Effects of perceptually rich manipulatives on preschoolers' counting performance: Established knowledge counts

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Abstract

Educators often use concrete objects to help children understand mathematics concepts. However, findings on the effectiveness of concrete objects are mixed. The present study examined how two factors—perceptual richness and established knowledge of the objects—combine to influence children's counting performance. In two experiments, preschoolers (*N* = 133; *M* age = 3;10) were randomly assigned to counting tasks that used one of four types of objects in a 2 (perceptual richness: high or low) x 2 (established knowledge: high or low) factorial design. Findings suggest that perceptually rich objects facilitate children's performance when children have low knowledge of the objects, but hinder performance when children have high knowledge of the objects.

Effects of perceptually rich manipulatives on preschoolers' counting performance: Established knowledge counts

Parents and teachers often use concrete objects such as toys, tiles, and blocks to help children understand abstract mathematics concepts. Use of these *manipulatives* is based on the long-held belief that young children's thinking is concrete in nature (Bruner, 1966; Montessori, 1964; Piaget, 1953). However, research into the usefulness of such objects has been mixed, with some studies reporting benefits, some reporting no benefits, and some reporting disadvantages (McNeil & Jarvin, 2007). These inconsistent findings present researchers with the challenging task of deciphering which factors affect whether or not children will profit from a given manipulative. In two experiments, we examined two factors hypothesized to affect children's interpretation of the manipulatives used in a mathematics task: the perceptual richness of the objects and how the objects interface with children's existing knowledge.

One example of a manipulative is a counter. Counters are small objects used in lessons on counting and sorting. As is the case for many manipulatives, counters come in many shapes and colors ranging from flat, solid-colored plastic disks to 3-D, brightly colored, realistic-looking plastic animals. Given the wide variety from which to choose, teachers face tough decisions whenever they purchase such objects for their classrooms. How are they to make an informed decision between the plainest and most perceptually rich manipulatives?

There are compelling reasons to choose perceptually rich manipulatives. Objects that stand out from their surroundings not only attract attention, but also stimulate further investigation of the objects. For this reason, manipulatives that are brightly colored, unusually textured, or highly dimensional may capture children's attention and help children stay focused on the given task. Such objects may increase interest and prevent children from getting bored.

This assumption seems to be held by many of the producers of manipulatives. Indeed, perceptually rich manipulatives far outnumber bland manipulatives on the shelves of leading teaching supply stores. Teachers themselves also seem to prefer perceptually rich manipulatives. We recently polled teachers at two local childcare centers and asked them which objects they would rather use for lessons on counting and sorting: flat, solid-colored plastic disks or 3-D, brightly colored, realistic-looking plastic animals. They unanimously chose the animals.

Although perceptually rich objects may increase children's engagement in the task at hand, they also may have undesirable consequences. Because the perceptual details of manipulatives are often irrelevant to the task, they may distract children from important information that educators intend to share because perceptual details (e.g., color, shape) may compete with the relational structure of the mathematics task (Kaminski, Sloutsky & Heckler, 2008). Moreover, perceptual richness may draw children's attention to the manipulatives as objects themselves and reduce their representational status (DeLoche, 2000; Uttal, Scudder, & DeLoache, 1997). The *representational status* of an object refers to the ease with which it can represent something else (Gelman, Chesnick, & Waxman, 2005). Reducing an object's representational status has obvious implications when children are using the object to represent mathematical ideas (e.g., using a pizza to represent fractions). However, it also has important implications when an object is being used as a counter because objects with low representational status are more likely than those with high representational status to be construed as individuals rather than members of a larger category, or set (Gelman et al., 2005). Children exhibit a better understanding of counters when they can construe them as a set (Mix, Huttenlocher, & Levine, 2002). Thus, when using a small toy giraffe as a counter, a child may focus on that object as a "giraffe" and not as one of several members of the countable set. According to this logic, teachers should seek out simple, bland materials rather than perceptually rich materials when choosing manipulatives for their classrooms.

Results from several studies support the idea that perceptually rich manipulatives hinder children's learning and performance on mathematics tasks. For example, McNeil, Uttal, Jarvin, and Sternberg (2009) tested fourth- and sixth-grade children's performance on word problems involving money. Children solved problems using one of three types of manipulatives: (1) perceptually rich bills and coins that resembled real U.S. currency, (2) bland bills and coins (i.e., black numbers printed on white paper), or (3) no manipulatives. Children in the perceptually rich condition solved fewer problems correctly than did children in the other conditions. These results suggest that perceptual richness decreases the usefulness of manipulatives on a problem-solving task.

Amaya, Uttal, O'Doherty, Liu, and DeLoache (2008) gave second grade children Digi-Blocks to help them learn to solve double-digit subtraction problems. Digi-Blocks are manipulatives designed to teach children the base-ten system. The Digi-blocks were either standard blocks, which were a uniform sea-green color, or perceptually rich blocks, which were brightly colored and patterned. Researchers videotaped children's actions with the Digi-blocks during two problem-solving tests and coded whether children ever used the manipulatives in irrelevant ways (e.g., building, sorting). They found that only one child in the standard Digi-blocks condition used the blocks in irrelevant ways, whereas the majority of children in the perceptually rich condition (70%) did. These results suggest that perceptual richness may increase task irrelevant behavior with manipulatives, thus rendering them less effective.

Kaminski and Sloutsky (2009) examined kindergartners' ability to identify common proportions across two different sets of stimuli. Children were trained on common proportions (e.g., 2 out of 3) with one set of stimuli and then asked to identify the same proportions in a set of novel stimuli. Children received training in either the *concrete* condition, in which stimuli were proportions of sprinkled cupcakes out of total cupcakes, or the *generic* condition, in which stimuli were proportions of black circles out of total circles. After training, children in both conditions were given a transfer task in which they had to identify common proportions within the context of novel sets of stimuli (e.g., matching proportion of yellow cars out of total cars). Results revealed that only the children in the generic condition performed above chance on the transfer test. These results suggest that perceptual richness can hinder children's ability to transfer their knowledge to instances outside the immediate learning context.

Based on these findings and others, some have argued that teachers should avoid perceptually rich manipulatives in mathematics lessons (McNeil & Jarvin, 2007). However, it is unclear whether poor learning and performance on the aforementioned mathematics tasks can be attributed to perceptual richness *per se* because perceptual richness has been conflated with established knowledge. The perceptually rich manipulatives were not only more perceptually rich than the "control" manipulatives, but also more similar to objects seen and used by children outside of school mathematics. For example, the perceptually rich bills and coins were highly similar to the play money that comes in board games and toy cash registers. Children in previous studies may have performed more poorly in the perceptually rich condition than in the control condition because their established knowledge of the objects made it difficult for them to use the objects in a new way. A large body of research suggests that children (and adults) often resist changing their well-established knowledge of objects, concepts, or procedures (e.g., Duncker, 1945; Mack, 1995; McNeil & Alibali, 2005). Children seem to have a particularly difficult time using an object symbolically once they have already gained experience with that object in a play setting (DeLoache, 2000). Thus, it is possible that the perceptual richness would have been helpful if children did not already have established knowledge of the objects.

The perceptual richness of objects and the established knowledge associated with those objects may form independent dimensions of concreteness. Unfortunately, research has tended to privilege one of these dimensions over the other or even to confound them. In the present study, we sought to disentangle these dimensions of concreteness and examine the ways in which they influence young children's interpretation of manipulatives. We hypothesized that children's established knowledge would moderate the effect of perceptual richness. Specifically, we predicted that perceptual richness would serve to attract children's attention to the objects in the mathematics task at hand. When children already have well-established knowledge of those objects in a non-school setting, this increased attention may serve to activate (and keep children focused on) the objects' known meaning. In turn, with this known meaning activated, children's ability to use the objects in a new way (e.g., as counters) should be hindered. In contrast, when children do not already have established knowledge of the objects, this increased attention may stimulate further interest in the set of objects and their purpose in the given task, thus preventing children from getting bored and improving performance on the task.

We tested this hypothesis in two experiments by examining the effects of different types of counters on preschool children's counting performance. Preschool children are the ideal population in which to study these issues because previous studies have suggested that manipulatives are most useful for children who are below the first-grade level (see Friedman, 1978 for a review). We focused on counting *performance* because accurate performance is important for the development of mathematical thinking. Indeed, children can discover new strategies and develop an understanding of higher-level concepts through their own repeatedly accurate performance (i.e., practice) on mathematics problems (e.g., Siegler & Stern, 1998). Accurate performance is particularly important for young children's developing knowledge of counting because it takes children years of counting accurately before they develop an understanding of cardinality (e.g., Fuson, 1988; Wynn, 1990).

Our goal in the first experiment was to maximize external validity and test our hypothesis using the types of objects that children typically use in their classrooms, so we used objects that could be purchased from teaching supply stores. Our goal in the second experiment was to have more systematic control of our factors of interest, so we constructed our own novel objects that were either high or low in perceptual richness and gave children knowledge of those objects (or other novel objects) prior to the counting tasks.

Experiment 1

We tested the effect of different types of counters on children's performance using two widely-used counting tasks: the puppet counting task (Briars & Siegler, 1984; Gelman & Meck, 1983) and the give-a-number task (Wynn, 1990). The only factor that varied between children was the type of objects being counted. Children were randomly assigned to object type in our 2 (perceptual richness: high or low) x 2 (established knowledge: high or low) factorial design. We selected objects from teaching supply stores that fit the criteria of each condition, and we used two different sets of objects within each condition to reduce the likelihood that the findings could be attributed to any one set (see Figure 1). We hypothesized that perceptual richness would hinder performance when children already had established knowledge of the objects, but would facilitate performance when children did not already have established knowledge of the objects.

Method

Participants. Children were tested at childcare centers located on two college campuses in a midwestern U.S. city. Tuition is based on a sliding scale, and 30% of children received some form of reduced tuition. The final sample contained 54 children (33 boys, 21 girls; 80% white and 20% Asian) between the ages of 2 years, 11 months and 4 years, 11 months (*M* = 3 years, 8 months; *SD* = 6.72 months). Six additional children were excluded because they failed to complete the tasks.

Materials and procedure. Children met individually with the experimenter for approximately 20-25 minutes in a quiet room in the childcare center. They completed the puppet counting task followed by the give-a-number task.

Puppet counting task. This task was a modified version of the one used by Briars and Siegler (1984) and Gelman and Meck (1983). Children watched as a frog puppet counted arrays of five, seven, or nine objects and then reported the total number of objects in the array. All arrays were prearranged. As in Briars and Siegler, the objects were pasted in a straight line on a cardboard strip, and objects on each strip alternated (exemplar A, exemplar B, exemplar A, exemplar B, etc.). Children's goal was to judge the acceptability of the frog's counting.

Children were introduced to the task as follows: "This is my friend, Frog. Would you like to say hi to Frog? Now, Frog is going to count for you, but he is just learning how to count and he sometimes makes mistakes. Frog is going to count these things on the table. I want you to watch him very carefully to see if he counts OK, or if he makes a mistake. After he is all done counting and he tells us how many there are, it is your job to tell him if he counted OK, or if he made a mistake. Now remember, you have to wait until he is all done counting and has told us how many there are before you tell him whether he counted OK, or if he made a mistake."

At the start of each trial, the experimenter said: "Let's see if Frog can count these." The puppet then counted the array and reported a number. The experimenter then asked the child:

"Did Frog count OK, or did he make a mistake?" After the child responded, the next trial began. If the child tried to correct the puppet before the count was over, the experimenter asked the child to wait until the puppet was finished counting. All 15 trials were performed in this manner.

Children judged the acceptability of 15 counts (presented in one of two random orders): five standard correct counts, five unusual but correct counts, and five incorrect counts.

Standard correct counts. All five standard correct counts were performed in a left-to-right fashion, counting adjacently. The puppet reported the correct total number after the count.

Unusual but correct counts. None of the five "unusual but correct" counts violated any of the counting principles (i.e., all were correct counts), but each was performed in a non-standard way. The five non-standard ways of counting were as follows: (a) non-adjacent – puppet counted every-other object during his first pass through the array and then came back to the beginning and counted the remaining objects; (b) double point – puppet pointed to each object twice, but counted each object only once during the count; (c) start in the middle – puppet started counting in the middle of the array, counting left-to-right until he reached the end and then went to the beginning and counted the remaining objects; (d) reverse – puppet counted every object from right to left; (e) end to middle – puppet started by counting the first and last objects, counting inward towards the middle of the array.

Incorrect counts. Each of the five incorrect counts contained an error that violated one of the counting principles as identified by Gelman and Gallistel (1978). Our errors were modeled after Briars and Siegler (1984) and Gelman and Meck (1983) as follows: (a) omitted word – puppet pointed to one of the objects without labeling it with a number word; (b) skipped object – puppet neither pointed to nor labeled one of the objects; (c) extra word – puppet pointed to one of the objects once while labeling it with two consecutive number words; (d) double count –

puppet pointed to one of the objects twice and labeled it with a number word each time; and (e) incorrect cardinal value - puppet followed an otherwise correct count by reporting a cardinal value that was one more than the correct cardinal value.

Give a number task. This task was a modified version of the task used by Wynn (1990). Children received a pile of 15 objects, and their goal was to give a monkey puppet a specified number of objects. The experimenter introduced children to the task as follows: "This is my friend, Monkey. Would you like to say hi to Monkey? Monkey wants to play with a number of these objects but he can't reach them, so he's going to ask you for the number he wants. Can you give him the number he wants?"

At the start of each trial, the experimenter said: "Monkey would like *n.* Can you give Monkey *n*?" After the child gave the puppet objects, the puppet said, "Thanks" and the experimenter asked, "Does Monkey have *n*?" If the child agreed, then the next trial began. If the child disagreed, then the experimenter prompted the child to give the correct amount by saying: "But Monkey wanted *n*. Can you make it so that he has *n*?" At the end of each trial, the experimenter returned all objects to the original pile. Thus, for each trial, children selected a number of objects from the pile of 15 objects.

Children were always asked to give one object on the first trial. Subsequent trials were based on children's performance. If children gave the correct number, they were asked to give the next consecutive number ($n + 1$). If children gave the incorrect number, they were asked to give the preceding number ($n - 1$). Trials continued in this manner until children failed on a given number twice. If children succeeded on all numbers 1-6, then the experimenter started again with one object and repeated the sequence of trials as described. A child was classified as a "knower" of the highest number of objects (out of 6) he or she could give correctly twice.

Experimental Conditions. Children were randomly assigned to one of four object types in a 2 (perceptual richness: high or low) x 2 (established knowledge: high or low) factorial design. Children were randomly assigned to the set of objects they used across both counting tasks. All objects were selected from teaching supply stores (see Figure 1). We also gathered perceptual richness ratings on the objects to ensure that the objects in the high perceptual richness conditions were perceived as more perceptually rich than the objects used in the low perceptual richness conditions. Thirty-nine undergraduates rated the perceptual richness of arrays of each of the eight sets of objects on a scale from one to seven. A paired t-test revealed that the undergraduates did indeed rate the objects in our high perceptual richness conditions as more perceptually rich (M = 5.46, SD = 0.72) than the objects in our low perceptual richness conditions (M = 2.61, SD = 0.67), $t(38) = 20.41$, $p < .001$.

Low perceptual richness, low established knowledge. These objects needed to be bland in appearance and not typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) 2” solid colored blue, green, and yellow plastic disks and (b) 2” x 1/8” solid colored blue, green, and yellow wooden pegs. Children’s teachers confirmed that they did not have objects like these in the classrooms.

Low perceptual richness, high established knowledge. These objects needed to be bland in appearance and typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) 4 ½” x 3/8” popsicle sticks that were dipped in blue, green, or red Kool-Aid to mimic the look of real popsicle sticks, and (b) 6” x ¼” blue, green, and red colored pencils. Children’s teachers confirmed that children often used colored pencils for drawing and coloring, and we took for granted that preschool children have experience with popsicles.

High perceptual richness, low established knowledge. These objects needed to be perceptually rich in appearance, but not typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) ½” pink, yellow and purple sparkly poms and (b) 2” yellow and green, yellow and orange, or green, yellow, and red pinwheels without the stem. Children’s teachers confirmed that they did not have objects like these in the classrooms.

High perceptual richness, high established knowledge. These objects needed to be both perceptually rich in appearance, and typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) plastic animals - 1 ½” x 3” zebras, 3” x ½” giraffes, and 2” x 1 ¾” tigers and (b) plastic miniature fruit - 1” x ½” strawberries, 1” x ¾” pears, and 2” x ½” bananas. Children’s teachers confirmed that children played with objects similar to these during free play in the classroom.

Results

As shown in Table 1, the pattern of performance was similar across the puppet counting and give-a-number tasks, so we created a composite measure for more efficient presentation (Cohen, 1990). Children received a point for each count they correctly identified on the puppet counting task (out of 15), and they received points corresponding to the number of objects they could correctly give twice (out of 6) on the give-a-number task. We took the z-scores of children’s performance on both the puppet counting task and the give-a-number task to ensure that the two tasks were given equal weight. Then, we added the z-scores from each task together to create the composite score.

We performed an analysis of covariance (ANCOVA) with perceptual richness (high or low) and established knowledge (high or low) as the independent variables, score on the composite measure as the dependent variable, and age as the covariate. We included age as a covariate because of the well-established link in the counting literature between age and performance on counting tasks (Briars & Siegler, 1984; Gelman & Meck, 1983; Wynn, 1990). Not surprisingly, we found a significant effect of age, with older children performing better than younger children, $F(1, 49) = 10.26$, $p = 0.002$, $\eta_p = .17$. As predicted, we found a statistically significant interaction between perceptual richness and established knowledge, $F(1, 49) = 7.53$, $p = 0.008$, $\eta_p = .13$. As shown in Figure 2, the direction of the effect of perceptual richness depended on children's established knowledge of the objects. Simple effects tests revealed that the perceptually rich objects facilitated performance relative to the bland objects when children had low knowledge of the objects, $F(1, 49) = 5.64$, $p = 0.02$, but not when children had high knowledge, $F(1, 49) = 2.53$, $p = 0.11$. Moreover, as predicted a planned contrast revealed that performance in the perceptually rich, high knowledge condition was significantly worse than performance in the other three conditions on average, $F(1, 49) = 5.09$ $p = .03$. Neither main effect was significant: perceptual richness $F(1, 49) = 0.20$, $p = .65$; established knowledge $F(1, 49) = 2.73$, $p = .11$.

Discussion

The data support our hypothesized interaction between perceptual richness and established knowledge. This interaction makes sense in the context of the research literature. Perceptually rich objects are salient. They grab children's attention and stimulate further investigation of the objects. When children already have established knowledge of the objects, this increased attention will be directed to the objects and activate (and keep children focused on) their known purpose. As a result, it may be more difficult for children to view the objects in terms of their new meaning or purpose in the current task. In contrast, when children do not have established knowledge of the objects, this increased attention will be directed to objects that have little or no established meaning to the children. Meaning will need to be created in the context of the current task. As a result, children may increase their interest in the set of objects and their meaning or purpose in the given task and be prevented from getting bored.

One of the primary goals of Experiment 1 was to provide teachers with data that would help them make informed decisions when choosing manipulatives. To this end, we manipulated our two factors of interest by searching teaching supply stores for objects that fit into each of the categories in our 2 x 2 design. In taking this approach, however, we also had less stringent control over the objects we used for the counting tasks. Although the objects in our high perceptual richness conditions were rated as more perceptually rich than the objects in our low perceptual richness conditions, we could not precisely control perceptual richness across conditions. For example, even though the perceptually rich poms and pinwheels used in the low established knowledge condition were rated similarly to the perceptually rich animals and fruit used in the high established knowledge condition in terms of overall perceptual richness, they nonetheless differed on several perceptual dimensions that were not controlled. The same can be said for the perceptually bland objects used in the two knowledge conditions.

Additionally, although we selected objects for the high established knowledge and low established knowledge conditions in consultation with children's teachers, we could not rule out potential individual differences in the amount of experience children had with the selected objects outside of the childcare setting. For example, whereas children might have used the toy animals only in the context of play, some may have had more diverse experience with the popsicle sticks (e.g., using them for eating, using them for art projects). Moreover, although all of the objects used in the high established knowledge conditions should have been easily identified at the superordinate level (i.e., animals, fruit, popsicle sticks, and pencils), the animals (giraffes and zebras) and fruit (strawberries and pears) may have been more easily identified at the basic level than the popsicle sticks (lime and cherry) and colored pencils (green and red). We addressed these types of limitations in Experiment 2.

Experiment 2

We wanted to have more systematic control of our two variables of interest, so we gave children experience with novel objects that we constructed ourselves and then used either those objects, or a new set of novel objects in the counting tasks. By manipulating established knowledge we ensured that all children within a given condition had equal experience with the objects used in the counting tasks (i.e., they either had the experience we gave them or no experience). By constructing our own novel objects we ensured that the objects within perceptual richness conditions were equated in terms of their perceptual richness. That is, children in both the high perceptual richness, high established knowledge and high perceptual richness, low established knowledge conditions used one of two sets of novel objects (see Figure 3). Children again performed two counting tasks: the puppet counting task and the give-a-number task. As in Experiment 1, we hypothesized that perceptual richness and established knowledge would interact to influence children's counting performance.

Method

Participants. Children were tested at the same childcare centers as in Experiment 1. The sample contained seventy-nine children (40 girls, 39 boys; 81% white, 10% Asian, 6% Hispanic or Latino, 1% black or African-American, and 1% other) between the ages of 3 years and 4 years, 10 months (*M* = 3 years, 10 months; *SD* = 6.72 months). Sixteen additional children were excluded: two because they failed to complete the tasks, and 14 because they failed the object knowledge reminder task (described below).

Materials and Procedure. Children met individually with the experimenter for two separate sessions in a quiet room in the childcare center. During the first session, children completed the object knowledge task (described below). This session lasted approximately ten minutes. One week later, children participated in a second session in which they completed the object knowledge reminder task (described below) and the two counting tasks (puppet counting and give-a-number). This session lasted approximately 25-30 minutes.

Object Knowledge Task. This task was used to manipulate children's established knowledge. The task was adapted from a task used by Gopnik, Sobel, Schulz, and Glymour (2001). Children were presented with a lamp that was shaped like an hourglass. They were led to believe that some specific objects called "blickets" made the lamp light up and play sounds when they were placed on top of the lamp, whereas other objects would not make the lamp work. To achieve this, the lamp was operated covertly via a remote control that was concealed under the table. When the remote control was in the 'on' position, the lamp lit up and played sound.

The objects that were used as blickets in this task (and as counters in the counting tasks) were one of four sets. These objects were adapted from objects used in Landau, Smith, and Jones (1988). Two sets of 1.75" x 1.25" objects were the same novel shape. One set was painted in solid, sparkly red and green. Red and green were chosen because they are complementary colors. The other set was painted in solid, dull light and dark gray. The remaining two sets of 1.25" x 1.5" objects were a different nonsense shape. Again, one set was painted in solid, sparkly red and green. The other set was painted in solid, dull light and dark gray.

We also constructed a set of fourteen objects that were used as non-blickets in this task and the object knowledge reminder task (described below). This set contained fourteen distinct shapes adapted from objects used in Diesendruck and Bloom (2003), Jones and Smith (2002), and Samuelson and Smith (2000). All fourteen objects were painted in solid light gray, dark gray, red, or green. Ten of the objects were used in this task, and four of the objects were used in the object knowledge reminder task.

To start the task, the experimenter focused the children's attention on the lamp by saying: "Look at this. It's a blicket detector! Only blickets will make the blicket detector work. I'm going to put some things on the blicket detector one at a time. Two of the objects will be blickets and will make the blicket detector work. Two objects will not be blickets and won't make the blicket detector work. Watch to see which things make the blicket detector work." The four objects were placed on the table in the following order: blicket, non-blicket, blicket, non-blicket. The four objects were then placed on the lamp one at a time so that the children would be able to see the effect or non-effect each object had on the lamp. When an object was placed on the lamp, the experimenter either said: "Look! The blicket made the blicket detector work!" or "Look! That wasn't a blicket and it didn't make the blicket detector work!" After all four objects were tested on the lamp, the lamp was removed from the table and the four objects were returned to their original places. The experimenter picked up the first object and said: "This blicket made the blicket detector work. Can you give me the other blicket that made the blicket detector work?"

If the child responded correctly, the lamp and objects were again placed on the table and the experimenter told the child: "You're right! Both of the blickets made the blicket detector work! Now it's your turn to try it. Can you make the blicket detector work?" If the child did not respond correctly, the experimenter said "Blickets make the blicket detector work," and the demonstration was repeated. The remaining four trials were completed in the same manner.

Object Knowledge Reminder Task. This task was used to test whether or not children remembered the blickets and their function one week after learning. It served as a manipulation check to ensure that children had acquired knowledge about the blickets. Children were presented with five objects. Four of the objects were non-blickets, and one of the objects was a blicket. Children were introduced to the task by being told: “Last time you got to see this machine. Do you remember what it is? That’s right! It’s a blicket detector. Let’s see if you remember how to make it work.” The experimenter then placed the five objects on the table and asked: “Can you make it work using any of these?”

After the child chose an object, the experimenter said: “Let’s see if you’re right. Put it on the blicket detector and see if it works.” If the child chose correctly, the experimenter said: “That’s right! Look, the blicket made the blicket detector work! Good job. Let’s play our next game!” If the child chose incorrectly, the experimenter said: “No, that one didn’t make the blicket detector work. Why don’t you try again?” If the child chose incorrectly the second time, the experimenter said: “No, that one didn’t make the blicket detector work. I think you should try this one. I think this one is a blicket. Put it on the blicket detector and see if it works.” Children who did not answer correctly were excluded from the analysis because they did not show evidence that they had acquired established knowledge about the objects.

Counting Tasks. The counting tasks were identical to those used in Experiment 1.

Experimental Conditions. Each child, regardless of condition, performed all tasks as described above. The only factor that varied between children was the objects they used in the tasks. Children were randomly assigned to one of four conditions in a 2 (perceptually richness: high or low) x 2 (established knowledge: yes or no) factorial design (see Figure 3 for an illustration of the objects used in this experiment). The two object types were properly counterbalanced. That is, one fourth of the participants saw objects of type A as blickets and counters; one fourth of the participants saw objects of type B as blickets and counters; one fourth of the participants saw objects of type A as blickets and objects of type B as counters; and one fourth of the participants saw objects of type B as blickets and objects of type A as counters.

Manipulation of perceptual richness. Children in the high perceptual richness conditions used one of the two sets of objects that were painted in solid, sparkly red and green. Children in the low perceptual richness conditions used one of the two sets of objects that were painted in solid, dull light gray and dark gray.

Manipulation of established knowledge. Children in the high established knowledge conditions used familiar objects for the counting tasks. These familiar objects were the blickets that children learned about in the object knowledge task during the first session. These blickets were high in perceptual richness or low in perceptual richness, depending on the assigned perceptual richness condition. Children in the low established knowledge conditions did not use familiar objects for the counting tasks. Instead, they used one type of objects on the object knowledge task and the other type of objects on the counting tasks (see Figure 3).

Results

Table 1 presents children's performance on the counting tasks by condition. As in Experiment 1, we performed an ANCOVA with perceptual richness (high or low) and established knowledge (high or low) as the independent variables, score on the composite counting measure as the dependent variable, and age as the covariate. There was a significant effect of age, with older children performing better than younger children, $F(1, 74) = 30.94$, $p < .001$, $\eta_p = .30$. More importantly, there was a significant interaction between perceptual richness and established knowledge, $F(1, 74) = 6.89$, $p = .01$, $\eta_p = .09$. As shown in Figure 4, the direction of the effect of perceptual richness depended on children's established knowledge of the objects. Simple effects tests revealed that the perceptually rich objects hindered performance relative to the bland objects when children had high knowledge of the objects, $F(1, 74) = 4.35$, $p = .04$, but not when children had low knowledge of the objects, $F(1, 74) = 2.71$, $p = .10$. Neither main effect was significant (both Fs < 1).

To confirm that the nature of the interaction did not differ across experiments, we analyzed the data across experiments and added experiment (1 or 2) as an independent variable. There was a significant effect of age, $F(1, 124) = 40.11$, $p <.001$, $\eta_p =.24$, and a significant interaction between perceptual richness and established knowledge, $F(1, 124) = 13.82$, $p < .001$, $\eta_p = .10$. Simple effects tests revealed that the perceptually rich objects facilitated performance when children had low knowledge of the objects, $F(1, 124) = 7.92$, $p = .01$, but hindered performance when children had high knowledge of the objects, $F(1, 74) = 6.74$, $p = .01$. There was also marginally significant effect of experiment, with a possible small advantage for experiment 1, $F(1, 124) = 3.16$, $p =.08$, $\eta_p = .03$. No other effects were significant.

Discussion

In Experiment 2, our goal was to have more stringent control over our two factors of interest. We constructed novel objects and gave children experience with those objects. Thus, we were able to equate perceptual richness within conditions of perceptual richness and to equate established knowledge within conditions of established knowledge. Results were generally consistent with the results of Experiment 1, and there was no evidence that the interaction differed across experiments. Thus, we found that the direction of the effect of perceptual richness depended on established knowledge both for objects that teachers commonly use in their classrooms, and for novel objects with which we gave children a small amount of experience.

General Discussion

Teachers' intuitions suggest that perceptually rich objects make good manipulatives because they attract attention and help children stay focused on and engaged in the mathematics task at hand. However, some researchers suggest that teachers should avoid using perceptually rich objects as manipulatives because they attract attention to themselves and away from the mathematics (e.g., Kaminski et al., 2008; McNeil & Javin, 2007; Uttal et al., 1997). In the present study, we sought a possible resolution to this debate by taking children's established knowledge into account. Specifically, we hypothesized that increased attention would hinder performance only in the case of a known object because the attention would activate the object's known meaning. Although results supported our hypothesis, we cannot state with certainty the mechanism(s) by which the activation of established knowledge hinders performance. We consider three possibilities in the following section.

Possible mechanisms

(1) **Functional fixedness.** When knowledge about an object's meaning is activated, children may fixate on the object's typical function and have trouble thinking about it in a novel way. This bias to use an object only in the way it is typically used is known as *functional fixedness*. Many studies have shown that people exhibit this bias (e.g., Duncker, 1945; Maier, 1931;). For example, knowledge of pliers as a gripping tool makes it difficult for people to use pliers as a weight (Maier, 1931), and knowledge of a box as a holder of tacks makes it difficult for people to use it as a candleholder (Duncker, 1945). In the present study, the perceptually rich, known objects may have induced a form of functional fixedness. The perceptual richness of the objects may have kept drawing children's attention back to the objects and activating their known function, which made it difficult to use them in a new way as counters (but see Defeyter & German, 2003 for evidence that young children are immune to functional fixedness).

(2) **Extraneous cognitive load**. When knowledge about an object's established meaning is

activated, it burdens children's limited working memory with information that is irrelevant to the given mathematics task. That is, it increases *extraneous load*. Cognitive load theory (e.g., Sweller, van Merrienboer, & Paas, 1998) distinguishes between three types of load: intrinsic, germane, and extraneous. Intrinsic load is imposed by the inherent difficulty of the task itself. Germane load is imposed by the processing, construction, and execution of task-relevant information. Extraneous load is imposed by the design and organization of the materials being used for the task. According to cognitive load theory, educators should minimize the use of materials that induce high levels of extraneous load, so adequate resources can be available for germane load. In the present study, the perceptually rich, known objects may have induced high levels of extraneous load by repeatedly drawing children's attention to their known meaning, which consumed resources that would have otherwise been devoted to the counting task.

(3) **Reduced salience of the set.** When established knowledge about an object's meaning is activated, children may be more likely to construe that object as an individual, rather than as part of a set. The more interesting an object is in its own right, the lower representational status it has. Thus, an object that has been touched or played with previously has lower representational status than one that has not (DeLoache, 2000). An object's representational status has implications for how that object is construed. Specifically, Gelman et al. (2005) have shown that objects with high representational status are more likely to be construed as members of a larger category, or set (e.g., one of many dogs), whereas objects with low representational status are likely to be construed as individuals (e.g., Lassie). This is relevant because research on children's early understanding of number suggests that children exhibit a better understanding of cardinality when they can construe the to-be-counted items as a set (Mix et al., 2002). Thus, in the present study, the objects with the lowest levels of representational status (i.e., the perceptually rich,

known objects) may have been more likely than the other objects to be construed as individuals rather than members of a set, and this may have hindered children's performance when using those objects on the counting tasks.

It is important to note that the mechanisms described above would only be expected to hinder performance when children's attention is drawn to the objects and their known meaning is activated. Functional fixedness is greatly reduced with small hints or variations in context that are designed to highlight aspects of the object other than the typical function (Adamson, 1952; Maier, 1931). Extraneous load is only a burden when the irrelevant information is actively held in working memory. And, the salience of a given set is only reduced when children are focusing on an individual object as an interesting object in its own right. Thus, established knowledge of the objects by itself may not be enough to hinder performance. Consistent with this view, we did not find a significant main effect of established knowledge in either experiment. Instead, established knowledge seems to hinder performance on the counting tasks only when objects are perceptually rich enough to repeatedly draw children's attention to back to the objects and reactivate their known meanings.

Regardless of the specific mechanisms involved, the present study makes an important contribution to the literature because it suggests that researchers should not look to the perceptual properties of objects alone to determine their usefulness as manipulatives. Instead, what children already know about the objects is also an important constraint on the ability to understand and use those objects in mathematical tasks. Moreover, from a practical standpoint the results demonstrate that children may benefit from the engaging nature of perceptually rich manipulatives, as long as the objects being used do not have other known meanings. Despite these contributions, at least three questions remain unanswered. First, which specific aspects of established knowledge affect whether or not a perceptually rich object can be used effectively as a manipulative? Second, do the results generalize to learning? Third, do the results generalize to other age groups?

Which aspects of established knowledge matter?

In the present study, we examined the effects of established knowledge at a coarse-grained level. Children likely had lots of extraneous knowledge about the toy animals and miniature fruit used in Experiment 1, and we provided both the name and the function of the blickets in Experiment 2. Because we did not manipulate specific aspects of knowledge, we cannot be certain which aspects of knowledge matter most. However, we can generate some hypotheses based on the three mechanisms discussed above.

First, if functional fixedness drives the effects, then established knowledge about an object's function should matter most. For example, knowledge that toy animals are used for pretend play (in Experiment 1) and that blickets are used to make blicket detectors work (in Experiment 2) may have made it difficult for children to use the animals and blickets as counters. If children had known only the names of the objects, without any information about their functions, then performance on the counting tasks may not have suffered as much.

Second, if extraneous cognitive load drives the effects, then the amount, complexity, and salience of children's established knowledge about the objects should matter most. For example, toy animals have several pieces of information associated with them (e.g., names of the animals, sounds the animals make, contexts in which the toy or real animals have been seen before, etc.), and children seem to be particularly captivated by animals (DeLoache, Bloom-Pickard, & LoBue, 2010). Thus, the knowledge activated by the toy animals in Experiment 1 was both sizeable and salient. Similarly, the knowledge activated by the blickets in Experiment 2—

although not sizeable—was both salient and complex. Children initially only had about 15 minutes of experience with the blickets, but the experience seemed to be particularly engaging and memorable. Indeed, children's remarks during the object knowledge reminder task in the second session often conveyed enthusiasm about the blickets even after the one-week delay. It was common for children to say things such as "Oooo… look at all the blickets!" immediately upon seeing the objects. Moreover, the relationship between the blickets and the blicket detector was causal and, accordingly, more complex than a simple fact. Thus, the extraneous information activated by the toy animals and perceptually rich blickets may have consumed working memory resources, leaving few resources available for the counting task. If children had known only one simple fact about the objects (e.g., "my uncle gave these to me," Markson & Bloom, 1997), then performance on the counting tasks may not have suffered as much.

Finally, if the salience of the set drives the effects, then knowledge of an object's label might matter most. Labels are important for young children's categorization decisions (Gelman & Markman, 1987). Thus, it may be difficult for young children to focus on a group of objects as a set when they know more specific names for individuals in the set. For example, knowing the specific names "giraffe" and "zebra" may have directed children's attention to the giraffes and zebras rather than to the animals as a set. This focus on the individuals may have, in turn, hindered counting performance. In the future, it will be important to tease apart the various aspects of extraneous established knowledge to determine which has the greatest hindrance on children's ability to use perceptually rich objects as manipulatives.

Future research should also examine the effects of other, more relevant types of established knowledge. In the present study, we considered the negative effects of *extraneous* established knowledge on performance (children's knowledge of the toy animals and perceptually rich blickets was irrelevant to the counting tasks). However, we did not consider the potentially positive effects of *relevant* established knowledge. For example, established knowledge of a set of objects as things that are routinely grouped and counted in the real world (e.g., pennies) may facilitate counting performance because it allows children to use the objects according to their typical function, increases germane load, and helps children construe the objects as a countable set. For such objects, perceptual richness would draw children's attention to the objects and activate knowledge that is helpful for the mathematics task at hand.

To help students develop relevant knowledge of manipulatives, teachers may want to use the same set of objects across mathematics lessons. This practice may encourage children to develop knowledge of the manipulatives as a set of things that are typically counted, added to, and subtracted from—knowledge that would likely facilitate children's use of the manipulatives to represent counting, arithmetic, and more advanced mathematics concepts. In support of this idea, Stevenson and Stigler (1992) found that children from East Asian countries, who are generally more successful than their peers from the U.S. in mathematics, typically use one set of manipulatives across lessons, across the elementary grades. According to Stevenson and Stigler, the Asian "view" is that this practice makes it easier for children to understand and solve mathematics problems. Son, Smith, and Goldstone (2011) recently echoed this view, suggesting that repeated use of the same materials across different situations may help children "perceive, discover, and work with relations" (p. 274). When teachers use multiple sets of manipulatives across lessons to add variety to their classrooms, their students are saddled with the additional task of discovering how the different manipulatives relate to one another. For this reason, Son et al. agree that it is best to use a common set of manipulatives across contexts.

Do the results generalize to learning?

Children in the present study were at least somewhat familiar with counting, and we tested their *performance* on counting tasks, not their learning. Thus, we cannot be certain if the interaction between perceptual richness and established knowledge would replicate in a context in which children use the objects to learn novel concepts. We suspect that the negative effects of perceptually rich, known objects would also be found in a learning context because functional fixedness, extraneous load, and low set salience all have the potential to hinder learning as well as performance. What is less clear, however, is whether the positive effects of perceptually rich, unfamiliar objects would be found in a learning context. Although such objects may keep children motivated and engaged in the learning task, the learned information may be dependent on the presence of those specific objects, so the generalizability of the learning may be limited.

Consistent with this view, some research suggests that perceptually rich objects make poor learning tools regardless of children's established knowledge of the objects because they discourage transfer. For example, Kaminski and Sloutsky (2009) found that children who learned to perform a task using perceptually rich materials showed benefits in initial learning, but disadvantages on an isomorphic transfer task in comparison to children who learned using bland materials. Goldstone and Sakamoto (2003) found a similar tradeoff between initial learning and transfer using perceptually rich materials with undergraduates. Other studies have found negative effects of perceptually rich materials for both initial learning and transfer (Kaminski et al., 2008; Sloutsky, Kaminski & Heckler, 2005; Son, Smith, & Goldstone, 2008).

Son et al. (2008) suggested that the advantage for bland objects in learning tasks is especially pronounced in young children because they are attentive to details of objects and are likely to encode unnecessary features during learning. When these encoded features are no longer available in a transfer scenario, young children's performance may suffer. The same team

(2011) further suggested that bland objects are also beneficial simply because they have fewer, less distinguishable surface features in general and, thus, can be used to represent more situations. The use of bland objects might be especially important for the task of learning to count because children's experiences with counting sets of bland objects might make it easier for children to perceive novel sets of objects in the real world as countable sets.

Taken together, the aforementioned studies suggest that educators may want to avoid using perceptually rich objects for learning because they hinder transfer of knowledge. However, all of these studies suffer from the same limitation that motivated the present study—that is, they have tended to focus on the perceptual richness of the learning materials without taking learners' established knowledge of the materials into account. Future studies are needed to disentangle the effects of perceptual richness and established knowledge in a learning task, just as the current study has done with a performance task.

Do the results generalize to other age groups?

In the present study, we focused exclusively on preschoolers, so it is unclear whether the interaction between perceptual richness and established knowledge would be present in other age groups. We would expect the negative effects of perceptually rich, known objects to apply across age levels because the negative effects of perceptually rich materials on performance, learning, and transfer have been shown in studies with preschoolers (Kaminski & Sloutsky, 2009; Son et al., 2008), elementary school children (Amaya et al., 2008; McNeil et al., 2009), middle school children (Kaminski, Sloutsky & Heckler, 2006; McNeil et al., 2009), and adults (Goldstone & Sakamoto, 2003; Kaminski et al., 2008; Sloutsky et al., 2005). However, the *strength* of the effect may differ across age groups because functional fixedness and extraneous load both depend on age. In the case of functional fixedness, younger children appear to more easily incorporate the current goal into their representations of an object's function, whereas older children and adults appear to have more resistance to thinking about an object in ways that differ from its typical function (Deyfeyter & German, 2003). Thus, if functional fixedness drives the effect, then we might expect the negative effect of perceptually rich, known objects to increase with age. In contrast, if extraneous load drives the effect, then we might expect the negative effect of perceptually rich, known objects to decrease with age. Children's working memory capacity increases with age (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004), so older children and adults may have greater ability than young children to handle the extraneous load that perceptually rich, known objects impose (cf. Son et al., 2008).

It is more difficult to predict whether older children and adults would also experience the *benefits* of perceptual richness when they are using unknown objects. It is possible that perceptual richness would similarly capture older children's and adults' attention and prevent them from getting bored. Alternatively, it is possible that because older children and adults have so much experience in educational settings that they do not need external aids to maintain interest in the task.

Conclusion

Overall, the current study makes an important contribution to our understanding of how children interpret different types of manipulatives. By identifying factors that help and hinder children's ability to interpret manipulatives, we not only gain deeper insight into the nature of children's developing knowledge (cf. Sophian, 1997), but also provide practical information for teachers who must make informed decisions about the objects they will use in the classroom each day.

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Table 1

Average (SD) Performance on the Counting Tasks in Experiments 1 and 2 by Condition

		High knowledge		Low knowledge	
Experiment	Task	High percept	Low percept	High percept	Low percept
1	Puppet	7.85 (2.23)	9.00 (1.92)	10.54 (2.07)	8.86 (2.11)
	Give-a-number	3.69 (2.21)	4.57 (1.45)	4.92 (1.71)	3.57 (1.60)
2	Puppet	8.14 (2.15)	9.43 (2.80)	8.24 (2.66)	7.60 (2.04)
	Give-a-number	3.71 (1.90)	4.38 (1.83)	4.82 (1.67)	3.90 (2.07)

Figure 1. Stimuli Used in Experiment 1

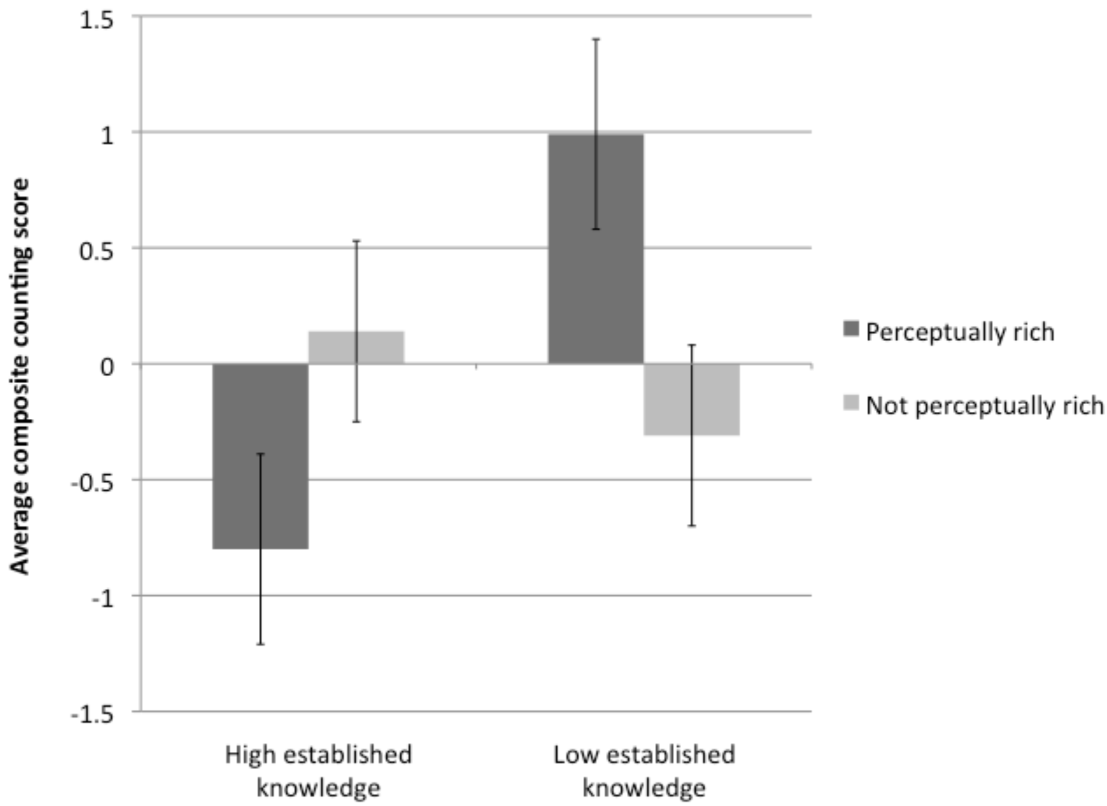

Figure 2. Performance on the Counting Tasks in Experiment 1 by Condition

Figure 3. Stimuli Used in Experiment 2

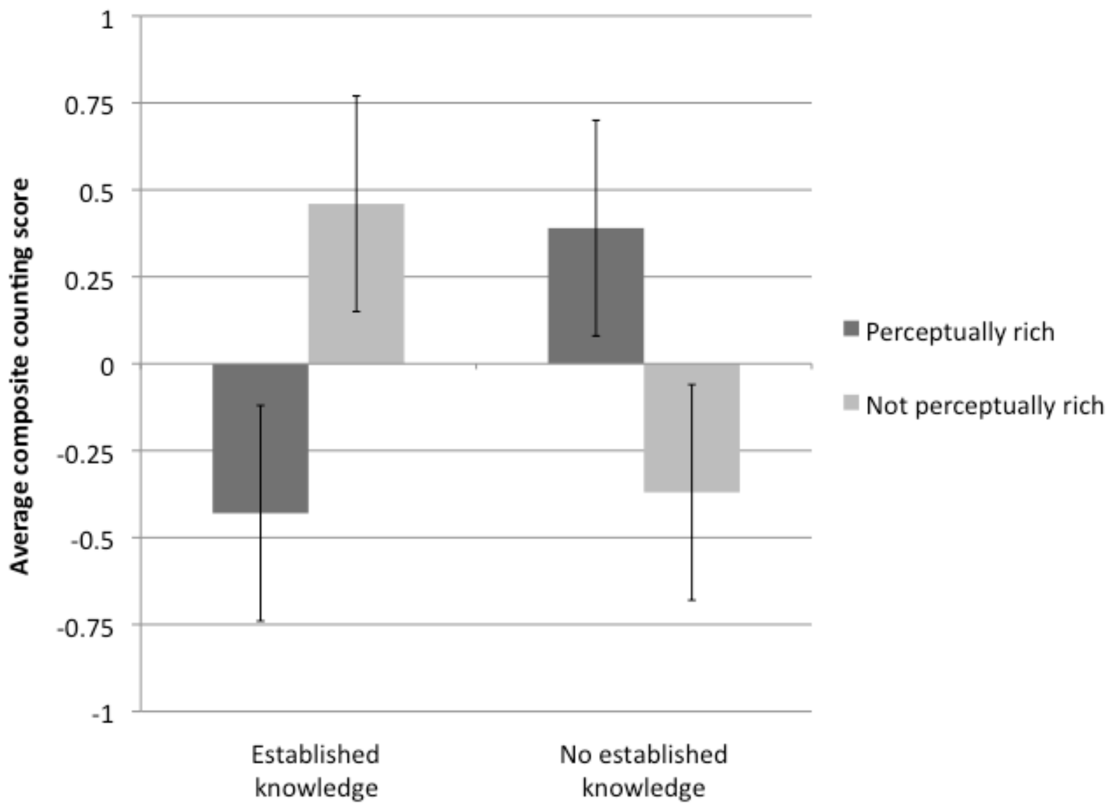

Figure 4. Performance on the Counting Tasks in Experiment 2 by Condition