 3- and 4-year-olds were more successful in learning new verb meanings from multiple exemplars when the study events all involved similar objects (making them highly alignable). A second study showed effects of progressive alignment. One group was given four trials of the same verb with highly similar objects, followed by four trials with highly dissimilar objects; the other group received an equal number (eight trials) with dissimilar objects. Children who received progressive alignment made correct verb extensions 86% of the time on the last four (dissimilar) trials. In contrast, those who received the same number of dissimilar events performed at chance (50%) throughout.

It might seem surprising that progressive alignment should be so effective. After all, we normally assume that abstraction is best fostered by presenting pairs that are very different. One possible explanation is that for very young children, relations are represented in a rather implicit and context-specific manner (Cameron-Faulkner et al., 2003; Gentner, 2003; Kotovsky & Gentner, 1996; Mareschal & Quinn, 2001). For example, the young child's representation for *cutting* a melon with a knife may be quite different from the *cutting* relation that holds between a tree and an axe. Young children may not reliably align two such diverse cutting relations. However, they can align a close similarity pair—for example, knife1 *cutter for* watermelon and knife2 *cutter for* orange—because even if the relational match is not initially evident, the similarity between the corresponding entities guides the child to the correct alignment. This renders the common structure more salient, and more readily discerned in future examples (Gentner & Medina, 1998; Gentner & Namy, 1999; Kotovsky & Gentner, 1996).

This explanation is consistent with Haryu et al.'s (2011) suggestion that object similarity ''plays a scaffolding role in children's extraction of relational commonality across events . . .'' In our studies, when 3-year-olds were confronted with two surface-dissimilar exemplars of a relational category (Experiment 2), they were unable to align them and thereby benefit from this comparison. But when they were given an initial ''fail-safe'' pair in Experiment 3, they could then go on to align the dissimilar pair and to abstract the relational category.

Concluding Thoughts

From the present results, we can infer that both relational language and structural alignment processes support the abstraction of a relation from exemplars. But we suggest that they do so in different, mutually reinforcing ways. Following Gentner's (2003, 2010) mutual bootstrapping theory, we suggest that comparison entails a process of structural alignment that naturally results in increased focus on shared relational structure, and that language both facilitates and is facilitated by this process. That alignment can facilitate language acquisition is indicated here by the fact that the two younger age groups were more likely to learn a relational meaning when they compared exemplars. In the other direction, we suggest that language promoted structural alignment in two specific ways. First, common labels serve as invitations to compare (Christie et al., 2007; Gentner & Namy, 2004; Namy & Gentner, 2002); by giving two things the same name, we invite children to compare them, even if they lack obvious similarities. Gentner and Medina (1998) termed this *symbolic juxtaposition*. This process of comparison can give birth to an abstraction that seeds a category (Brown, 1958; Waxman & Markow, 1995). In the present study, common labels encouraged 4- to 5-year-olds to align superficially dissimilar exemplars such as person–house and bird–nest. The second way that language operated here is that the use of a relational construction signaled the relational nature of the concept. Thus, language may be playing two roles in our studies: (a) the *common label* invites a comparison process that highlights common structure, and (b) the relational *construction* specifically suggests a relational meaning.

The present findings add to the evidence that comparison can foster the emergence of abstract, portable generalizations from specific exemplars. These findings bear on cross-situational learning, a central phenomenon in language acquisition. We suggest that structural alignment—including progressive alignment—is the mechanism that drives much cross-situational learning and that allows children to abstract relational commonalities across exemplars (Gentner & Namy, 2006; Tomasello, 2000; see also Bowerman & Choi, 2003).

Relational categories are an essential part of our conceptual armamentarium. Our findings suggest that relational language conspires with structure-mapping processes to support children's learning of such categories. Relational language helps orient the child to a relational construal and also serves to invite alignment across exemplars. Structural alignment helps the child discover the relational structure to which the word refers. These two factors form a mutual bootstrapping process that underpins children's phenomenal learning abilities.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Complete list of materials (Experiment 1a).

Appendix S2. Complete list of materials (Experiment 1b).

Appendix S3. Complete list of materials (Experiment 2).

Appendix S4. Check for translation effects and justifications.

Appendix S5. Complete list of materials (Experiment 3).

Appendix S6. Similarity ratings for the items in Experiment 3.