Using Perceptually Rich Objects to Help Children Represent Number: Established Knowledge Counts

Lori A. Petersen (lpeters4@nd.edu)
University of Notre Dame
Department of Psychology, 118 Haggar Hall
Notre Dame, IN 46556 USA

Nicole M. McNeil (nmcneil@nd.edu)
University of Notre Dame
Department of Psychology, 118 Haggar Hall
Notre Dame, IN 46556 USA

Abstract

Concrete objects are used to help children understand math concepts. Research suggests that perceptually rich objects may hinder children's performance on math tasks relative to bland objects. However, previous studies have confounded the perceptual richness of objects with children's established knowledge of the objects. The present study examined how these two factors influence children's developing counting skill. Children (*M* age = 4 yrs, 1 mo) were randomly assigned to counting tasks that used one of four types of objects in a 2 (perceptually rich or not) x 2 (established knowledge or not) factorial design. Results revealed an interaction between the two factors. When children already had knowledge of the objects, perceptual richness hindered performance on the counting tasks. However, when children did not have established knowledge of the objects, perceptual richness facilitated performance. These findings suggest that the use of perceptually rich objects can convey both advantages and disadvantages for children's performance on math tasks, depending on how the objects interface with children's established knowledge.

Parents and teachers often use concrete objects such as toys, tiles, and blocks to help children understand abstract math concepts. Use of these *manipulatives* is based on the long-held belief that young children's thinking is strictly concrete in nature (Bruner, 1966; Piaget, 1953; Montessori, 1964). However, research into the usefulness of such objects has been mixed, with some studies reporting benefits, some reporting no benefits, and some reporting harms (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 the present study, we examined two factors hypothesized to affect children's interpretation of manipulatives: 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 that preschool and kindergarten teachers often use 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 of colors, sizes, and shapes 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 have the potential to increase children's engagement in the task at hand, they also may have undesirable consequences. Indeed, because the perceptual details of manipulatives are often irrelevant to the task, they may simply distract children from important information that educators intend to share (Kaminski et al., 2007). Moreover, perceptual richness may draw children's attention to the manipulatives as objects themselves and make it more difficult for children to see them as a symbol of something else (Uttal et al., 1997). This idea is known as the *dual representation hypothesis* (DeLoache, 2000; Uttal et al., 1997). According to this view, factors such as perceptual richness that increase an object's salience increase children's focus on the object itself and decrease children's focus on the object as a symbolic representation.

Results from two recent studies support the idea that perceptually rich manipulatives hinder children's performance on math tasks. The first examined fourth- and sixth-grade children's performance on math word problems involving money (McNeil et al., in press). Children solved problems in one of three conditions. In the first condition, children used perceptually rich bills and coins that resembled real U.S. currency to help them solve

the problems. In the second condition, children used bills and coins that were stripped of extraneous perceptual detail. In the third condition, children did not use bills and coins. Children in the perceptually rich condition solved fewer problems correctly than did children in the other conditions.

The second study examined second grade children's use of Digi-Blocks to solve double-digit subtraction problems (Amaya et al., 2008). Digi-blocks are manipulatives designed to teach children the base-ten system. The study included two different types of Digi-blocks: standard blocks, which are a uniform sea-green color, and perceptually rich blocks, which were brightly colored and patterned. Amaya and colleagues videotaped children's actions with the Digi-blocks during two problem-solving tests. They coded whether children ever used the manipulatives in ways that were irrelevant to the math task (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 did.

Taken together, these findings have been used to argue that teachers should avoid perceptually rich manipulatives (McNeil & Jarvin, 2007). However, based on the available evidence, it is unclear whether poor performance on the math tasks can be attributed to perceptual richness *per se*. This is because the perceptually rich manipulatives used in the aforementioned studies were not only more perceptually rich than the "control" manipulatives, but also more similar to objects seen and used by children outside of school math. For example, the perceptually rich bills and coins were highly similar to the play money that comes in board games and toy cash registers. Similarly, the colorful Digi-blocks with decorative patterns closely resembled building blocks and sorting toys. Thus, children in both studies may have performed more poorly in the perceptually rich condition than in the control condition because their established knowledge of the objects as toys made it more difficult for them to use the objects in a school math task. Indeed, it is possible that the perceptual richness would have been helpful if children had not already had established knowledge of the objects as toys. 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; Son & Goldstone, 2007).

A study by DeLoache (2000) illustrates how children's knowledge of an object as a toy can hinder their ability to use it symbolically. In the study, children's goal was to use a scale model of a room to locate an object hidden in a larger room. Children were randomly assigned either to an experimental condition, in which they played with the scale model before using it to locate the object in the larger room, or to a control condition, in which they did not play with the model beforehand. Children who played with the model beforehand performed much worse on the search task than did children in the control condition. These results suggest that children's knowledge of the scale model as a toy

interfered with their ability to use it symbolically as a representation of the larger room.

These results suggest that researchers need to take children's established knowledge into account when hypothesizing about the effects of various manipulatives. We hypothesize that children's established knowledge moderates the effect of perceptual richness. Specifically, we predict that perceptual richness will attract children's attention to the objects at hand. When children already have well-established knowledge of those objects in a non-school setting, this increased attention will serve to highlight the objects' known meaning. In turn, children's ability to use the objects in a new way—as counters—will be hindered. In contrast, when children do not already have established knowledge of the objects, this increased attention may be directed to the objects and their purpose in the task, thereby increasing children's chances of forming a new association between the objects and their current purpose as a set of countable objects. We tested this hypothesis by examining the effect of different types of counters on preschool children's developing counting skill. 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).

Method

Participants
The study was conducted at childcare centers located on two college campuses in the Midwest. Tuition is based on a sliding scale, and 30% of children receive some form of reduced tuition. Sixty children participated. Six were excluded because they failed to complete the tasks. Thus, the sample contained fifty-four children (33 boys, 21 girls; *M* age = 4 years, 1 month). The race/ethnicity of the sample was 20% Asian and 80% White.

Materials and Procedure
Children met individually with the experimenter for approximately 20-25 minutes in a quiet room in the childcare center. They completed two counting tasks: puppet counting and give-a-number.

Puppet Counting Task This task was adapted from Gelman and Meck (1983) and Briars and Siegler (1984). 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. 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? [pause for child to respond] 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 total 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 by saying: "Now remember, you have to wait until Frog is all done counting and has told us how many there are before you tell him if he counted OK, or if he made a mistake. Let's try it again." All 15 trials of the puppet task were performed in this manner.

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

Incorrect Counts. Each of the five incorrect counts contained an error that violated the principles underlying counting. The five errors were modeled from prior studies as follows: (a) omitted word – puppet points to one of the objects without labeling it with a number word; (b) skipped object – puppet neither points to nor labels one of the objects; (c) extra word – puppet points to one of the objects once while labeling it with two consecutive number words; (d) double count – puppet points to one of the objects twice and labels it with a number word each time; and (e) incorrect cardinal value - puppet follows an otherwise correct count by reporting a cardinal value that is one more than the correct cardinal value.

Unusual But Correct Counts. None of the five "unusual but correct" counts violated the principles underlying counting (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 counts every other object during his first pass through the array and then comes back to the beginning and counts the remaining objects; (b) double point – puppet points to each object twice, but counts each object only once during the count; (c) start in the middle – puppet starts counting in the middle of the array, counting left to right until he reaches the end and then goes to the beginning and counts the remaining objects; (d) middle to end – puppet starts counting from the middle of the array outward toward the ends of the array; (e) end to middle – puppet starts by counting the first and last objects, counting inward towards the middle of the array.

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

Give a Number Task This task was adapted from Wynn (1990) and LeCorre et al. (2006). 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? [pause for child to respond] 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 a number of objects, the puppet said, "Thanks." The experimenter then asked the child "Does Monkey have *n*?" If the child agreed that the puppet had the correct number, then the next trial began. If the child disagreed that the puppet had the correct number, 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*?"

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 of objects, they were asked to give the next consecutive number (*n* + 1). If children gave the incorrect number of objects, 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
All children completed the puppet counting task followed by the give-a-number task. The only factor that varied between children was the type of objects being counted. Children were randomly assigned to one of four object types in a 2 (perceptually rich or not) x 2 (established knowledge or not) factorial design. Thus, the four conditions were: neither perceptually rich nor established knowledge, perceptually rich only, established knowledge only, and both. We used two different sets of objects within each condition to reduce the likelihood that the findings could be attributed to any one set of objects. To maximize external validity, we only used objects that could be purchased from teaching supply stores.

Neither perceptually rich nor established knowledge The objects for this condition needed to be both relatively bland in terms of their appearance, and not typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) solid colored plastic disks and (b) solid colored wooden pegs. The 2" plastic disks were blue, green, or yellow. The 2" x 1/8" pegs were blue, green, or yellow. Children's teachers confirmed that they did not have objects like these in the classroom or play areas.

Established knowledge The objects for this condition needed to be relatively bland in terms of their appearance and typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) popsicle sticks and (b) colored pencils. The 4 1/2" x 3/8" popsicle sticks were dipped in blue, green, or red Kool-Aid to mimic the look of real popsicle sticks. The 6" x 1/4" pencils were blue, green, or red. Children's teachers confirmed that children often used colored pencils in the classroom for drawing and coloring, and we took for granted that preschool children have experience with popsicles.

Perceptually rich The objects for this condition needed to be perceptually rich in terms of their appearance, but not typically seen or used by preschool children. We found two sets of objects that met these criteria: (a) sparkly poms and (b) neon and metallic pinwheels without the stem. The ½" poms were pink, yellow, or purple. The 2" pinwheels were yellow and green, yellow and orange, or green, yellow and red. Children's teachers confirmed that they did not have objects like these in the classroom or play areas.

Both The objects for this condition needed to be both perceptually rich in terms of their appearance, and typical seen or used by preschool children. We found two sets of objects that met these criteria: (a) plastic animals and (b) plastic miniature fruit. The animals were 1 ½" x 3" zebras, 3" x ½" giraffes, and 2" x 1 ¾" tigers. The fruits were 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

On average, children judged 9.06 (SD = 2.23) counts correctly (out of 15) on the puppet counting task. We performed a 2 (perceptually rich or not) x 2 (established knowledge or not) ANOVA with number correct on the puppet counting task as the dependent measure. The analysis revealed a significant interaction between perceptual richness and established knowledge, $F(1, 50)$ = 6.25, p = .02, partial η^2 = .11.
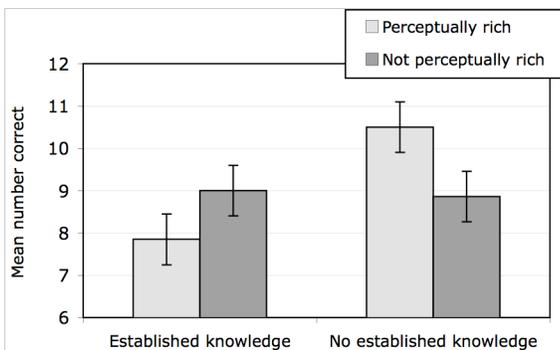

Figure 1. Performance on the Puppet Counting Task by Condition

Consistent with predictions, the effect of perceptual richness on performance depended on children's established knowledge of the objects. When children already had knowledge of the objects (left two bars of Figure 1), their performance was lower when objects were perceptually rich (M = 7.85) than when objects were not perceptually rich (M = 9.00). In contrast, when children did not already have knowledge of the objects (right two bars of Figure 1), children's performance was higher when objects were perceptually rich (M = 10.54) than when objects were not perceptually rich (M = 8.86). The main effect of established knowledge was significant, $F(1, 50)$ = 5.06, p = .03, partial η^2 = .09, and the main effect of perceptual richness was not, p = .64.

Results from the give-a-number task were similar (see Figure 2). On average, children were classified as "four knowers" on the task (M = 4.18, SD = 1.80). We performed a 2 (perceptually rich or not) x 2 (established knowledge or not) ANOVA with number known as the dependent measure. The analysis revealed a significant interaction between perceptual richness and established knowledge, $F(1, 50)$ = 5.43, p = .02, partial η^2 = .10. Neither main effect was significant, both p-values > .50.
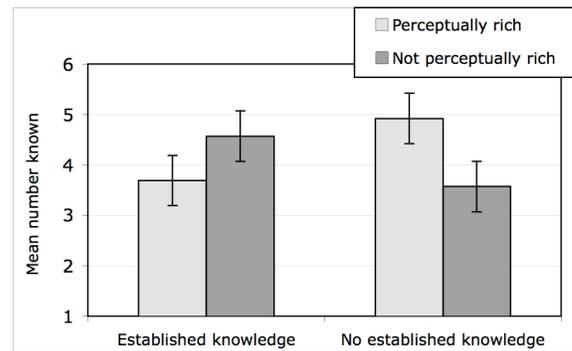

Figure 2. Performance on the Give-A-Number Task by Condition

These results suggest that perceptual richness hinders children's ability to use objects as counters, but only when children already have an established way of thinking about the objects that does not correspond to the meaning intended in the task. In fact, perceptual richness actually seemed to help when children did not already have an established way of thinking about the objects.

Discussion

Teachers' intuitions suggest that perceptually rich objects make good manipulatives because they attract attention and help children stay focused on the task at hand. However, current theories of children's symbolic understanding predict that perceptually rich manipulatives should hinder performance relative to bland manipulatives (e.g., McNeil & Jarvin, 2007; Kaminski et al., 2008; Uttal et al., 1997). The present study provides partial support for both ideas. We found that the effect of perceptual richness could be positive or negative, depending on whether or not children already had established knowledge of the objects. When children did not have established knowledge of the

objects, perceptual richness facilitated performance. However, when children had established knowledge of the objects, perceptual richness hindered performance.

The interaction between perceptual richness and established knowledge 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 their known purpose. As a result, it will be more difficult for children to view the objects in terms of their (new) symbolic meaning 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 no established meaning to the children. Meaning will need to be created in the context of the current task. As a result, it may be easier for children to view the objects in terms of their symbolic meaning (because that is their meaning in the task). These findings suggest that it will be easier for children to interpret objects symbolically when those objects have maximum "bling" and minimum recognizability. However, it remains possible that some types of familiar objects may be useful, such as objects that prompt appropriate inferences about their symbolic meaning.

It is important to note that the difference between one manipulative and another has implications not only for theory, but also for decisions that teachers face each day. When preschool teachers are preparing lessons on counting, they have to choose between animal counters and wooden peg counters. One of our primary goals in the current study 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. However, we acknowledge that this method also has its drawbacks. Specifically, we did not have rigorous control over the perceptual features of the objects we used, nor did we have control over the specific nature of children's previous experience with the objects.

Our next step will be to create our own novel stimuli that vary in terms of perceptual richness and then randomly assign children to receive particular experiences with the objects prior to using them symbolically. This method will allow us to examine systematically how perceptual richness and established knowledge interact to affect children's ability to interpret objects symbolically. For example, we need to pinpoint the types of established knowledge that matter most (e.g., knowledge of a name for the object, knowledge of a function for the object, etc.).

Finally, it is important to note that the current study examined the effects of different types of manipulatives on children's counting *performance*. Results may or may not generalize to *learning*. It is possible that perceptually rich objects make poor learning tools regardless of children's established knowledge of the objects because they may discourage transfer (Kaminski et al., 2008). Nevertheless, the current study makes an important contribution to our understanding of how children interpret symbolic objects. By identifying task factors that help and hinder children's ability to interpret objects as symbols, 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 as symbols in the classroom each day.

Acknowledgments

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