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Simplicity and generalization: Short-cutting abstraction in children's object categorizations

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ABSTRACT

Development in any domain is often characterized by increasingly abstract representations. Recent evidence in the domain of shape recognition provides one example; between 18 and 24 months children appear to build increasingly abstract representations of object shape [Smith, L. B. (2003). Learning to recognize objects. *Psychological Science, 14*, 244–250]. Abstraction is in part simplification because it requires the removal of irrelevant information. At the same time, part of generalization is ignoring irrelevant differences. The resulting prediction is this: simplification may enable generalization. Four experiments asked whether simple training instances could shortcut the process of abstraction and directly promote appropriate generalization. Toddlers were taught novel object categories with either simple or complex training exemplars. We found that children who learned with simple objects were able to generalize according to shape similarity, typically relevant for early object categories, better than those who learned with complex objects. Abstraction is the product of learning; using simplified – already abstracted instances – can short-cut that learning, leading to robust generalization.

1. Introduction

The adaptive application of past experience to new circumstances requires the recognition of similarities between those past experiences and the present. The similarities that are relevant to useful generalizations are often embedded within many task irrelevant similarities and differences. Thus, processes of abstraction – of finding the right similarities – are crucial to theories of generalization in a variety of cognitive domains, including vision, language, social behavior, and higher level reasoning (Harnad, 2005; Macrae, Milne, & Bodenhausen, 1994). Abstraction and generalization are also crucial to understanding the differences between immature and mature learners and between novices and experts; mature learners generally and experts more specifically seem to know the right similarities over which to generalize past experiences. This paper reports new findings on the relation between abstraction and generalization that derive from an experimental attempt to shortcut the learners' needs to find the right similarities for themselves. The domain is the generalization of 3-dimensional object categories by 1½ to 2-year-old children.

1.1. *Abstraction makes generalization*

One way or another, all theories of categorization are about abstraction. This is explicit in theories of prototype formation which propose summary descriptions of the commonalities across instances, thereby decreasing the influence of irrelevant, within-category variance on generalization (Homa, Sterling, & Trepel, 1981; Posner & Keele, 1968; Rosch, 1973; Smith & Minda, 1998). Abstraction is implicit in theories of exemplar learning which use mechanisms such as selective attention to simplify available information by deemphasizing uninformative dimensions and emphasizing diagnostic ones (Nosofsky, 1984; Palmeri

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& Gauthier, 2004). By many accounts, young learners are deficient in these selective processes, failing to generalize what they have learned because they attend to too much information or to the wrong information (Gentner, 1988; Hartshorn et al., 1998; Keil & Batterman, 1984; Piaget, 1969). These same deficiencies also mark adult performance in domains in which they have had little experience. Like children, adult novice generalizations overly rely on immediately perceptible and salient features while experts are able to use subtle features that have been important in past experience (Barnett & Ceci, 2002; Gentner & Markman, 1997; Gick & Holyoak, 1987; Newell & Simon, 1972).

All this suggests that proper generalization requires forming the right abstraction. Considerable experimental and theoretical work suggests that forming such minimalist abstractions is best achieved by experiencing many diverse instances (Dixon & Bangert, 2004; O'Reilly and Munakata, 2000; Reeves & Weisberg, 1994). But could not just *one* instance also produce robust generalization, if that instance were simple in the right way with just the right properties for abstraction? That is, one might be able to short-cut training with diverse exemplars by directly teaching the relevant abstraction and, as a consequence, get broad and appropriate transfer. This is the hypothesis for the present experiment.

We test this hypothesis in the context of young children's learning of object names. By 2½ years of age, children are skilled at generalizing object names, so skilled that they only need experience with one exemplar to generalize the name systematically to new instances by overall shape, ignoring other properties (Gershkoff-Stowe & Smith, 2004; Golinkoff, Mervis, & Hirsh-Pasek, 1994; Heibeck & Markman, 1987; Landau, Smith, & Jones, 1988). This ability to "fast map" (Heibeck & Markman, 1987) names of to novel objects of the same global shape occurs around the time children begin to recognize known object categories from highly abstract versions of their 3-dimensional shapes (Smith, 2003; see also Jones & Smith, 2005; Pereira & Smith, in press). The minimalist versions used in these studies were derived from a specific theory (Biederman, 1989) about the abstract internal representations of object shape that underlie adult object recognition. These objects consisted of 2–4 geometric volumes ("geons") in a spatial arrangement that evoked common object categories (e.g., chair, cat, hat).

While recognizing geon-like versions of cats and chairs directly result from a process of abstraction over many instances, "fast mapping" – generalizing by shape after just *one* instance – is not as clearly connected to abstraction. One hypothesis tying these two developmental achievements together is that these shape-sensitive children are able to abstract structural information from texture and color-rich stimuli even after one training exemplar. In order to abstract shape information, a child must deemphasize differences on other dimensions and highlight shape. However, children with very little category experience may have trouble doing this for themselves and are thus unable to fast-map or identify abstract versions of known objects. This provides the basis for testing our hypothesis: by providing the learner with the right simplification, we can *simulate* abstraction and thus promote generalization. To this end, our participants are young children, who do not yet systematically generalize object names by shape (Gershkoff-Stowe & Smith, 2004) and are not expected to recognize simplified abstractions of common objects (Smith, 2003). Can we bolster children's generalizations by providing them with simplified abstractions as the training exemplars?

2. Experiment 1

The first experiment is a straightforward test of the idea that minimalist descriptions of geometric structure promote appropriate category generalization (by shape) in young children. We do this by using novel stimuli and participants who are too young to extract the complex geometric shape of an object on their own. We attempt to induce better shape-based generalization by providing children with simplified renderings of object shape. In the training phase, we link an unfamiliar name either to a richly detailed complex instance or to a simplified shape, asking whether in the test phase generalization by shape is more likely in the latter than the former case.

The experiment was also designed to provide information about the relative contributions of simplicity and similarity in promoting generalization. Simplicity may promote generalization for a number of reasons that may be related (ultimately) to abstraction, including ease of learning in the first place or selective attention. However, generalization is also typically linked to the similarity between the training material and the testing materials. This similarity may not be independent of complexity. Indeed, some studies have shown that adults judge a complex thing to be more similar to *itself* than a simple thing is to itself (Tversky, 1977). Here we ask children to generalize a name from one complex shaped thing to an identical complex thing that differs only in color *or* to generalize a name from a simply shaped thing to an identical simple thing that again differs only in color. In terms of number of matching shape features, one might expect the complex thing to be more similar to a same-shaped thing (or at least as similar) as is the simple shaped thing to a same-shaped thing. However, if the simplicity of the internal representation is key, then the simple shape may lead to better generalization.

2.1. Method

2.1.1. Participants

Thirty-two children, 16 male, 16 female with a mean age of 17.33 months (range 15–20 months) were randomly assigned to one of two conditions, Complex or Simple. Because we were particularly interested in young children who were unlikely to be able to abstract the major geometric components from complex shapes on their own, we also measured children's productive vocabulary using the MacArthur Communicative Development Inventory (Fenson et al., 1994) as this is a strong predictor of children's attention to shape (Pereira & Smith, in press; Smith, 2003). The children in the present stud had average of 42 nouns in their productive vocabulary ($SD = 31$, range 0–98) and 71 total words ($SD = 55$, range 1–198). These are relatively typical vocabularies for this age and for children who do not yet attend to shape on naming tasks.

2.1.2. Materials

The stimuli consisted of two corresponding sets of novel objects, complex and simple. The complex set consists of six pairs of complex, richly detailed, and novel toy vehicles intricately painted with three colors to enhance their finer details (two example pairs are shown in Fig. 1). In each pair, one instance served as the training instance and the other served as the generalization test case, differing only in color and matching exactly in shape. For each participant, three pairs were randomly chosen to be learning exemplar and generalization *target* pairs and the other three were used as learning and generalization *distracter* pairs so the same six pairs were seen by all the participants.

The simple set also consisted of six pairs (also shown in Fig. 1). These were constructed from 2 to 4 geometric components with no smaller details and painted a uniform color to maintain the same major geometrical structure as the complex set. These were arranged into comparable pairs of training and generalization, targets and distracters. The labels used for the exemplars and at test were: *zupp*, *wazzle*, and *peema*.

2.1.3. Procedure and design

There were two between-subject conditions, Complex-to-Complex and Simple-to-Simple. Children in the Complex condition were trained and tested with complex objects and those in the Simple condition were trained and tested with simple objects.

The task, based on one used previously by Woodward and Hoyne (1999), consisted of the Training and Test phases described in Table 1. During training, the child was told the name of the exemplar (e.g., “This is a zupp.”) and was also acquainted with a second unnamed object, the training distracter. Each object was presented one at a time and this training sequence was repeated for a total of two presentations for each object. The test phase, beginning with a memory test, occurred after a three second delay. The original target and distracter were placed on the table and the child was asked to get the target by name. For the generalization test, two new objects, the transfer target and test distracter, were placed on the table, one matching the exemplar in exact shape, the other matching the distracter in shape. Both of these test objects differed in color from both the training exemplar and distracter. The child was asked for the target by name. The memory and generalization tests were then repeated for this same set. The spatial location of the correct choice alternated between test trials. This whole procedure was repeated for each of the 3 exemplars, yielding a total of 6 memory test trials and 6 generalization test trials. The total experiment lasted about 15 min.

Table 1
Sample script for the Training and Test phases of Experiment 1

Training phase	Exemplar – “This is a zupp.” Distracter – “See this, look at this.”
Test phase	
Memory test	Test choices – Training Exemplar vs. Distracter, “Where is the zupp?”
Generalization test	Test choices – Transfer Target vs. Distracter, “Where is the zupp?” Then the memory and generalization tests were repeated with the same objects.

2.2. Results and discussion

As shown in Fig. 2, children in both the Complex-to-Complex and Simple-to-Simple conditions mapped the name to the exemplar and remembered it over a 3 s delay. However, only children in the Simple-to-Simple condition generalized their learning to the transfer object at levels above chance, $t(15) = 3.43$, $p_{rep} = .98$. These conclusions were confirmed by a 2 × 2 × 2 (condition × gender × trial type) repeated measures ANOVA with trial type as a within-subjects factor. The analysis yielded a reliable main effect of trial type, $F(1,28) = 5.11$, $p_{rep} = .91$, $\eta^2 = .15$, and a reliable interaction between trial type and condition, $F(1,28) = 4.26$, $p_{rep} = .88$, $\eta^2 = .13$. Performance on memory trials was not significantly different between the Complex-

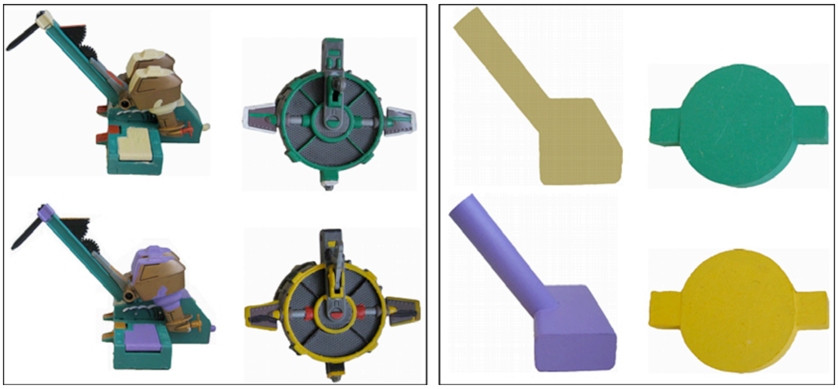

Fig. 1. On the left, a complex training exemplar and distracter are shown with their corresponding generalization target and distracter. Half of the participants were trained with the long-necked object as the exemplar and the other half learned that the round object was the exemplar. On the right, a simple training pair and generalization pair are shown.

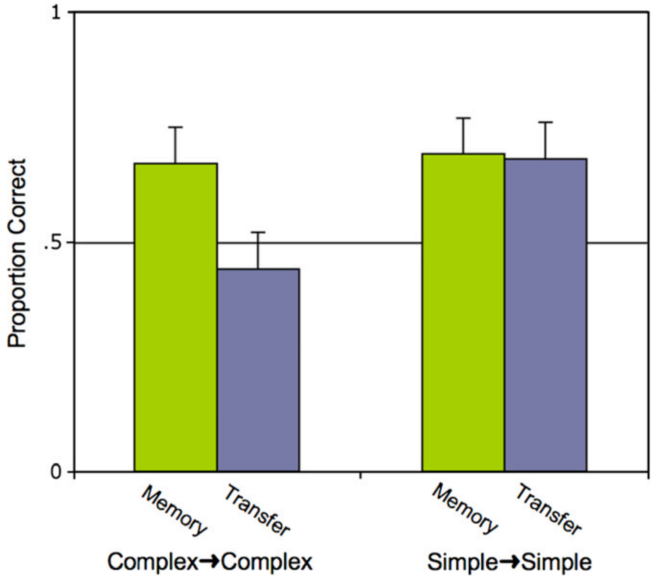

Fig. 2. Mean proportion correct and standard errors of shape-match choices in memory and generalization tests for Experiment 1.

to-Complex condition ($M = .67$, $SD = .22$) and the Simple-to-Simple condition ($M = .69$, $SD = .27$), $t(31) = .06$. This was not the case for generalization trials where there was a significant difference between conditions with the Complex-to-Complex condition transferring significantly less ($M = .44$, $SD = .30$) than the Simple-to-Simple condition ($M = .68$, $SD = .21$), $t(31) = 7.03$, $p_{\text{rep}} = .95$. Even though children in both conditions were able to remember the named objects, they did not transfer equally well. Further support for these results comes from a conditional probability analysis, examining only the trials where children succeeded on the memory task. By this analysis, children in the Complex condition still generalized less ($M = .48$, $SD = .33$) than those in the Simple condition ($M = .83$, $SD = .23$), $t(31) = 11.64$, $p_{\text{rep}} = .98$. Simplified shapes that present only the major geometric components apparently foster generalization.

There are other analyses of similarity and generalization that might be expected to predict an opposite pattern to what was observed here. Specifically, in the present task format, the many extra details on the complex forms (excluding color) could be construed as *relevant* in that they were shared by the exemplar and transfer target. Especially if similarity was the critical component in generalization, these extra details could have been more helpful. Under one classic construal of similarity (Tversky, 1977), sharing a greater number of overlapping features makes identical pairs of complex objects more similar to each other than identical pairs of simple objects. Indeed, Tversky (1977) found that adults judge a complex object as more similar to itself than a simple object is to itself, presumably because of the increase in number of overlapping features. If we interpret generalization in young children as a proxy for similarity, the present results seem to developmentally qualify the prediction from Tversky's feature contrast model of similarity (1977).

One possible developmental constraint on this adult finding, that complex and many-featured shapes are more self-similar than simpler shapes, could be that very young children may not register all the features of the complex novel objects but instead may sample different featural details of the complex training and test objects. The bare forms in the simple shape condition solve the possible problem of too much information by limiting the information available to that which is most relevant for common object categories (e.g., Biederman, 1989). Simplicity in learning may be more influential than similarity between learning and generalization instances due to processing limitations of young children's working memory, attention, and other cognitive functions. At present, we do not know whether this simplicity plays a greater role in learning, that then promotes better generalization, or, perhaps in generalization itself given that both the training exemplars and the generalization test items were either both simple or both complex.

In summary, Experiment 1 examined children's ability to make *near* transfers of an object name to an *exact* shape match. The results indicate that simple training exemplars lead to more generalization than the complex ones. If this is due to the nature of the representation formed, and if those representations promote transfer, then directly teaching abstractions may enable appropriate *further* transfer (to objects that are not identical in shape) without extensive experience with a variety of different instances.

3. Experiment 2

In real-life object categories, members usually differ in a number of irrelevant shape details. Perhaps simple training instances, having fewer details in general and preserving only the relevant ones, can direct attention to the relevant properties of more detailed transfer objects than vice versa. To test this hypothesis, there were two conditions in Experiment 2: Simple-to-Complex and Complex-to-Simple. In the Simple-to-Complex condition, children were presented with the simple version as the exemplar, taught its name, and then tested to determine if they would extend that name to a richly detailed and complex version of the same object. In the Complex-to-Simple condition, children were presented with a complex realistic object, taught its name, and then tested to determine if they would extend that name to a simplification that presented only the major geometric components. All that differs between the two conditions is the direction of transfer. Assuming symmetrical similarity, the psychological similarity from exemplar to transfer target in the two cases is identical. However, the direction of transfer should matter if an internally represented abstraction (the memory for the simple shape) directs attention to the right properties at transfer. If this is so, generalization should be greater in the Simple-to-Complex condition than in the Complex-to-Simple condition. However, there is also a possibility that the generalization found in Experiment 1 may not be determined by simple *learning* instances but by simple *transfer* instances. Here is the dilemma of explaining Experiment 1: was the simple condition's success in generalization caused by the simplicity of the learning object or the simplicity of the transfer object? If the object in consideration for generalization determines transfer more than (or equal to) the learned object, we should expect the name of a complex learning item to extend to simple transfer item. Alternatively, the complexity of both training and testing objects may be important, leading to the expectation that simplicity either at learning or transfer facilitates transfer. Finally, past research on generalization by shape indicates that children with larger noun vocabularies are more likely to generalize object names by shape, specifically, children with noun vocabularies greater than 100 nouns have been reported to attend to shape in at least some tasks. Accordingly, we selected children varying more broadly in age, and thus most likely also in vocabulary, with the plan of comparing children with larger and smaller vocabularies.

3.1. Method

3.1.1. Participants

In order to better understand the development of these generalization processes, we tested 18 children in the 16–21 month range as in Experiment 1 but also included 19 children in the 22–27 month range. A total of 37 children (mean age: 20.5 months, with a range 16.9–27.0), 16 males, 21 females, were randomly assigned to the two conditions. In terms of productive vocabulary, this was a diverse group of children averaging 105 nouns (*SD* = 101, range 4–347) and 166 words (*SD* = 167, range 5–645).

One additional participant was determined to be a late-talker and the collected data were analyzed in the context of a different set of experiments (Jones & Smith, 2005). None of these children had participated in Experiment 1.

3.1.2. Materials

The stimuli (see Fig. 3 for examples) were broadened to include a variety of kinds of objects, not only vehicle-like things which may have been highly confusable in their similarity to one another. The objects were *artichoke, manatee, doily, reamer, masher, jellyfish, watering can, castle*. They were named with the English nouns provided above (names unlikely to be in the vocabularies of 20 month olds as indicated in a prior name comprehension study with same age children, see Smith, 2003; and by normative data, see Fenson et al., 1994). There were two versions of each object, one a richly detailed, complex, and colorful real or toy version and the other a shape idealization constructed from 2–4 geometric volumes and painted gray. The realistic and simplified versions were all approximately 15 cm^3.

3.1.3. Procedure and design

The procedure was nearly identical to that in Experiment 1. For the children in the Complex-to-Simple condition, the training stimuli (exemplar and distracter) were the richly detailed, complex objects and the generalization stimuli (transfer target and distracter) were the simplified idealizations of these complex objects. For children in the Simple-to-Complex condition, the training stimuli were the shape idealizations and the generalization stimuli were the complex versions of these same things. Each child had

Fig. 3. Complex object shown with its corresponding simplified shape version used in Experiment 2.

four test blocks made up of a training exemplar and distracter and two corresponding transfer objects. Each set had four objects – two of which were simple and two corresponding objects that were complex (e.g., simple artichoke, simple reamer, complex artichoke, complex reamer). Since each memory and generalization test trial in each block were repeated, there was a total of 8 memory tests and 8 transfer tests. Order of stimulus sets and designation of target and distracter within a set was counterbalanced across children. The target's spatial location alternated across trials.

3.2. Results and discussion

As shown in Table 2, children remembered the names of the complex and simple exemplars equally well but generalized the names from simple exemplars to complex test objects more frequently than from complex exemplars to simple test objects. This was confirmed by a 2 × 2 (condition × trial type) repeated measures ANCOVA with trial type as a within-subjects factor, that revealed a significant main effect of trial type, $F(1,33) = 6.31$, $p_{\text{rep}} = .94$, $\eta^2 = .16$, and a reliable interaction between condition and trial type, $F(1,33) = 6.07$, $p_{\text{rep}} = .93$, $\eta^2 = .16$. There was no significant effect of condition, $F(1,33) = .476$, and even though we tested a wide range of ages as well as noun vocabulary levels, neither were reliable covariates (age, $F(1,31) = .1.67$; noun count, $F(1,31) = .415$).

Although there was no significant difference in memory trial performance between the Complex-to-Simple condition ($M = .76$, $SD = .16$) and the Simple-to-Complex condition ($M = .70$, $SD = .21$), $t(36) = .987$, there was a significant difference on the generalization trials. The children in the Complex-to-Simple condition, when faced with two simply shaped objects, did not generalize by shape similarity ($M = .57$, $SD = .16$) as well as Simple-to-Complex children did when faced with more complex objects ($M = .70$, $SD = .18$), $t(36) = 4.258$, $p_{\text{rep}} = .88$. And even though generalization performance was worse in the Complex-to-Simple condition, they were reliably above chance, $t(18) = 2.12$, $p_{\text{rep}} = .88$, as was the Simple-to-Complex condition, $t(17) = 4.64$, $p_{\text{rep}} = .99$ (see Table 2), the Complex-to-Simple versus Simple-to-Complex data.

The results of Experiment 2 resolve this ambiguity in Experiment 1: is transfer caused by the simple instance shown in learning or the similar instance in transfer? Here, simplified *transfer* items did not facilitate generalization but simplified *learning* exemplars did. Although lexical generalization in Experiment 1 were cases of "near" transfer to another object of the exact same shape, Experiment 2 involved "far" transfer to a complex object of the same global shape but not the same exact shape. A critical component to the successful learning of object categories is to overcome differences among instances of a basic level category since category members, although roughly similar in shape, are not exactly the same shape. All varieties of chairs, all varieties of cups, all variety of trucks, for example, are the "same shape" only under some highly abstract and simplified description of shape. The present results indicate that explicitly presenting children with simplified representations enhances generalization. Simple representations, whether explicitly taught or abstracted from experience, may promote generalization.

Table 2
Results of Experiment 2 broken up by noun count and experimental condition for ease of comparison to Experiment 1

	Memory trials	Generalization trials
Nouns ⩽ 100		
Complex-to-Simple (*N* = 13)	.73 (*SD* = .18)	.56 (*SD* = . 17)
Simple-to-Complex (*N* = 11)	.70 (*SD* = .20)	.73 (*SD* = .18)
Nouns > 100		
Complex-to-Simple (*N* = 6)	.83 (*SD* = .10)	.60 (*SD* = .17)
Simple-to-Complex (N = 7)	.70 (*SD* = .25)	.68 (*SD* = .17)
All children		
Complex-to-Simple (*N* = 19)	.76 (*SD* = .18)	.58 (*SD* = .16)
Simple-to-Complex (*N* = 18)	.70 (*SD* = .21)	.70 (*SD* = .18)

4. Experiment 3

Experiment 1 found that simple instances foster generalization to other similar and simple instances but complex instances do not generalize as well to other similar and complex instances. Experiment 2 found that simple abstract instances foster generalization to complex rich ones. Combining these two findings gives rise to an odd expectation. Is it possible that simple abstract instances generalize more easily to complex test objects than even a complex learning item? Could a Simple-to-Complex sequence enable greater transfer than Complex-to-Complex? This seems unlikely because similarity is obviously an important factor in transfer and complex training instances are more similar to complex test instances than are simple training instances. The transfer literature is rife with situations where learned solutions are not applied to dissimilar situations (e.g., Holyoak & Koh, 1987; Keane, 1987; Perfetto, Bransford, & Franks, 1983; Reed, Ernst, & Banerji, 1974). However, our results suggest that not all dissimilarities are equal. Transfer depends on what is represented about the training examples and complex training examples might limit the formation of the right representation. We do not specifically predict that transfer from a complex item to an identically shaped complex item would be *more* difficult that transfer from a simple shaped thing to a different and more complex version of that shape. However, our previous experimental results suggest that an apt simple training exemplar may promote strong generalization even in this case.

4.1. Method

4.1.1. Participants

We sampled a broad range of children as in Experiment 2. A total of 41 children (mean age: 20.7 months, range 15–26), 22 males, 19 females, were randomly assigned to the two conditions. These children had a wide range of productive vocabulary with an average of 74 nouns ($SD = 73$, range 0–286) and 124 words ($SD = 106$, range 4–353). Three additional children were excluded from analysis, one due to experimenter error and two experienced multiple disruptions during the experiment.

4.1.2. Materials, procedure, & design

The procedure was almost identical to Experiment 1 and the same vehicular stimuli were used. The children in the Simple-to-Complex condition were presented simply shaped stimuli in training and the generalization stimuli were the corresponding complex stimuli. The Complex-to-Complex condition was nearly identical to the same condition in Experiment 1, the children were presented with complex training items and corresponding complex generalization items. In both conditions, the generalization stimuli differed in color from the training stimuli. However, in the Simple-to-Complex condition, there were also differences in shape in that there were additional details in the generalization stimuli. In order to reduce choices of test objects according to novelty or salience (a problem more likely in the Simple-to-Complex condition because the test objects were more novel to the children than in the Complex-to-Complex condition in which the test objects had the same shape as the training objects), we introduced a familiarization period immediately after linguistic training. Specifically, prior to the test question, children were given the unnamed test objects (target and distracter) to explore for about 30 s.

Each child had three test blocks with alternating memory and generalization trials. There were a total of 6 memory trials and 6 generalization trials. Order of stimulus sets and designation of target and distracter within a set was counterbalanced across children. The target's spatial location alternated across trials.

4.2. Results and discussion

As shown in Table 3, all children were able to memorize the exemplars even after the delay introduced by the familiarization period. However, while children in the Complex-to-Complex condition were asked to generalize to a complex object that was exactly the same shape as the training exemplar, children in the Simple-to-Complex condition were required to generalize their training to a complex object that was highly dissimilar, but shared the same shape structures. We found that children in both conditions were able to generalize. A 2 × 2 (condition x trial type) repeated-measures ANCOVA with trial type as a within-subjects factor including age and number of nouns as covariates, showed no significant difference between trial type, $F(1,37) = .003$, and, more relevant to our hypotheses, no significant difference between condition, $F(1,37) = 1.552$. This suggests that the generalization advantage of a simplified shape approximately compensated for its decreased similarity to the test object. The overall performance on generalization trials in the Complex-to-Complex condition is similar to that in Experiment 1 suggesting that the brief familiarization period with training and test objects on each trial did not influence performance. Finally, although age was not a significant covariate, $F(1,37) = .551$, noun count was a significant covariate, $F(1,37) = 4.249$, $p_{\text{rep}} = .88$, $\eta^2 = .10$. This result confirms previous research showing that category knowledge at this age is better predicted by vocabulary levels than age (e.g., Waxman, 1998; Xu, 1999).

Children were divided into two groups according to the number of nouns in their vocabulary: fewer than 100 nouns and more than 100 nouns. We found that having a higher vocabulary does not result in significantly better memory performance ($M = .73$, $SD = .19$) than children with lower vocabulary ($M = .67$, $SD = .23$), $t(40) = .745$, but high vocabulary is related to significantly better generalization performance, $t(40) = 5.61$, $p_{\text{rep}} = .92$. Children with higher vocabularies generalized the newly learned label to the generalization items ($M = .81$, $SD = .18$) better than children with lower vocabularies ($M = .64$, $SD = .22$).

Children who had more experience with category labels had better generalization than children with few words for object categories. Whether the learning stimuli were complex and similar or simple and different, more experienced children were able to generalize to new complex instances. It is not surprising that these children show good transfer between highly similar learning and generalization objects given that lexical categorization studies typically find robust influences of similarity on generalization (Anglin, 1977; Clark, 1973; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Sperber, Davies, Merrill, & McCauley, 1982). The new result is that despite substantial dissimilarity between the learning and generalization objects in the Simple-to-Complex condition, we found similar levels of transfer. The simple training exemplar only shared global shape similarities with the target complex object yet that was enough to foster lexical generalization. If we consider that vocabulary is an indicator of category experience, perhaps around the time children understand that object categories include many shape variants, they are better able to take cues from an object with overall structural similarities as well as highly similar complex objects.

Table 3
Results of Experiment 3 broken up by noun count and experimental condition

	Memory trials	Generalization trials
Nouns ⩽ 100		
Complex-to-Complex ($N = 11$)	.60 ($SD = .24$)	.62 ($SD = .26$)
Simple-to-Complex ($N = 15$)	.73 ($SD = .21$)	.67 ($SD = .20$)
Nouns > 100		
Complex-to-Complex ($N = 8$)	.73 ($SD = .18$)	.80 ($SD = .17$)
Simple-to-Complex ($N = 7$)	.73 ($SD = .21$)	.81 ($SD = .19$)
All children		
Complex-to-Complex ($N = 22$)	.65 (.22)	.70 (.20)
Simple-to-Complex ($N = 19$)	.73 (.21)	.71 (.20)

5. Experiment 4

Thus far, the complexity of objects has been manipulated by varying the detail of their parts. Thus, there are two possible accounts for the generalization advantage for the simple objects observed in Experiments 1 and 2. First, objects that have idealized, smooth shapes with few details may generalize robustly because children are not distracted by a superfluity of details. Second, there may be a more general advantage for *any* simplified object, regardless of the nature of the simplification. In the latter case, generalization advantages should extend to other instantiations of simplicity. An obvious alternative way to manipulate simplicity is by varying the number of features. If simplicity generally promotes transfer, then learning about an object with two features should generalize better to an object with four features (two shared features and two unique features) than vice versa.

5.1. Method

5.1.1. Participants

Twenty children (mean age: 23.8 months, with a range 22.0–28.0), 12 males, 8 females, were randomly assigned to the two conditions. None of the children had participated in the prior experiments. One child was left out of the analysis because he did not complete the experiment. In addition, pilot tests on five children in the 16–21 month range revealed that these younger children could not complete the task. The children who participated had productive vocabularies with an average of 132 nouns (*SD* = 132, range 20–294) and 207 words (*SD* = 128, range 24–529).

5.1.2. Materials, procedure, & design

The procedure mimicked Experiment 2. Children in the Four-to-Two condition participated in a condition comparable to the Complex-to-Simple condition of Experiment 2. Children in the Two-to-Four condition participated in a condition comparable to the Simple-to-Complex condition of Experiment 2.

The stimuli (see Fig. 4 for examples) were either two or four small objects (less than 5 cm) of various materials and shapes (i.e., screws, wires, pompoms) mounted on Styrofoam bases (roughly 15 × 10 × 2 cm). Each two-feature item had a corresponding four-feature item that shared two features and had two additional features all mounted on the same-color same-shape Styrofoam base. During the training phase, the exemplars were labeled with these names: *heejo, zuku, bajoo,* and *camu*.

There were four test blocks made up of four objects with the same Styrofoam base (e.g., orange semi-circle): a training exemplar and distracter and two corresponding transfer objects. The four objects expressed in terms of features (indicated in capital letters) would be AB, WX, ABCD, and WXYZ. Correct generalization is determined by matching features rather than overall shape.

5.2. Results and discussion

A 2 × 2 (condition x trial type) repeated measures ANCOVA with trial type as a within-subjects factor, age and noun count as covariates, revealed a significant main effect of condition, $F(1,15) = 5.32$, $p_{\text{rep}} = .90$, $\eta^2 = .26$, and no significant main effect of trial type, $F(1,15) = .07$. Like Experiment 3, although age was not a significant covariate, $F(1,15) = .96$, number of known nouns was, $F(1,15) = .7.53$, $p_{\text{rep}} = .94$, $\eta^2 = .35$. These results are shown in Fig. 5.

Although there was no difference in memory performance between the Four-to-Two condition ($M = .63$, $SD = .21$) and the Two-to-Four conditions, ($M = .69$, $SD = .13$), $t(18) = .51$, memory performance in the Four-to-Two condition were only marginally above chance,

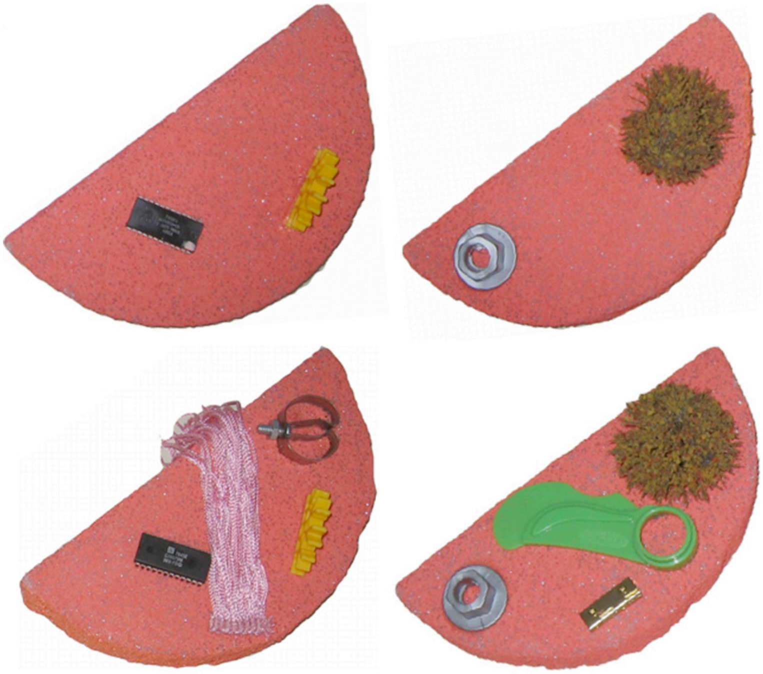

Fig. 4. Note that in these stimuli, the four-feature object has the same two features of its corresponding two-feature object and two additional small objects attached onto the base. Experiment 4's redefinition of the Simple-to-Complex condition was the Two-to-Four condition, where children were shown two-feature objects (shown at the top) as the training exemplar and distracter. Generalization tests were conducted with the four feature objects. The Complex-to-Simple condition is redefined as the Four-to-Two condition, where the four-feature objects (shown at the bottom) were the training exemplar and distracter. Generalization tests were conducted with the two feature objects.

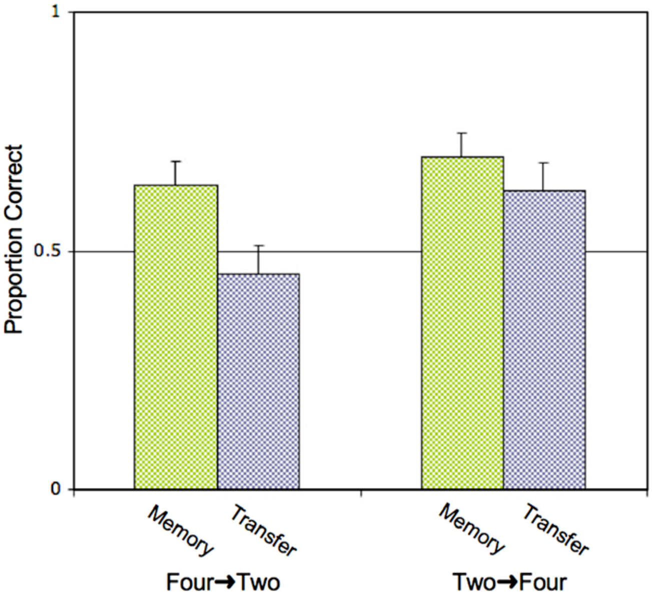

Fig. 5. Mean proportion correct (matching feature sets) and standard errors of feature-match choices in memory and generalization tests for Experiment 2.

$t(9) = 2.09$, $p_{\text{rep}} = .85$, indicating that merely remembering the named four-featured object and its link to the name was difficult. However, children in the Two-to-Four condition were able to remember their two featured training objects at levels reliably above chance, $t(8) = 4.60$, $p_{\text{rep}} = .98$. Because this small but potentially interesting difference in memory trials may account for differences found in generalization trials, we opted to perform a Univariate ANOVA with memory performance, noun count, and age as covariates and condition as a between-subject factor. This analysis confirmed that memory performance, $F(1,14) = .08$, and age were not significant covariates, $F(1,14) = .96$, to generalization performance while noun count was, $F(1,14) = 7.53$, $p_{\text{rep}} = .94$, $\eta^2 = .35$. Even when taking these factors into account, we found that condition was a significant factor, $F(1,14) = 6.840$, $p_{\text{rep}} = .93$, $\eta^2 = .33$, with children in the Two-to-Four condition correctly generalizing on .63 of the trials ($SD = .19$) while the Four-to-Two condition only generalized on .45 ($SD = .18$).

Additional support for generalization advantage of the Two-to-Four condition came from an analysis of the conditional probabilities, only considering generalization trials following successful memory trials. Even when considering only cases in which participants were able to point out the named exemplar, children in the Four-to-Two condition only generalized on average .54 of the trials ($SD = .32$) whereas children in the Two-to-Four condition did so .89 of the trials ($SD = .13$). This is a highly reliable difference, $t(18) = 11.91$, $p_{\text{rep}} = .98$.

The broad pattern of Experiment 4 is consistent with the results of the previous experiments: simpler learning instances promote generalization. Children in the Four-to-Two condition may be distributing their attention at learning across four features while children in the Two-to-Four condition only distribute their attention among the two features available. Alternatively, perhaps children only sample a subset of the four or two features available. For children in the Two-to-Four condition, regardless of which feature was encoded, all four features are available at the time of generalization. However, in the Four-to-Two condition, only half of the potentially encoded features are present at generalization. Although the stimuli used in Experiments 1–3 are simplified by eliminating shape details, the stimuli used in Experiment 4 were specifically simplified by including fewer "features" (parts). The results of this study may be specific to missing or matching features, but they are also relevant to the idea that less complex objects, possessing fewer features, can help novices pay attention to all of the presented features, which in this case are all relevant for future generalization instances. The complex learning instance has potentially useless information (i.e. the two features that are not going to be present in the generalization target), while the simpler instance does not so that the learning situation is more constrained for the young child.

Cognitive load (Sweller, 1988) can provide several mechanistic explanations of the benefits of simplicity seen in this experiment. On the one hand, it could be that increasing cognitive load makes children extract and encode fewer features all together (i.e. they are only able to extract 1–2 features). On the other hand, it could also be that an overwhelming load leads to weaker represented features (i.e. they have a fragile, easily confusable representation of the many features that were presented at learning). These same processes can also work at the time of generalization. Children may not be able to recall all the features that were encoded. Also the recalled features may be too weak for productive comparison to the new test objects. Our experiments cannot distinguish whether children are more affected by their limited attentional resources at learning (encoding) *or* at generalization (recalling what they have learned). However, the results suggest that processing fewer features helps novices pay attention to all of the presented and encoded features, both in number and strength.

6. General discussion

Past research tells us that older word learners are more skilled and systematic in their generalization of object names than younger children (e.g., Gershkoff-Stowe & Smith, 2004; Woodward & Markman, 1998). Past research also tells us that older word learners also represent the shapes of objects more abstractly than younger children, in terms of minimalist descriptions of geometric structure (Smith, 2003; Jones & Smith, 2003). The present results imply a connection between these two achievements. Very young word learners' generalizations of object names to new instances by shape is promoted by explicitly giving them abstract and simple versions of those shapes. Interestingly, toys made and bought for toddlers are typically made from a small number of geometric components (like the simple stimuli of Experiments 1–3) whereas toys for older preschoolers are typically complex with many details at higher spatial frequencies (like the complex stimuli of Experiments 1–3). Thus, the observed advantage of teaching through simply shaped exemplars may have already been implemented by toy manufacturers and parent consumers. The benefits of simplification for generalization, however, do not appear specific to learning about 3-dimensional shape. Rather, as indicated by Experiment 4, simplification by reducing the number of detailed parts also promotes generalization.

Several aspects of the present results are novel. If one combines the results across the four experiments, one ends up with following conclusion: It is just as straightforward for children to transfer a label to a complex object given training on a simpler version of that object as training on a nearly identical but complex object. Accordingly, our generalization results are not solely determined by the similarity relations between training and transfer objects. The results of Experiment 2 suggest that the relevant similarities for transfer are not symmetrical. In that experiment, children readily transferred a name from a simplified version of an object to a complex version, but not vice versa. Additionally the results of Experiment 4 suggest that if the relevant similarities for transfer are available in a simplified form, dissimilarity *due to simplification* does not prevent children from transferring.

These are unexpected results under some accounts of lexical generalization. For example, if comparisons between learned objects in memory and objects in plain view were symmetrical, then it would be difficult to explain the results of Experiments 2 or 4 since the same objects are presented in different order. There are several explanations for this asymmetry of generalization. One explanation is that memory effects cause simplification during training to be different from simplification at transfer (Thibaut, 2007). A simplified transfer object may not have enough retrieval cues to link it to the name of a learned complex object. Another way to view these results in terms of memory recognition, is to think of detecting additions, in transfer items of increased complexity, versus detecting deletions, in simplified transfer objects. The logic from recognition to generalization might go like this: detecting that an item is different may hinder generalization whereas failure to detect a difference may result in generalization. Since many studies of feature additions/deletions have found that additions are more easily detected than deletions (Agostinelli, Sherman, Fazio, & Hearst, 1986; Hearst & Wolff, 1989; Miranda, Jackson, Bentley, Gash, & Nallan, 1992 for a review), our results may be a reflection of the idea that more salient additions hinder children's generalizations.

A second alternative is that objects in memory may be different from objects in transfer because of feature comparisons involved in similarity and categorization. For example, Tversky's Contrast Model of Similarity (1977) compares the distinctive features of one object (the subject) to the features of another object (the referent). The referent object anchors comparison in that features from the subject are compared to the features of the referent. Although Tversky's theory holds that the object in attention is the referent, it does not say whether a learned object in memory is the referent or whether the test object in view is the referent. It could be that the memorized object is the referent since it is attached to the linguistic label in the question, "Where is the *zupp*?" It is the object that is associated with the category in question. However, the referent could also be the test object since it is clearly available in view. The Contrast Model and its affiliated Focusing Hypothesis are agnostic on which of these characterizations is correct but the present results suggest a direction of interpretation because the lexical generalization task used here can be construed either as a process of memorized object representations compared to subsequently presented objects, or presented objects compared to memorized representations. If we assume that generalization is more likely when similarity is higher, then the Simple-to-Complex ordering yields a more similar comparison than Complex-to-Simple. In the same way that North Korea (simple) compared to China (complex) is more similar than vice versa (Tversky, 1977), a simple object *in memory* compared to a complex object *in view* is more similar than vice versa. This result suggests that the correct way to interpret the Contrast Model is this: the memorized representation (simple) gets compared to the presented object (complex). Another possible variant on feature-based accounts of similarity might be this: learned features that are missing in transfer (i.e. many colors to single color) hinder transfer more than the addition of mismatching features in transfer (i.e. one color to many colors). Although our results are in a lexical generalization task, the asymmetry might be informative to models of similarity.

To take this conjecture full circle, if an asymmetry in similarity can account for lexical generalization, this could be informative to models of categorization. Generally, there are two ways that categories and test objects may interact: (1) test objects can be fit into known categories or (2) categories can be applied to the test objects. Models that match a presented test object to known category representations take the former approach while other models match categories to the test objects, the latter option. Our interpretation of the Contrast Model suggests that a memorized representation is matched to, or adapted to, a physically presented object than vice versa. In many prominent models of categorization, part of the process is the retrieval of similar objects (Medin & Schaffer, 1978) or similar categories (Smith, Shoben, & Rips, 1974) or similar prototypes (Rosch & Mervis, 1975) such that the test object is placed into the retrieved category. Rather, our results suggest that the purpose of this retrieval is to find candidates to compare to the test object.

A further possibility focuses on attentional and encoding processes. It may be that names of complex objects are harder to learn and represent, particularly for children who may not have much experience with object categories (Experiment 3) or when the objects have too many interesting features (Experiment 4). If participants are overloaded with too much information, either features or dimensions, to learn and map onto a name, then perhaps very young children are forced to only encode partial information. A variety of results suggest that early in development, children rely on easily separable features and parts to recognize things rather than overall shape. For example, Rakison and colleagues (Rakison & Cohen, 1999, see also Rakison & Butterworth, 1998) have found that 14- to 22-month-old children classify cows with vehicles rather than with animals if the cows are on wheels (and classify vehicles with cows if the vehicles have legs). Likewise, Colunga (2003) showed that 18-month-olds looked at and used features such as eyes and face when recognizing pictured animals, and wheels and headlights when recognizing vehicles. In contrast, 24-month-olds looked broadly at different parts of the pictures, and used overall shape in deciding what the entities were. Other results (Dukette & Stiles, 1996) suggest that young children – particularly in hard tasks – attend to information at higher spatial frequencies (which carries information about details and smaller parts) rather than to the lower spatial frequencies (which carries information about overall shape). Models of vision development corroborate these results. Dominguez and Jacobs (2001) have found that a system that is only able to detect lower frequencies at first (to result in stimuli more like our simple objects) is better at generalization than a system that starts off with higher frequency detection. Since young children pay attention to fine-grained details, if such details are available, they may potentially pull children's attention away from overall shape. Additionally if these encoded details are taken away during transfer, generalization performance would be hurt. An over-emphasis on localized parts and details rather than global shape may be a general property of non-expertise in object categorization. For example, studies with monkeys, show that shape selective neurons in the inferotemporal cortex increase their whole-object shape selectivity (rather than part selectivity) with training (Connor, 2002). Altogether, these results suggest developmental change in the stimulus information used to categorize objects.

If a major problem for inexperienced learners is trying to figure out what information is relevant, then simple training stimuli may help young learners by reducing this problem. Simple training instances presenting relevant features for transfer can also alter how transfer stimuli are perceived. A good example of this comes from an adult study by Schyns and Rodet (1997). They taught adult learners about two different kinds of "Martian cells," cell type A or cell type AB. Transfer tests showed that subjects who first learned about cell type A subsequently conceive cell type AB as being composed of two separate features, A and B. Subjects who learned about AB cells first and A cells in transfer, did not learn that AB was composed of separate features, but simply learned that the two cell types differed overall. In Schyn and Rodet's terms, learning cell type A (the simpler stimulus type) set up a perceptual vocabulary (feature A*) through which* AB was subsequently perceived as feature A plus another feature. The present results are strongly consistent with this pattern. Learning the simple shape first may have enabled young learners to see the complex object as containing the simple shape along with other features. Learning the complex shape first does not provide a decomposed perceptual vocabulary and thus the learner may simply see the first complex object as simply different from the shapes, simple or complex, that follow.

Providing the right perceptual vocabulary may be one way that simple training instances facilitate generalization. But simplicity during initial training may also direct children's attention to the right perceptual description by merely *removing* possible competing descriptions. If shape or size or color is important and relevant for transfer, then perhaps all other details besides the relevant information should be stripped away. Consistent with this idea, Rattermann, Gentner, and DeLoache (1990) found that young children were better able to make shape matches when the objects were highly impoverished and only differed in size than when they were richly detailed with an abundance of unique features. Even adults are facilitated by the removal of possible competing interpretations. When feature similarities compete with more abstract construals, increasing feature similarities distract adult learners (Goldstone & sakamoto, 2003; Kaminski, Sloutsky, & Heckler, 2008). In brief, there appears to be an advantage to learning with perceptually sparse representations that do not compete with a more abstract description of the training set (for similar ideas, see also, DeLoache, 1995; Uttal, Liu, & DeLoache, 1999; Rattermann & Gentner, 1998; Sloutsky, Kaminski, & Heckler, 2005).

These explanations, taken together, are related to an insight that emerges from a large body of learning literature: simple training instances may highlight relevant similarities and influence transfer by both guiding information gathering during learning and by affecting the perception of the generalization target. Precedents for this idea come from a wide variety of domains. For example, Biederman and Shiffrar (1987) showed that they could train a novice with no chicken sexing experience to near-expert levels simply by teaching the learner about a small set of relevant features. Also relevant are Deloche's experiments on young children's use of scale models to find target locations in an actual room. DeLoache (1991), DeLoache (1995) found that children relate the scale model to the room better when it is simpler (more impoverished) than when it is too richly detailed. Other researchers report that children reason about number better with simple discs or blocks (Uttal, Scudder, & DeLoache, 1997) than with richer and more interesting objects (Mix, 1999; Uttal et al., 1999). A similar advantage for simplicity in training has been found in adults' learning in domains such as mathematics (Sloutsky et al., 2005; Uttal et al., 1999), physics (Bassok & Holyoak, 1989), and complex systems principles (Goldstone & Sakamoto, 2003). In brief, there appears to be a broad advantage for increased generalization when learning with simplified representations. If the broad goal of teaching and learning is generalization, these findings provide a direct route towards such an end.

The present conceptualization of the role of simple training examples in fostering generalization is that they do so through processes related to the formation and access of appropriately *abstract* representations of the training materials, although as the discussion above makes clear there are a number of different (and non-mutually exclusive) processes that might contribute to this. An alternative possibility, that cannot be ruled out at present, is that complexity itself limits generalization independently of the nature of the memory representation. That is, complex stimuli may increase the cognitive load in ways that limit generalization processes themselves (Sweller, 1988). What is needed in future research are measures of representation independent of the measures of generalization.

7. Conclusion

If there were enough time and resources for learners to experience a wide variety of many richly detailed instances, generalization would probably occur anyway. The type of mental abstractions that occur over many richly detailed instances is likely to be different from the experience of a single simple instance. However, the present results suggest that when there is only limited opportunity for training, a single instance in these experiments, simpler instances foster greater learning of the generalization. This may be the case because simplified training instances somehow reflect the process of abstraction over many instances. As such, they help explain why it is that children's ability to abstract simple shape abstractions from complex and richly detailed things may be developmentally related to an expansion in learning object categories. Particular members of a common noun category each have their own detailed shapes but are part of an equivalence class only under an abstract simplified description of shape. Furthermore, this description, like the simple training stimuli used here, is category-encompassing precisely because it leaves out many of the idiosyncratic details of more complex real things.

The results also raise some new issues about similarity and transfer. Object category learning by children may well be built on general learning mechanisms such that the benefit of simplicity *in training* may hold in a variety of domains. The value of simplicity may be this: Experts do not necessarily perceive *all* available aspects of a situation but they clearly see the *relevant* ones. In fact, part of being an expert is the ability to ignore irrelevant information that may be misleading. Simplicity during learning allows novices to simulate experts because only the relevant similarities are available.

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