HOW DOES THE REPRESENTATIONAL STATUS OF TO-BE-COUNTED OBJECTS AFFECT CHILDREN’S UNDERSTANDING OF CARDINALITY?

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Abstract

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When counting, the final word used to tag the final item in a set represents the cardinality, or total number, of the set. Understanding of this concept serves as a foundation for children’s basic mathematical skills, such as arithmetic. However, little is known about how variations in the early learning environment affect children’s understanding of this important concept. The current study examined the effects of the representational status of to-be-counted items on preschoolers’ understanding of cardinality. Children ($M$ age = 3 years, 6 months) were randomly assigned to receive counting practice with either physical objects or pictures over five practice sessions. Children’s counting skill and understanding of cardinality were assessed at pretest and posttest. Results revealed that only children in the picture condition increased their understanding of cardinality from pretest to posttest. These findings suggest that small variations in the materials children use during counting practice can affect what they learn from that practice. Specifically, results suggest that picture books are better than physical objects at supporting children’s understanding of cardinality.
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CHAPTER 1:
INTRODUCTION

In touring any local teaching supply store, one can see that teachers are given a wide variety of materials from which to choose. Preschool teachers can use books featuring stories and poems about the number “three” or activity books featuring connect-the-dots to teach their students to count. Teachers can also choose from board games, flashcards, and two- or three-dimensional materials. With such a variety available to them, how can teachers choose which learning materials to bring into their classrooms? Unfortunately, research on this point has been mixed. Some research suggests that children learn best with materials that highlight their representational status (e.g., pictures), whereas other research suggests that children learn best with materials that are the most interactive (i.e., objects that children can manipulate). This study will investigate which materials are most effective – more representational pictures versus more interactive objects – in the context of preschoolers learning how to count.

1.1 Development of counting knowledge

Learning to count is a difficult process that spans throughout children’s earliest years of life: from two years to eight years (Geary, 1994; Fuson, 1988). Most researchers agree that counting understanding begins as part of a memorized routine (Bialystok & Codd, 1997; Briars & Siegler, 1984; Frye et al., 1989; Fuson, 1988; Geary, 1994; Le Corre & Carey, 2008; Sarnecka & Carey, 2008; Wynn, 1990). Children’s counting
behavior has been taken as evidence for this claim. For example, young children have difficulty counting when they are asked to start from a count word that is not at the beginning of their count list, or when they are interrupted during the recitation of their count list (Frye et al., 1989). Previous research suggests that children first start learning their count list around 2 years of age, but that their earliest count list may include idiosyncratic counting (e.g., consistently counting “one,” “two,” “ten”), or (rarely) letters from the alphabet (Fuson, 1988; Gelman & Gallistel, 1978). By the age of three, however, most children reserve number words for their counting (Fuson, 1988).

Research suggests that it is from a great deal of practice of the counting routine that children appear to abstract the principles that define correct counting (Bialystok & Codd, 1997; Briars & Siegler, 1984; Fuson, 1988; Wynn, 1990). Gelman and Gallistel outlined the three “how to count” principles in their 1978 book. First, they identified the “one-one” principle, which is the understanding that only one count word can be applied to one object during a count. Second, they identified the “stable-order” principle, which is the understanding that the order of the count words used to tag items in a count must be used consistently. Finally, they identified the cardinal principle, which is the understanding that the final count word used to tag the final item in the count represents the number of items in the set. Development of the counting principles is important because it allows children to understand counting as more than a meaningless activity—as a process to determine the cardinality of a set. The counting principles also guide children to count correctly (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990).

Research suggests that it may take a year or more from children’s earliest recitation of the counting list before they develop understanding of the cardinal principle
Le Corre, et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990). Wynn’s (1990, 1992) research suggests that children go through a series of stages in their development of the understanding of the cardinal principle. Le Corre and colleagues (2006) have referred to children in the stages before acquisition of the cardinal principle as “subset knowers.” This is because children who are subset knowers slowly (with several months between each stage) show understanding of a subset of the words in their count list. Wynn’s Give-a-number task has been used to showcase this development. In this task, children are typically asked to give a puppet a number of objects, typically ranging from 1-6. Children are credited as a “knower” of the highest number of objects that they can correctly produce. Wynn’s research has shown that children can typically be classified as a “one-knower, a “two-knower, a “three-knower, and some studies have found “four-knowers (Le Corre et al., 2006). For example, a child who is a “one-knower on Wynn’s task will consistently give the puppet one object when asked for “one.” When asked for “two” or more objects, children will provide a seemingly random number of objects, but never one.

It is after passing through the stage of “four-knower that children’s performance on the Give-a-number task, or their understanding of counting in general, experiences a radical change. This is when children become what Le Corre and colleagues (2006) call cardinal principle (or CP) knowers. Whereas subset knowers slowly came to understand the numbers “one,” “two,” “three,” and “four,” CP-knowers, in contrast, seemingly all at once develop understanding of any numeral in their count list (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990, 1992). It is not until about 3 ½ to 4 years of age that children usually reach the stage of CP-knower (Sarnecka & Gelman, 2004; Wynn,
The understanding of a CP-knower appears to differ radically than that of a subset knower.

For example, subset knowers cannot do many of the things that CP-knowers can do. As stated before, subset knowers only understand the meaning of a subset of the count words in their count list. Additionally, they do not seem to understand that they can use counting to determine cardinality. For example, in response to a request for set size (e.g., “How many apples are there?”), a child may always respond with the number “4.” Subset knowers also consistently violate the rules defined by the counting principles. For example, a child may apply multiple count word tags to a single item during a count. Thus, these children cannot detect and correct errors in others’ or their own counts (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990, 1992).

CP-knowers, in contrast, can correctly produce their own counts, and they can detect and correct errors in others’ counts (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990). Importantly, cardinality is associated with the ability to connect higher number words (i.e., numbers beyond the 1-3 range) with magnitudes. Indeed, this ability is something that undergoes further development even after induction of the cardinal principle (Le Corre & Carey, 2007; Mix, 2012; Sarnecka et al., 2007).

Even after children become CP-knowers on the Give-a-number task, Geary (1994) suggests that children still exhibit difficulties understanding cardinality into early elementary school. He suggests that counting performance is inconsistent and influenced by perceptual cues that are unrelated to number (e.g., a child may not consider a set that is comprised of heterogeneous categories, such as a dog, a ball, and a cup countable). Indeed, development of an understanding of cardinality is gradual. Children appear to
succeed on counting tasks with smaller numerosities before they can succeed with larger numerosities. Additionally, children appear to succeed on counting tasks with homogeneous sets before they can successfully count heterogeneous sets (Mix, 1999; Mix, Huttenlocher, & Levine, 1996, 2002; Mix, Sandhofer, & Baroody, 2005; Siegel, 1994).

It is unfortunate that children’s understanding of cardinality is so slow to develop because research suggests that children’s understanding of cardinality serves as a foundation for other basic mathematical skills, such as arithmetic (Aunio & Niemivirta, 2010; Carpenter & Moser, 1984; Levine et al., 2010; Siegler & Shrager, 1984; Stock et al., 2009). According to the National Council of Teachers of Mathematics (NCTM, 2002), teaching young children to “count with understanding and recognize ‘how many’ in sets of objects” is one of the earliest ways to get them on the path toward developing a good number sense. This is not surprising given that children need to have an adequate understanding of “five,” for example, before they can understand the rules for and consequences of performing various operations on it. Given the foundational role of children’s understanding of cardinality in their future mathematics achievement, it is surprising that little research has examined how variations in the learning environment affect children’s understanding of cardinality.

The assumption seems to be that the learning environment matters, as preschool teachers and curricula focus on teaching cardinality. Many early childhood curricula focus on teaching children to count through play, which the National Council of Teachers of Mathematics suggests is “children’s work” (NCTM, 2000). The Big Math for Little Kids curriculum also recommends the use of play to help children learn the count names...
in their count list (Greenes et al., 2004). This particular curriculum details lessons in which children contort their faces to help them learn the “yucky teens” and to contort their bodies to learn the “twisty twenties.” Finally, the Building Blocks curriculum recommends the use of well-planned play with structured materials to teach children to count (Sarama & Clements, 2009). These curricula all advise specific counting instruction under the premise that certain environmental input about cardinality is better than others.

Some research has investigated whether variations in the learning environment may account for individual differences in knowledge of cardinality (Gunderson & Levine, 2011; Levine et al., 2010; Mix, 2012; Ramscar et al., 2011). For example, Levine and colleagues (Gunderson & Levine, 2011; Levine et al., 2010) have looked into the math-related talk that children hear at home. They found that the math talk parents use when children are 14- to 30-months of age – both in terms of overall quantity and quality – predicts children’s understanding of cardinality at 46-months of age. They looked at the types of math talk parents produce. They found that by the time children are 30-months of age, their parents’ math talk is dominated by talk about cardinality. Although parents tend to talk about cardinality when they talk about math, there are differences in terms of how much parents talk about cardinality, and those differences are related to children’s understanding of cardinality at 46-months (Levine et al., 2010). In another study, the same research group found that math talk in which parents specifically label or count “large” number sets of 4-10 visible objects for their children is related to their children’s knowledge of cardinality, whereas other math talk (e.g., labeling an Arabic numeral for
the child) is not similarly related. Importantly, in all of these studies, parents’ math talk has predicted their children’s understanding of cardinality even after controlling for SES.

Mix (2012) has provided experimental evidence that variations in children’s learning environment do influence children’s learning of cardinality. Specifically, she showed that counting practice in which the cardinality of the set is labeled first and then counted is more effective than other types of counting practice at promoting conceptual understanding of cardinality. In her study, she randomly assigned preschoolers to one of five different counting interventions. In the ideal condition, children both counted and labeled sets of objects on each page of a counting book. In a second condition, children counted sets of objects on some pages, and labeled sets of objects on other pages, but never performed both of these actions on any page of a counting book. In a third condition, children only counted sets of objects on each page of a counting book. In a fourth condition, children only labeled sets of objects on each page of a counting book. Finally, in the control condition, children received no counting experience with a counting book. Instead, they learned about the set of objects on all pages of a counting book. For example, if children were shown a page of images of crackers, the tutor would say: “These are crackers! Crackers are yummy!”

Children in all conditions received six sessions of one-on-one counting practice with an adult using counting books. Children’s counting knowledge was tested before they received counting practice, during the counting practice, and immediately after counting practice. Results showed that only the ideal intervention in which the cardinality of the set was labeled first and then counted led to improvements in understanding of cardinality. Moreover, this type of practice improved understanding after only three
practice sessions (during the midtest), whereas practice in the four other interventions did not lead to increases in understanding of cardinality even after six practice sessions (during the posttest).

In another experimental test of variations in environmental input on children’s understanding of cardinality, Ramscar and colleagues (2011) analyzed the effect of labeling a set before presenting it. In their study, they gave 30- to 40-month-old children a pretest to assess their understanding of the numbers 2-7. Children were asked to identify a set of objects based on its numerosity. Each trial had three sets of the same type of object (e.g., four hearts, two hearts, and six hearts). On half the trials, children received instruction in which the numerosity of the set preceded the category of the set (e.g., “Look! Can you show me four hearts?”), and on the other half of the trials, children received instruction in which the numerosity of the set followed the category of the set (e.g., “Look! Hearts. Can you show me four?”).

Children then received training on the numbers 2, 4, and 6 in succession from small to large using familiar items. Children were shown 18 slides with sets of items (e.g., 2 bears) and were provided with labels for these sets. The way the sets were labeled depended on condition. Half of the children saw the set first and then heard it labeled (e.g., “What can you see? There are two balls.”). For the rest of the children, the sets were labeled first and then shown to the children (e.g., “What can you see? Balls. There are two.”). Following training, children received a posttest that was identical to the pretest. They found that children who heard the set labeled first performed significantly better at posttest than did children who saw the set before it was labeled.
Both Mix (2012) and Ramscar et al. (2011) strongly suggest that variations in the learning environment are important for children’s understanding of cardinality. However, these studies are the only ones to date to experimentally investigate the relation between early learning environment and counting. The goal of my dissertation was to further investigate how variations in children’s early learning environment influence children’s understanding of cardinality. Given the lack of research on this topic, there are many different variations in the learning environment that could be considered. For example, one could examine whether the source of the correct count matters. In other words, do children learn better from watching a parent, a teacher, a peer, or a character on television count? One could also examine whether the target of the correct count matters. In other words, is it more beneficial to count some entities rather than others? This is the question I addressed in my dissertation: I examined whether the objects children count affect their understanding of cardinality. I focused specifically on the role of the representational status of the counted entities.

1.2 Representational status

Children do not always understand the connection between the materials their instructors use and the conceptual knowledge those materials are intended to represent. DeLoache, Uttal, and colleagues (Uttal et al., 1998) have identified several factors that affect a child’s understanding of this connection. They have studied this question using the scale model task. Generally, the task involves the child watching an experimenter hide a small toy in a scale model of a larger room behind toy furniture in the model. The goal is for the child to use the information from the scale model to help them locate the
corresponding larger toy in the larger room. Once children reach the age of 3, they usually succeed on the standard form of this task.

One factor that DeLoache and colleagues have identified as important in young children’s ability to correctly perform this task is how transparent the scale model is as a representation. They suggest that the scale model, like all objects that must be used symbolically, is both a representation of something else (the large room), and is an object in its own right. Young children have difficulty appreciating this dual nature of symbolic objects. According to the dual representation hypothesis, the more interesting an object is as an object in its own right, the more difficult it is for children to think of it as a symbol of something else (DeLoache, 2000; Uttal et al., 1997). DeLoache and colleagues have tested this hypothesis using several versions of their scale model task.

One way DeLoache and colleagues have tested their hypothesis is by examining performance on the scale model task after the model has been made more interesting as an object itself. The rationale was that if the scale model was made more interesting as a thing in its own right experimentally, children would be more likely to fail on the scale model task. To make the model more interesting as an object, the experimenters allowed 3-year-olds to play with the scale model (or not) for five minutes before they used it for the scale model task (DeLoache, 2000). Children who played with the model beforehand were less likely to succeed on the scale model task than children who did not play with the scale model before using it for the task. Playing with the scale model made the model more interesting as an object itself and more difficult for children to use it to locate a corresponding object.
Another way that DeLoache and colleagues have tested their hypothesis is by making the scale model less interesting as an object itself. The rationale behind this approach is that if the scale model is less interesting as an object in its own right, children will have a lesser chance of becoming distracted by its object properties, and become better able to see it as a representation of something else. To make the scale model less interesting as an object, experimenters placed the scale model behind a window as they showed 2.5-year-olds where the miniature object was placed in the model. Children who participated in this version of the scale model task, in comparison to the standard task, were more likely to succeed on it (DeLoache, 2000). Thus, making the scale model less interesting as an object in its own right makes it easier for children to use it to locate a corresponding object in a larger room.

Some symbols, such as pictures, are inherently less interesting as objects in their own right than are other symbols (DeLoache, 1991). According to the dual representation hypothesis, children should be more likely to succeed on the scale model task when they use these less interesting objects to locate the hidden toy than when they have to use the scale model. Indeed, DeLoache (1991) found that although 2.5-year-old children typically fail on the standard scale model task, they typically succeed on the scale model task when they are shown pictures of the furniture where the toy has been hidden behind, as opposed to using a scale model to obtain this information. Thus, pictures, which are inherently less interesting than physical objects as objects in their own right, are more easily understood as representations of something else.

Taken together, the findings by DeLoache and colleagues highlight the fact that symbols vary in terms of how readily they serve as a representation of something else.
Objects that are especially interesting are inherently less representational than objects that are less interesting because they are much more difficult for children to ignore as objects in their own right. Gelman and colleagues (2005) have referred to this property of symbols as representational status. Representational status is ease with which an object can stand in for or represent something else. Objects that are less interesting in their own right have higher representational status, whereas objects that are more interesting in their own right have lower representational status. Treating an object in a way that draws attention to it, such as allowing children to play with a scale model before performing the scale model task, decreases the representational status of it. In contrast, treating an object in a way that takes attention away from it, such as placing the scale model behind a window or depicting the scale model in pictures, increases its representational status. Factors that affect an object’s representational status affect how well the child will understand it symbolically.

1.3 Current study

In my study, I examined whether the representational status of the entities used to teach children to count affected children’s understanding of cardinality. Specifically, I tested whether it is better for children to learn to count with picture books versus physical objects. As mentioned, DeLoache’s (1991) research suggests that pictures have higher representational status than objects because they are less interesting as objects in their own right. I chose to focus on this particular topic for several reasons. First, my previous research has shown that the objects that children use to count affect their performance on counting tasks (Petersen & McNeil, 2012). Second, the concreteness of instructional materials is an important and unresolved debate in cognitive development and education.
research. For example, a recent issue of Child Development Perspectives outlined the viewpoints of several authors debating the benefits of concreteness or abstraction and the contexts with which they are best used (Brown, McNeil, & Glenberg, 2009; Kaminski, Sloutsky & Heckler, 2009; Martin, 2009; McNeil & Uttal, 2009; Sarama & Clements, 2009; Uttal et al., 2009). Third, it is not intuitively obvious which materials teachers and parents should use when teaching children to count. Mix used picture books in her study, and a lot of parents and teachers use picture books. At the same time, when children spontaneously count, it tends to be objects – they count their toys, the number of jumps they take etc. (Saxe et al., 1987). Moreover, teachers tend to predict that more interactive objects would be better to use in a lesson on counting (Petersen & McNeil, 2012).

1.3.1 Benefits of pictures

Pictures might be better than objects for practicing counting because of their higher representational status. As mentioned above, pictures are inherently less interesting as objects themselves than are physical objects because of their two-dimensionality. They do not vary greatly in texture or functionality. Children can do little more with a picture than simply point at it. One piece of evidence for the high representational status of pictures is that children can succeed on some representational tasks, like the scale model task, using pictures before they can succeed on those tasks using objects (DeLoache, 1991). Another piece of evidence is that children start treating pictures representationally from a very young age. Although 9-month-old infants try to pinch and slap the things depicted in pictures, 19-month-old infants point at them and begin treating them as “objects of contemplation and communication, not action” (DeLoache et al., 1998, p. 209). Young children also use pictures as a medium in which
they can obtain information. By 18-months, infants are already able to extend the name of a novel object they learned about in a picture to its real-world referent (Ganea et al., 2008; Preissler & Carey, 2004). Children at this age are also able to reenact a novel action sequence they learned from a picture book using actual objects (Simcock & DeLoache, 2006).

There are at least two reasons why the high representational status of pictures might make them particularly well suited for practicing counting. First, by definition, objects with high representational status are less distracting than objects with low representational status. According to the dual representation account, anything that draws children’s attention to the objects themselves distracts children, and makes it more difficult for children to think about the objects representationally (DeLoache, 2000; Uttal et al., 1997). For example, allowing children to play with the scale model before participating in the scale model task makes the scale model more interesting to children as a thing in its own right, and less transparent as a representation (DeLoache, 2000).

Similarly, Sloutsky, Kaminski, and Heckler (2005) also warn against using interesting, or perceptually detailed objects when teaching children mathematical concepts. They suggest that the superficial features of such materials distract children from understanding the information that educators intend to explain because they compete with the relational structure of the mathematics task. For example, Kaminski and Sloutsky (2009) found that kindergarteners who were trained on the concept of common proportion using perceptually detailed objects (proportions of sprinkled cupcakes out of total cupcakes) were less likely to correctly solve transfer problems of common proportion using novel objects (e.g., matching proportion of bears with flags out of total
bears) than kindergarteners who were trained using bland materials (black circles out of total circles). In summary, objects that have higher representational status are better objects to teach children mathematical concepts, such as cardinality, because they are less distracting. Consequently, children will be more likely to focus on the objects in terms of their purpose in the mathematics task, and less likely to focus on them as objects in their own right. Additionally, children will be more likely to focus on the information that educators intend to explain in their lesson.

Second, by preschool, children tend to think about objects depicted in pictures in terms of their “kinds” or category memberships. Gelman and colleagues (2005) found that children were more likely to talk about objects as representations of a larger category when they were presented in pictures versus as the physical objects themselves. They measured the way in which preschoolers and their parents talked about objects that were either free or depicted in a picture. They found that children and their parents talked about free objects more as individuals (e.g., saying phrases such as “Lassie likes to run!” in response to a toy dog). When those same objects were depicted in pictures, however, children and their parents were more likely to talk about the objects in terms of “kinds” (e.g., saying phrases like “Dogs are furry” in response to a picture of a toy dog). Gelman and colleagues argue that because the representational status of pictures is higher than that of objects, children are more likely to think about and treat pictured things as a category, or group of things. Thus, pictures might be especially useful learning materials in situations where it is necessary for children to appreciate the depicted objects as a set.

Because objects depicted in pictures are better understood as members of a group, picture books might be an especially good way for children to learn about the cardinality
of a set. Mix and others’ research suggests that children display a better understanding of cardinality when they can appreciate to-be-counted items as a set of countable things (Mix, 1999; Mix, Huttenlocher, & Levine, 1996, 2002; Mix, Sandhofer, & Baroody, 2005; Siegel, 1974). Ramscar et al.’s (2011) previously discussed finding that drawing attention to the set by labeling it first benefits children’s understanding of cardinality is also evidence for this point. As children gain experience counting, recitation of the count list becomes increasingly associated with set size. Cues that draw attention to the set help children relate their count list to set size. Thus, children who are learning how to count will show better understanding of cardinality when they can appreciate to-be-counted items as members of a set of countable things. According to these ideas, children should construct a better understanding of cardinality when they count objects in picture books than when they count the objects themselves because pictures are more representational and should increase children’s attention to the set, which is important for children’s understanding of cardinality.

In summary, pictures have higher representational status than objects. Because of their higher representational status, pictures have at least two characteristics that make them well suited for counting practice. One benefit of pictures is that they are less distracting than objects, and thus should help children to focus on the lesson at hand and the mathematical information the objects are intended to convey. A second benefit of pictures is that children tend to think of the things depicted in them in terms of “kinds,” which may help children to focus on the set they are counting. Because of these benefits of pictures, I predicted that children who practiced counting using picture books would
develop a better understanding of the concept of cardinality than children who practiced counting with physical objects.

1.3.2 Benefits of objects

Although there is strong theoretical rationale for predicting that counting with picture books will be better than counting with actual objects, there are also some theoretical reasons to predict that learning to count with physical objects might lead to better counting skill. One reason is that objects might simply be more engaging and motivating than pictures, and may thus help children to stay engaged in a given task. A second reason is that objects are more interactive than pictures in general. Being able to touch and manipulate objects is important in a learning context because previous research has shown that it benefits children’s comprehension and memory, even when children simply watch this action or perform the actions on computerized objects (Glenberg et al., 2004; Glenberg et al., 2007; Glenberg et al., 2011; Marley et al., 2007; Marley et al., 2010; Marley et al., 2011; Marley & Szabo, 2010; Manches et al., 2010).

It is important to note that research does not necessarily support the idea of action on learning materials for the sake of moving objects. As theorized by Martin and Schwartz’ (2005) Physically Distributed Learning theory, the benefits of action on children’s learning and comprehension depend on the child’s current understanding of the concept and the structure of the learning environment. They suggest that action allows children to come up with and test ideas about how the concept they are learning works. In the context of counting, although children may not fully understand the concept that the last number they count represents the total number of the set they are counting, they do slowly come to know the quantities “one,” “two,” and “three.” While a child is counting
four apples, she may decide to move the apples she’s already counted to a different spot
than the objects she has yet to count. By performing the same actions that she knows will
give her “three” apples to “four,” (e.g., counting 1-2-3 and moving those objects as she
counts them) she may discover that when she counts “four” she also has four objects. She
may then extend this discovery to other numbers in her count list. The child’s firm
understanding of “three,” gives meaning to the actions she is performing on them.
Without this previous understanding, the movements may have no benefit. Furthermore,
the structure of the environment, or the movements that are made, is important. Although
being able to move the apples into separate locations following counting of them may
lead to new understanding, tossing the objects off the table while counting aloud may not
similarly lead to new understanding. These specific actions she performs on the objects
in turn give her understanding of “4.” Martin and Schwartz (2005) thus consider the
benefits of action and learning to be iterative.

Alibali and DiRusso (1999) have found evidence that certain actions are
beneficial in the domain of counting. They found that touching an object while counting
helped children to be more effective counters. Touching was beneficial for children’s
counting skill even when they watched a puppet touch the items during a count. Objects
that are more touchable may help children to better individuate objects in a set into
groups of counted and to-be-counted objects, thus helping children to implement one-to-
one correspondence.

1.3.3 Hypothesis

I hypothesized that children who practiced counting with picture books would
develop a better understanding of cardinality than would children who practiced counting
with objects. I tested my hypothesis with preschoolers who practiced counting using picture books or objects. My study design was based on the intervention that Mix (2012) found to be the most effective in her study. First, children completed three pretest measures: one to assess their counting skill and two to assess their understanding of cardinality. The first cardinality measure was the Give-a-number task (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990). It is the gold standard measure of children’s understanding of cardinality. However, it uses objects as the to-be-counted stimuli, which may unfairly bias the results toward the object condition, so I also included the “What’s on this Card?” task (Gelman, 1993; Le Corre et al., 2006), which is a more recently developed measure that uses pictures as the to-be counted stimuli. The to-be-counted stimuli in the measure of counting skill were intermediate between objects and pictures—flat disks pasted on cardboard. After the pretest, children received five scripted sessions of counting practice in which a tutor modeled correct counting and provided children with feedback when they made errors. Immediately after the final session, children completed a posttest that was similar to the pretest. Finally, one-week later children completed a delayed posttest.
2.1 Participants

The study was conducted at childcare centers located on two college campuses in the Midwestern United States. Tuition at the childcare centers is based on a sliding scale, and 30% of children receive some form of reduced tuition. Fifty-seven children participated in this study. Five children dropped out of the study because they were no longer interested in participating. Two of these children participated in one session; two children participated in two sessions; and one child participated in three sessions. One child participated in all sessions, but did not actually engage in any of the tasks. Thus, the final sample contained 51 children who completed the pretest and five practice sessions.

Of these 51 children, an additional 12 (4 picture, 8 object) did not have complete data for one or more of the pre-post measures because of refusal to participate (3 picture, 3 object), uncodable performance (4 object), or experimenter error (1 picture, 1 object). An additional 8 children would have had to be excluded if delayed posttest were also taken into account because of absence (3 picture, 1 object) or incomplete data for one or more measures (3 picture, 1 object). That would have taken the sample size down to only 31 participants. An a priori power analysis indicated that I would need a total sample size of 54 to detect the predicted interaction assuming a small-to-medium effect ($f = 0.175$) at $1-\beta = 0.8$ (Faul, Erdfelder, Buchner, & Lang, 2009). Thus, to maximize power, I focused
the analyses on the participants who had complete pre-intervention-post data. This sample contained 39 children (25 girls, 14 boys; M age = 3 years, 6 months; 81% White, 12% Asian, 4% Black or African American, 4% Hispanic or Latino).

2.2 Design

The design was a pretest-intervention-posttest design. Children were randomly assigned to one of two counting interventions: the picture intervention or the object intervention. They completed one measure to assess their counting skill and two measures to assess their understanding of cardinality immediately before and after receiving the intervention.

2.3 Measures

2.3.1 Give-a-number

This task was administered because it is the standard measure of understanding of cardinality used by most researchers. It was a modified version of the task (Le Corre et al., 2006; Sarnecka & Carey, 2008; Wynn, 1990). Children received a pile of 15 disks, 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 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 always were 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 gave correctly twice.

2.3.2 “What’s on this card?”

This task was also administered to assess children’s understanding of cardinality. I included it because it uses pictures as the to-be-counted stimuli instead of the physical objects used in the Give-a-number task. It was important to include one measure that used pictures and one measure that used objects to ensure that our assessment of children’s understanding of cardinality would not be biased toward one intervention condition versus the other. The “What’s on this card?” task has been used in two previous studies (Gelman, 1993; Le Corre & Carey, 2007). Children were shown three decks of cards with homogeneous sets of 1-8 stickers placed on them in one row. The cards in
each deck featured one sticker type (e.g., one deck features cards with apples). The sticker types were apples, trains, and stars.

The first card of each deck featured one sticker. The experimenter showed the first card of each deck and said: “What’s on this card?” The experimenter modeled the first card of each deck by saying: “That’s right, that’s one X,” where X is a descriptor of the stickers on the card (e.g., apple) after the child’s response regardless of what they said. The experimenter never counted to model the task. Modeling only occurred on the first trial of each deck. For the rest of the cards, the experimenter only asked: “What’s on this card?”

For each deck, the first card always featured one sticker. Second were cards featuring two or three stickers (in a random order). Next were cards featuring four or five stickers (in a random order). Last were cards featuring six, seven, or eight stickers (in a random order).

Three trials per each deck were “probe trials.” On these trials, children were asked by the experimenter “Can you show me?” to elicit a count response if they failed to count and only gave a cardinal response (e.g., the child says “Two apples!”). If children counted but failed to give a cardinal response, they were asked, “So, what’s on this card?”

2.3.3 Count disks

This task was used to assess children’s counting skill. It was a modified version of the task used in Mix (2012). Children were shown 20 one-inch disks affixed on poster board in a line and spaced one-inch apart. The disks alternated in color to help children keep track of their count. The experimenter pointed to the leftmost disk and asked the
children to count all the disks starting there. The largest number children reached without a tagging error was considered their highest count. Because tagging errors are common in this age range, I allowed one tagging error before I determined the highest count, as Mix (2012) did in her study. For example, if a child counted “1-2-3-4-5-6-7-8-9” but double-counted the sixth and seventh disks (i.e., say “6-7” while pointing to the sixth disk and “8-9” while pointing to the seventh disk), the first error was ignored but the second determined the cut-off, resulting in a highest count of 7. The task ended once children indicated they were finished counting.

2.4 Counting interventions

2.4.1 Picture intervention

Children participated in five sessions during the pretest-intervention-posttest portion of the study. In the first session, children completed the pretest followed by their first counting session with modeling and feedback provided by the experimenter. The next three sessions (sessions 2, 3, and 4) were purely counting practice sessions with modeling and feedback provided by the experimenter. In the fifth session, children first completed their final counting session with modeling and feedback provided by the experimenter and then completed the posttest.

All children in the picture intervention used counting “books” during their counting practice. These books were three-ring binders with pictures of one to nine objects on each page. These objects came from three categories: animals, vehicles, and food. The three types of animals were: elephants, lions, and hippos. The three types of vehicles were: boats, planes, and buses. The three types of foods were: strawberries,
carrots, and bananas (see Figure 9). During practice-only sessions, children viewed one entire picture book that contained two different pages for each of the quantities one through nine (i.e., 18 pages total). During practice-and-testing sessions, children viewed one entire picture book that contained one page for each of the quantities one through nine (i.e., 9 pages total). Thus, counting practice during practice-only sessions was twice as long as that during practice-and-testing sessions.

The training procedure was based on the intervention that Mix (2012) found was most effective for promoting children’s understanding of cardinality. On each page of the picture books, the experimenter first labeled the set’s quantity (e.g., “Look, this page has three cars. Can you say it with me? Three cars.”). Next, the experimenter immediately counted the same set (e.g., “Let’s count them 1, 2, 3!”). Children then were asked to count and label the items. They were told: “Now it’s your turn. How many cars are there?” They were asked to point to each object as they labeled it with a number name. Children were given feedback on both their counting and labeling of the set. For example, if a child correctly labeled the set, but counted incorrectly, the experimenter demonstrated the correct count (e.g., “Right, there are three cars, but watch: 1, 2, 3.”). If a child labeled the set without counting, the experimenter requested the counting procedure (e.g., “Right! Three cars. Can you count them?”). If a child counted the objects without labeling the set, the experimenter requested a label (e.g., “Right! 1, 2, 3. So, how many are there?”). If the child failed to point to the objects, the experimenter reminded them to point to each object (e.g., “Right! 1, 2, 3. Can you point to them like this: 1 [point], 2 [point], 3 [point]?”).
2.4.2 Object intervention

The object intervention was identical to the picture intervention in all ways except training materials. Children in the object intervention used the real, plastic versions of the objects depicted in the books in the picture intervention. Instead of counting two-dimensional pictures of objects in books, children in the object intervention counted three-dimensional plastic objects that were placed on a white work mat. As in the picture intervention, the to-be-counted items were presented simultaneously. As the experimenter set up the objects in the same orientation and position as they were depicted in the picture books, she hid the objects with a piece of cardboard. Once the objects were placed, she moved the cardboard so the child could see all objects presented simultaneously.

Children in the object intervention received the same number of sessions and trials, received training and testing in the same order, were given the same practice procedure, and counted the same kinds of things; however, they counted objects instead of pictures of those objects.

2.5 Procedure

Children participated in five sessions during the pretest-intervention-posttest portion of the study. The pretest immediately preceded the first intervention session. The posttest immediately followed the fifth intervention session. During the pretest and posttest, children completed the two measures to assess their understanding of cardinality and one measure to assess their counting skill (described above). Children did not receive feedback on any of the measures. Children were randomly assigned to one of two training interventions (picture or object) in which they received training once a week for five weeks. Each child was trained and tested individually.
3.1 Performance during counting practice sessions

I analyzed the errors children made during the counting practice sessions. Children could make two types of errors on each trial: counting errors and set errors. For each session, I added all of children’s counting errors and set errors and divided that number by the total number of trials that children performed during that session. To test whether children made fewer errors over time, I performed a mixed ANCOVA with time (sessions 1-5) as the within-subjects factor, condition (object or picture) as the between-subjects factor, ratio of total number of errors to total number of trials as the dependent variable, and age as a covariate. Figure 1 presents the ratio of counting errors to total trials performed across sessions for children in each condition. The main effect of time was significant, \( F(4, 136) = 2.6, p = .04, \eta^2 = .07 \), suggesting that children made fewer errors with more practice. The main effect of condition was not significant, \( F(1, 34) = .13, p = .73, \eta^2 = .004 \). The interaction of condition by time was not significant, \( F(4, 136) = .85, p = .5, \eta^2 = .02 \). The main effect of age was significant, \( F(1, 34) = 10.29, p = .003, \eta^2 = .23 \).

I repeated the analysis using all children who participated in counting practice \( (N = 49) \). Mauchly’s Test of Sphericity on the variance-covariance matrix indicated that sphericity could not be assumed, \( X^2(df = 9) = 19.05, p = .03 \), so I multiplied the
numerator and denominator degrees of freedom by the relevant Huynh-Feldt estimates of epsilon (ε = .92) for tests involving the repeated factor. When all children who participated in the counting practice were included, the main effect of time was no longer significant, \( F(3.68, 169.39) = 1.73, p = .15, \eta^2 = .04 \). The main effect of condition was not significant, \( F(1, 46) = .1, p = .75, \eta^2 = .002 \). The interaction of condition by time was not significant, \( F(3.68, 169.39) = .58, p = .67, \eta^2 = .01 \). The main effect of age was significant, \( F(1, 46) = 6.39, p = .02, \eta^2 = .12 \).

3.2 Effect of condition on understanding of cardinality

I hypothesized that the picture condition would be better than the object condition at facilitating children’s understanding of cardinality. Thus, the first set of analyses I will present test the effects of condition on pre-to-post changes in performance on the two measures of understanding of cardinality: Give-a-number task and “What’s on this card?” task.

3.2.1 Give-a-number task

I performed a mixed ANCOVA with time (pretest and posttest) as the within-subjects factor, condition (object or picture) as the between-subjects factor, performance on the Give-a-number task as the dependent variable, and age as the covariate. I included age as a covariate because of the well-established link between age and performance on this task (Wynn, 1990). The main effect of time was not significant, \( F(1, 36) = 2.72, p = .11, \eta^2 = .07 \). The main effect of condition was not significant, \( F(1, 36) = .15, p = .70, \eta^2 = .004 \). Importantly, however, the predicted interaction of condition by time was significant, \( F(1, 36) = 6.38, p = .02, \eta^2 = .15 \). Figure 2 presents the performance on the
Give-a-number task at pretest and posttest for children in each condition. Although children in the object condition on average remained “three-“knowers from pretest to posttest ($N = 18$, $M_{\text{pretest}} = 3.8$, $SD_{\text{pretest}} = .42$, $M_{\text{posttest}} = 3.8$, $SD_{\text{posttest}} = .39$), children in the picture condition increased their understanding of cardinality from the “three-“knower level to the “four-“knower level from pretest to posttest ($N = 21$, $M_{\text{pretest}} = 3.07$, $SD_{\text{pretest}} = .39$, $M_{\text{posttest}} = 4.13$, $SD_{\text{posttest}} = .36$). The main effect of age was significant, with older children performing better than younger children, $F(1, 36) = 14.66$, $p < .001$, $\eta^2 = .29$.

Results were the same when I performed the analysis using all the children who participated in the Give-a-number task at pretest and posttest ($N=43$). The main effect of time was not significant, $F(1, 40) = 1.76$, $p = .19$, $\eta^2 = .04$. The main effect of condition was not significant, $F(1, 40) = .06, p = .81, \eta^2 = .001$. The interaction of condition by time was significant, $F(1, 40) = 5.56, p = .02, \eta^2 = .12$. The main effect of age was significant, $F(1, 40) = 11.72, p = .001, \eta^2 = .23$.

3.2.2 “What’s on this card?” task

I performed a mixed ANCOVA with time (pretest and posttest) as the within-subjects factor, condition (object or picture) as the between-subjects factor, performance on the “What’s on this card?” task as the dependent variable, and age as the covariate. Figure 3 presents the performance on the “What’s on this card?” task at pretest and posttest for children in each condition. The main effect of time was not significant, $F(1, 36) = .007, p = .93, \eta^2 < .001$. The main effect of condition was not significant, $F(1, 36) = 1.64, p = .21, \eta^2 = .04$. In contrast to the Give-a-number task, the predicted interaction of condition by time for the “What’s on this card?” task was not significant, $F(1, 36) = .004,$
The main effect of age was significant, with older children performing better than younger children, $F(1, 36) = 9.3, p = .004, \eta^2 = .21$.

Results were the same when I performed the analysis using all the children who participated in the “What’s on this card?” task at pretest and posttest ($N = 51$). The main effect of time was not significant, $F(1, 48) = .08, p = .79, \eta^2 = .002$. The main effect of condition was not significant, $F(1, 48) = .39, p = .54, \eta^2 = .01$. The interaction of condition by time was not significant, $F(1, 48) = .37, p = .54, \eta^2 = .008$. The main effect of age was significant, $F(1, 48) = 7.71, p = .008, \eta^2 = .14$.

### 3.3 Effect of condition on counting skill

Because the research literature is more mixed in terms of predicting whether counting pictures or physical objects would be more beneficial for children’s counting skill, I did not necessarily expect one condition to be better than the other at facilitating children’s counting skill. To test the effect of condition on counting skill, I performed a mixed ANCOVA with time (pretest and posttest) as the within-subjects factor, condition (object or picture) as the between-subjects factor, performance on the Count disks task as the dependent variable, and age as the covariate. Figure 4 presents the performance on the Count disks task at pretest and posttest for children in each condition. The main effect of time was not significant, $F(1, 36) = 1.7, p = .20, \eta^2 = .05$. The main effect of condition was not significant, $F(1, 36) = 1.83, p = .18, \eta^2 = .05$. The interaction of condition by time was not significant, $F(1, 36) = .11, p = .74, \eta^2 = .003$. The main effect of age was significant, with older children counting better than younger children, $F(1, 36) = 11.19, p = .002, \eta^2 = .24$. 
Results were the same when I performed the analysis using all the children who participated in the Count disks task at pretest and posttest \( (N = 47) \). The main effect of time was not significant, \( F(1, 44) = .32, p = .58, \eta^2 = .007 \). The main effect of condition was not significant, \( F(1, 44) = 1.25, p = .27, \eta^2 = .03 \). The interaction of condition by time was not significant, \( F(1, 44) = .57, p = .46, \eta^2 = .01 \). The main effect of age was significant, \( F(1, 44) = 10.11, p = .003, \eta^2 = .19 \).

3.4 Potential mechanisms

Results revealed some support for my hypothesis that the picture condition better facilitated children’s understanding of cardinality, as measured by the Give-a-number task. Thus, I took a closer look at the data to examine the potential mechanisms involved in this effect.

3.4.1 Does the picture condition encourage attention to set?

I coded children’s performance during the counting practice sessions to see if children in the two conditions differed in terms of the types of responses they made during the sessions. Recall that for each trial, the set was presented, the experimenter labeled the set (e.g., “Look, we have four strawberries. Can you say that with me? Four strawberries.”), and then counted the set (e.g., “1, 2, 3, 4.”). The experimenter then prompted the child to repeat the same process (e.g., “Now it’s your turn, how many strawberries are there?”). It was reasonable for children to make one of three responses following this first prompt: (1) they could count the set (e.g., “1, 2, 3, 4”), (2) they could report the numerosity of the set (e.g., “There are 4.”), or (3) they could do both (e.g., “There are 4. 1, 2, 3, 4.”).
If the picture condition encourages attention to the set, then children should make
more set responses than children in the object condition. Children were coded for what
type of response they made during each trial. Children were coded as making a set
response either if they reported the numerosity of the set, or if they counted and reported
the numerosity of the set as their first response during each trial. Children were coded as
making a counting-only response if they counted as their first response during each trial. I
calculated the ratio of set responses children made out of the total number of trials that
children completed during that session.

First, I analyzed whether age predicted children’s tendency to make a set response
during the counting practice sessions. I performed a linear regression with children’s
tendency to make a set response as the dependent variable, and children’s age as the
predictor. To calculate tendency to make a set response, I added the total number of set
responses a child made during each session and divided that by the total number of trials
that children performed in that session. I then took the average over all the sessions. Age
was not a significant predictor of tendency to make a set response, $b = .25, t(37) = 1.59, p = .12$. I, therefore, did not include it as a covariate in the model.

To test whether children’s tendency to make a set response during the counting
practice sessions changed over time and by condition, I performed a mixed ANOVA with
time (sessions 1-5) as the within-subjects factor, condition (object or picture) as the
between-subjects factor, and tendency to make a set response (total number of set
responses in session/total number of trials performed in session) as the dependent
variable. Mauchly’s Test of Sphericity on the variance-covariance matrix indicated that
sphericity could not be assumed, $X^2(\text{df} = 9) = 51.4, p < .001$, so I multiplied the numerator
and denominator degrees of freedom by the relevant Huynh-Feldt estimates of epsilon ($\varepsilon = .74$) for tests involving the repeated factor. Figure 5 presents the ratio of total set responses to total trials performed across sessions for children in each condition. The main effect of time was not significant, $F(2.96, 106.52) = 1.47, p = .23, \eta^2 = .04$. The main effect of condition was not significant, $F(1, 36) = 1.55, p = .22, \eta^2 = .04$. The interaction of condition by time was not significant, $F(2.96, 106.52) = .15, p = .93, \eta^2 = .004$.

I also tested if children’s tendency to make a set response during the counting practice sessions predicted performance on the Give-a-Number task at posttest. I performed a linear regression with performance on the Give-a-number task at posttest as the dependent variable, and tendency to make a set response (total number of set responses in session/total number of trials performed in session), age, and performance on the Give-a-number task at pretest as the predictors. Children’s tendency to make a set response was not a significant predictor of children’s performance on the Give-a-number task at posttest, $b = -.15, t(35) = -1.31, p = .20$. Age was not a significant predictor of performance on the Give-a-number task at posttest, $b = .06, t(35) = .57, p = .57$. Performance on the Give-a-number task at pretest was a significant predictor of performance on the Give-a-number task at posttest, $b = .76, t(35) = 7.05, p < .001$.

3.4.2 Does the object condition distract children and encourage task-irrelevant behaviors?

As discussed in the introduction, one potential downside to using objects is that they may pull children’s attention to themselves as objects in their own right and away from the task at hand. I had two strategies for examining this hypothesis. First, I coded how distracted children were during the counting practice. Children were coded as
exhibiting an instance of distraction if they mentioned something off-topic in their speech (e.g., “Where is my team going?”), or if they exhibited behaviors that were irrelevant to the counting task (e.g., playing with objects, flipping the pages of the book, getting up and walking around the classroom). Children were not credited with an instance of distraction if they were talking about the task itself but not necessarily counting (e.g., “Why are we using that board?”).

First, I analyzed whether age predicted children’s tendency for distraction during the counting practice sessions. I performed a linear regression with across session average tendency for distraction (total number of distractions in session/total number of possible trials in session) as the dependent variable, and age as the predictor. I calculated tendency for distraction by adding the total number of distractions per session and dividing it by the total number of possible trials per session (i.e., 9 for practice-and-testing sessions, and 18 for practice-only sessions) and taking the average across sessions. Age was not a significant predictor of tendency for distraction, $b = -.25$, $t(37) = -1.57$, $p = .13$. I, therefore, did not include it as a covariate in the model.

Next, I analyzed whether children in the object condition were in fact more distracted during the counting practice sessions than children in the picture condition. To answer this question, I performed a mixed ANOVA with time (sessions 1-5) as the within-subjects factor, condition (object or picture) as the between-subjects factor, and tendency for distraction (total number of distractions in session/total number of possible trials in session) as the dependent variable. Mauchly’s Test of Sphericity on the variance-covariance matrix indicated that sphericity could not be assumed, $X^2 (df = 9) = 43.25$, $p < .001$, so I multiplied the numerator and denominator degrees of freedom by the relevant
Huynh-Feldt estimates of epsilon (\(\varepsilon = .64\)) for tests involving the repeated factor. Figure 6 presents the ratio of total distractions to total trials possible across sessions for children in each condition. The main effect of time was not significant, \(F(2.57, 89.87) = 1.97, p = .13, \eta^2 = .05\). As hypothesized, the main effect of condition was significant, \(F(1, 35) = 116.02, p < .001, \eta^2 = .77\), with children in the object condition (\(M = .93, SD = .05\)) being more distracted than children in the picture condition (\(M = .16, SD = .05\)). The interaction of condition by time was not significant, \(F(2.57, 89.87) = 1.96, p = .13, \eta^2 = .05\).

I also tested if being distracted during the counting practice sessions was associated with poor performance on the Give-a-number task at posttest. To answer this question, I performed a linear regression with performance on the Give-a-number task at posttest as the dependent variable, and across session average tendency for distraction (total number of distractions in session/total number of possible trials in session), age, and performance on the Give-a-number task at pretest as predictors. Tendency for distraction was a significant negative predictor of performance on the Give-a-number task at posttest, \(b = -.22, t(35) = -2.07, p = .05\). Age was not a significant predictor of performance on the Give-a-number task at posttest, \(b = .06, t(35) = .5, p = .62\). Children’s performance on the Give-a-number task at pretest was a significant predictor of performance on the Give-a-number task at posttest, \(b = .70, t(35) = 5.75, p < .001\).

The second method I used to assess the effect of condition on children’s level of distraction was to code children’s actions on the to-be-counted items. Actions were coded as relevant or irrelevant. Actions on the objects were considered irrelevant in the object condition for the following situations: tapping or banging the objects on the table, pretending to walk the objects around the table or floor, pretending to eat the objects,
moving the objects around to different spots on the table, knocking over the objects in a
disorganized manner, or holding the objects. Actions on the objects were considered
irrelevant in the picture condition in the following situations: changing the orientation of
the book, playing with the binder clasp, looking through the pages during a trial, and
turning the page before the trial ended. These actions were not considered to be helpful
towards improving children’s counting skill.

Actions on the objects were considered relevant when they could help children’s
counting skill. These actions included the following behaviors in the object condition:
moving objects that have already been counted to one general area, moving objects into a
line, knocking over objects one at a time as child counts, picking up objects one at a time
as child counts, and pointing to the objects as the child counts them. For the picture
condition, a relevant action was pointing to the depicted objects while the child counts.

First, I analyzed whether age predicted tendency for irrelevant actions during the
counting practice sessions. I performed a linear regression using tendency for irrelevant
actions as the dependent variable and age as the predictor. I calculated tendency for
irrelevant actions by adding the number of irrelevant actions in each session and dividing
that number by the total number of trials performed in that session. I then took the
average across the five sessions. Age was a marginally significant negative predictor of
tendency for irrelevant actions, $b = -0.29$, $t(37) = -1.82$, $p = .08$, so I included it as a
covariate in the model.

To test if condition was associated with tendency for irrelevant actions, I
performed an ANCOVA with condition (object or picture) as the independent variable,
across session average tendency for irrelevant actions (total number of irrelevant actions
in session/total number of trials performed in session) as the dependent variable, and age as the covariate. The main effect of condition was significant, $F(1, 36) = 20.62, p < .001, \eta^2 = .36$. Children in the object condition ($M = .34, SD = .05$) had greater tendency to make irrelevant actions on the objects than children in the picture condition ($M = .06, SD = .04$). The main effect of age was not significant, $F(1, 36) = 1.66, p = .21, \eta^2 = .04$.

Next, I tested whether tendency for irrelevant actions on the objects during counting practice affected children’s understanding of cardinality at posttest. I performed a linear regression with children’s performance on the Give-a-number task at posttest as the dependent variable, and across session average tendency for irrelevant actions (total number of irrelevant actions in session/total number of trials performed in session), age, and children’s performance on the Give-a-number task at pretest as the predictors. Tendency for irrelevant actions was a significant negative predictor of performance on the Give-a-number task at posttest, $b = -.26, t(35) = -2.51, p = .02$. Age was no longer a significant predictor of the Give-a-number task at posttest once the other variables were taken into account, $b = .03, t(35) = .23, p = .82$. Performance on the Give-a-number task at pretest was a significant predictor of performance on the Give-a-number task at posttest, $b = .72, t(35) = 6.09, p < .001$.

Because children’s irrelevant actions on the sets they counted during counting practice were negatively associated with their understanding of cardinality at posttest, and because these actions were also considered to be distractions during my previous analysis of distractions, I wanted to check if children’s irrelevant actions on the sets they counted were driving the negative effects of distraction on children’s understanding of cardinality at posttest. To answer this question, I recalculated distractions during the counting
practice sessions. I removed instances of irrelevant actions on the set during counting practice from the total number of distractions per session. I also removed instances of speech that were unrelated to the task at hand and that were elicited by the objects (e.g., “I saw two lions at the zoo.”). Thus, distractions for this analysis involved speech that was not directed at the task (e.g., “Where did my team go?”) and actions that were off-task that did not involve the to-be-counted stimuli (e.g., walking around the room).

First, I analyzed whether age predicted children’s tendency for distraction during the counting practice sessions. I performed a linear regression with across session average tendency for distraction (total number of distractions in session/total number of possible trials in session) as the dependent variable, and age as the predictor. Age was not a significant predictor of tendency for distraction, $b = -.14, t(37) = -.89, p = .38$. I, therefore, did not include it as a covariate in the model.

I performed a mixed ANOVA with time (sessions 1-5) as the within-subjects factor, condition (object or picture) as the between-subjects factor, and tendency for distraction (total number of distractions in session/total number of possible trials in session) as the dependent variable. Mauchly’s Test of Sphericity on the variance-covariance matrix indicated that sphericity could not be assumed, $\chi^2(9, df = 9) = 26.88, p < .001$, so I multiplied the numerator and denominator degrees of freedom by the relevant Huynh-Feldt estimates of epsilon ($\varepsilon = .8$) for tests involving the repeated factor. Figure 7 presents the ratio of total distractions to total trials possible across sessions for children in each condition. The main effect of time was not significant, $F(3.21, 109.05) = .85, p = .48, \eta^2 = .02$. Consistent with the original distraction analysis (presented above), the main
effect of condition was significant, $F(1, 34) = 28.17, p <.001, \eta^2 = .45$. The interaction of condition by time was not significant, $F(3.21, 109.05) = .92, p = .44, \eta^2 = .03$.

I next analyzed whether there were differences in conditions on tendency for relevant actions on the objects in the set during the counting practice sessions. If picture books are less distracting, they may encourage more relevant actions. First, I analyzed whether age predicted tendency for relevant actions. I performed a linear regression with tendency for relevant actions as the dependent variable, and age as the predictor. To calculate tendency for relevant actions, I added the number of relevant actions children made in each session and divided that number by the total number of trials performed in that session. I then took the average across the five sessions. Age was not a significant predictor of tendency for relevant actions, $b = -0.09, t(37) = -.53, p = .60$. I, therefore, did not include it as a covariate in the model.

To test if condition predicted tendency for relevant actions, I performed a one-way ANOVA with condition (object or picture) as the independent variable, and across session average tendency for relevant actions (total number of relevant actions in session/total number of trials performed in session) as the dependent variable. The main effect of condition was not significant, $F(1, 37) = .03, p = .87, \eta^2 = .001$. Children in the object condition ($M = 1.16, SD = .17$) had a similar tendency for relevant actions as children in the picture condition ($M = 1.15, SD = .19$).

Finally, I analyzed whether tendency for relevant actions on the set during the counting practice sessions was related to better understanding of cardinality at posttest. I performed a linear regression using performance on the Give-a-number task at posttest as the dependent variable, and across session average tendency for relevant actions (total
number of relevant actions in session / total number of trials performed in session), age, and performance on the Give-a-number task at pretest as predictors. Tendency for relevant actions was not a significant predictor of posttest performance, $b = -.21, t(35) = -1.85, p = .07$. Age was not a significant predictor of performance on the Give-a-number task at posttest, $b = .15, t(35) = 1.22, p = .23$. Performance on the Give-a-number task at pretest was a significant predictor of performance on the Give-a-number task at posttest, $b = .6, t(35) = 4.43 p < .001$.

3.5 Post-hoc analysis of the “What’s on this card?” task

Although children’s understanding of cardinality as assessed by the “What’s on this card?” task did not significantly improve from pretest to posttest, some children did improve from pretest to posttest, so I wanted to test if attention to the set and distraction could account for individual differences in performance on this measure at posttest.

3.5.1 Does attention to the set predict performance on the “What’s on this card?” task?

To answer this question, I performed a linear regression with performance on the “What’s on this card?” task at posttest as the dependent variable, and tendency to make a set response, age, and performance on the “What’s on this card?” task at pretest as the predictors. Recall that I calculated tendency to make a set response by adding the number of set responses a child made during each session and dividing that number by the total number of trials that children completed during that session. I then took the average over all the sessions. Tendency to make a set response was not a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .09, t(35) = .80, p = .43$. Age was not a significant predictor of performance on the “What’s on this card?” task at
posttest, $b = -0.01, t(35) = -0.09, p = .93$. Performance on the “What’s on this card?” task at pretest was a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .78, t(35) = 7.23, p < .001$.

3.5.2 Does distraction predict performance on the “What’s on this card?” task?

I answered this question in two ways. First, I coded for children’s tendency for distraction during the counting practice. Recall that I calculated tendency for distraction by adding the number of distractions per session and dividing that number by the total number of possible trials per session (i.e., 9 for practice-and-testing sessions, and 18 for practice-only sessions). I then took the average across the five sessions. I performed a linear regression using performance on the “What’s on this card?” task at posttest as the dependent variable, and tendency for distraction, age, and performance on the “What’s on this card?” task at pretest as predictors. Tendency for distraction was not a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .04, t(35) = .36, p = .72$. Age was also not a significant predictor, $b = .14, t(35) = 1.23, p = .23$. Performance on the “What’s on this card?” task at pretest was a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .73, t(35) = 6.5, p < .001$.

A second way I addressed this question was by coding for children’s tendency for irrelevant actions on the sets during the counting practice. Recall that I calculated tendency for irrelevant actions by adding the number of irrelevant movements children made for each session and dividing that number by the total number of trials performed in that session. I then took the average across the five sessions.

I tested whether tendency for irrelevant actions during the counting practice sessions was associated with performance on the “What’s on this card?” task at posttest. I
performed a linear regression using performance on the “What’s on this card?” task at posttest as the dependent variable, and tendency for irrelevant actions, age, and performance on the “What’s on this card?” task at pretest as predictors. Tendency for irrelevant actions was not a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .07, t(35) = .66, p = .51$. Age was not a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .15, t(35) = 1.31, p = .2$. Performance on the “What’s on this card?” task at pretest was a significant predictor of performance on the “What’s on this card?” task at posttest, $b = .73, t(35) = 6.56, p < .001$.

3.6 Post-hoc analysis of children’s counting performance as a function of their knower-level

Although I found that children’s performance on the counting practice did not differ as a function of which condition children were randomly assigned to, it is possible that children who were subset-knowers (i.e., “one-,” “two-,” “three-,” and “four-“knowers) as assessed by their performance on the Give-a-number task performed differently on the counting practice than children who were CP-knowers (i.e., “five-“ and “six-“knowers). Thus, I tested whether children’s knower-level (subset-knower or CP-knower) as assessed by the Give-a-number task at pretest was a significant predictor of children’s performance during the counting practice. To answer this question, I performed a mixed ANCOVA with time (sessions 1-5) as the within-subjects factor, knower-level (subset or CP) and condition (object or picture) as the between-subjects factors, ratio of total number of errors to total number of trials as the dependent variable, and age as a covariate. Mauchly’s Test of Sphericity on the variance-covariance matrix
indicated that sphericity could not be assumed, \( \chi^2 (df = 9) = 17.37, p < .04 \), so I multiplied the numerator and denominator degrees of freedom by the relevant Huynh-Feldt estimates of epsilon (\( \varepsilon = .95 \)) for tests involving the repeated factor. Figure 8 presents the ratio of counting errors to total trials performed across sessions for children in each category of knower-level. The main effect of time was marginally significant, \( F(3.79, 121.11) = 2.03, p = .1, \eta^2 = .06 \). The main effect of condition was not significant, \( F(1, 32) = .36, p = .56, \eta^2 = .01 \). The main effect of knower-level, however, was significant, \( F(1, 32) = 5.67, p = .02, \eta^2 = .15 \). Subset-knowers made more errors during the counting practice (\( M = .31, SD = .03 \)) than CP-knowers (\( M = .16, SD = .05 \)). The interaction of condition by time was not significant, \( F(3.79, 121.11) = .63, p = .64, \eta^2 = .02 \). The interaction of knower-level by time was not significant, \( F(3.79, 121.11) = .94, p = .44, \eta^2 = .03 \). The main effect of age was not significant, \( F(1, 32) = 2.57, p = .12, \eta^2 = .07 \).

3.7 Post-hoc analysis of effect of condition on posttest-delayed posttest gain score

To maximize power, all analyses that I have performed so far have concerned only children’s performance on pretest and posttest measures, and thus have ignored children’s performance on the delayed posttest. Despite this issue of low power, I was interested in whether children who gained counting skill and understanding of cardinality from pretest to posttest continued to show increased counting skill and understanding of cardinality at delayed posttest.

3.7.1 Give-a-number task

To answer whether children maintained increases in understanding of cardinality at delayed posttest, I calculated gains scores of children’s performance on the Give-a-
number task from pretest to delayed posttest by subtracting children’s knower-level at pretest from their knower-level at delayed posttest. I reserved this analysis only for children who participated in the delayed posttest whose understanding of cardinality increased from pretest to posttest (object = 3, picture = 9). All three children in the object condition who improved their knower-level from pretest to posttest maintained their increased knowledge at the delayed posttest, and six of the nine children in the picture condition did, suggesting that the gains made from pre-to-posttest were stable.

3.7.2 “What’s on this card?” task

To answer whether children maintained increases in understanding of cardinality at delayed posttest, I calculated gains scores of children’s performance on the “What’s on this card?” task from pretest to delayed posttest by subtracting children’s knower-level at pretest from their knower-level at delayed posttest. I reserved this analysis only for children who participated in the delayed posttest whose understanding of cardinality increased from pretest to posttest (object = 5, picture = 5). None of the children in the object condition who improved their knower-level from pretest to posttest maintained their increased knowledge at the delayed posttest. In contrast, three of the five children in the picture condition did.

3.7.3 Count disks task

Finally, to answer whether children maintained increases in counting skill at delayed posttest, I calculated gains scores of children’s performance on the Count disks task from pretest to delayed posttest by subtracting children’s highest count at pretest from their highest count at delayed posttest. I reserved this analysis only for children who participated in the delayed posttest whose counting skill increased from pretest to posttest
(object = 10, picture = 7). Six of the 10 children in the object condition who improved their counting skill from pretest to posttest maintained their increased knowledge at the delayed posttest, and all seven children in the picture condition did, suggesting that the gains made from pre-to-posttest were stable.
CHAPTER 4:
DISCUSSION

In the current study, I compared the effect of counting practice with picture books versus physical objects on children’s understanding of cardinality. As hypothesized, I found that children who practiced counting with picture books improved their understanding of cardinality, as assessed by the Give-a-number task, more than children who practiced counting with physical objects. The benefits of counting with picture books were specific to understanding of cardinality, as there were no group differences on counting skill at posttest, as assessed by the Count disks task. Children’s understanding of cardinality, as assessed by the “What’s on this card?” task, did not improve, however, after the counting practice intervention.

It is somewhat surprising that children showed an increase in understanding of cardinality on the Give-a-number task but not on the “What’s on this card?” task, given that both tasks are supposed to be measuring the same thing. Le Corre et al. (2006) conducted the only study before the current study to compare children’s performance on both tasks, and they found that performance on the two tasks was comparable. For each task, they coded children’s performance, or knower-level, based on three criteria: 1) children had to give/say \( N \) for 2/3 of the trials in which \( N \) was requested/presented, 2) children could not give/say \( N \) more than half as often when other numbers were requested/presented, and 3) the first two conditions had to be satisfied for all numbers lower than \( N \). Children were then classified as a “knower” of the highest number in
which they reached those criteria. Children were categorized as “one-“, “two-“, “three-“, “four-“, and “CP-knowers”. “CP-knowers” were children who succeeded on the number five or above for either task. Le Corre and colleagues compared children’s knower-level on the Give-a-number task to their knower-level on the “What’s on this card?” task. They found that 66% of the children in their study could be classified as the same knower-level on both tasks, and they found that there was not a significant difference in performance between the two tasks.

In contrast to LeCorre et al. (2006), I found that at pretest only 26% of the children in my study had the same knower-level on the Give-a-number task and the “What’s on this card?” task. At posttest, only 18% of the children in my study had the same knower-level on both tasks. As in Le Corre et al. (2006), I tested for systematic differences in scores on the Give-a-number task and the “What’s on this card?” task using the Wilcoxon Signed Ranks test. I computed difference scores like Le Corre et al. (2006) did by assigning a numerical code that matched children’s knower-level on each task for children who were classified as a “two-“ knower or above. Children who were classified as “0-“knowers or “one-“knowers were given the numerical code “.5.” At pretest, I found that more children had higher knower-levels as assessed by the Give-a-number task (n = 24) than the other way around (n = 3), and this effect was significant, Z = -3.46, p = .001. At posttest, I again found that more children had higher knower-levels as assessed by the Give-a-number task (n = 27) than the other way around (n = 7), and this effect was significant, Z = -3.91, p <.001. Although children tended to score higher on the Give-a-number task than they did on the “What’s on this card?” task, their scores on each task were positively correlated with each other at pretest, r = .53, p <.001, and at posttest, r =
.49, p = .002. However, one would expect much higher correlations than .5 if the two tasks were measuring the same underlying construct.

Why might performance on the two measures of understanding of cardinality be more similar in Le Corre and colleagues’ study than in mine? One possible cause of between-study differences might be due to differences in administration of the “What’s on this card?” task. Although a numerical response was modeled during the first trial of each deck of cards in my study (e.g., “That’s right. That’s one apple.”), I did not explicitly tell children to respond with the number of objects on the card. Although Le Corre and colleagues did not mention giving any explicit instructions to the children in their method section, it is possible that children were explicitly told that the goal of the task was to provide a numerical response during the first trial in Le Corre and colleagues’ study. Because children in my study were not explicitly told to respond with the number of objects on the card, the desired task response was clearer in the Give-a-number task than it was in the “What’s on this card?” task. For example, in the Give-a-number task, the puppet asks the child to give a specified number of objects. Thus, the goal of the task is clear. In contrast, in the “What’s on this card?” task, the instructions are much more ambiguous. Children are simply asked: “What’s on this card?” Consequently, there are several appropriate responses to that question. Children could correctly report that there are “apples” on the card, or “4,” or they could count “1, 2, 3, 4.”

The ambiguity of the task could cause children to lose sight of the desired response—the set size. Some evidence for this idea is that it was common for children in the current study to focus their responses on counting and naming object kind. For example, a child might respond: “1, 2, 3 apples!” It is possible that these children could
have responded with “3 apples” or “3” after a prompt for set size, but chose not to without a prompt. Thus, the “What’s on this card?” task may have underestimated children’s understanding of cardinality in my study simply because the instructions were too ambiguous to encourage a consistent set size response.

Being able to label the size of the set is an important component to understanding cardinality, but it is not the only component. Another important component is the understanding that the purposeful use of counting is to determine a set size. The Give-a-number task may be a better task to assess cardinality than the “What’s on this card?” task because the purposeful use of counting to determine a set is required on every trial in the Give-a-number task. If children did not count to create the set they gave to the puppet, the experimenter asked them to count after they created the set to “check” that they gave the puppet the required set size. Children only received credit for a given trial if they gave the requested set size and were able to count it correctly. The “What’s on this card?” task does not similarly stress the importance of using counting to determine set size on every trial. Recall that the “What’s on this card?” task has 9 “probe” trials (out of a total of 24 trials) in which children are prompted for both set size and counting. For the remainder of the trials, children only need to give the correct set size to receive credit for a given trial. Because correct performance on the Give-a-number task requires the use of counting to determine a set, it may be a more accurate measure of children’s understanding of cardinality than the “What’s on this card?” task. The fact that the Give-a-number task is a more accurate measurement of cardinality may explain why counting practice in the picture condition increased understanding of cardinality as measured by the Give-a-number task, but not the “What’s on this card?” task.
Regardless of the potential problems with interpreting the “What’s on this card?” task, I did replicate Mix’s (2012) finding that children’s understanding of cardinality, as assessed by the “gold standard” Give-a-number task, increased by one knower-level after participating in a six-week picture book intervention. This finding is impressive given that previous research suggests that children slowly increase their knower-level on this task with many months in between acquisition of a new knower-level (Le Corre et al., 2006; Wynn, 1990). Note that children in the object condition also practiced counting in the same way that Mix’s (2012) study found was beneficial for understanding of cardinality, and yet they showed no gains in understanding by posttest. This finding may suggest that simply linking counting and set size during counting practice with objects was not enough to improve children’s understanding of cardinality. However, it is important to note that Mix (2012) designed her intervention for use with picture books, and that may be the context in which it works best. Children in the object condition were often distracted during counting practice, so it may have been difficult for them to reap the benefits of instruction that juxtaposed labeling the numerosity of the set and counting the set because it required them to attend to and link two pieces of information that were presented in succession. It is possible that counting practice with objects may require instructional methods that exploit children’s interest in the objects and redirect their attention to aspects of the counting practice that benefit children’s understanding of cardinality.

Ramscar and colleagues’ (2011) study provides one possible way to beneficially redirect children’s inherent interest in the objects. They suggest that by presenting a familiar label of the set before the set size (e.g., “Look, apples. There are four.”), a child
will be more likely to direct her attention to the relevant dimension (i.e., set size). The results of this study suggest that presentation of a familiar label may serve as a good cue for the relation between set size and the count words. It is possible that children in the current study’s object condition would have increased their understanding of cardinality if during practice they heard a familiar label first to direct their attention, and then heard counting words immediately afterwards (e.g., “Look, cars. There are 3. 1, 2, 3.”).

Despite receiving counting practice that was identical to the object condition in all ways but the specific items counted, only children in the picture condition improved their understanding of cardinality. I have suggested that the benefits of the picture books are due, at least in part, to the higher representational status of pictures versus objects, but why should the representational status of the counted objects affect the construction of children’s understanding of cardinality? Previous studies have suggested that one major benefit of learning mathematics concepts with objects that have high representational status is that they are less distracting than objects with low representational status (DeLoache, 2000; Uttal et al., 1997). The results from the current study provide some support for this idea. Children in the object condition were generally more distracted than children in the picture condition, and they were more likely to exhibit behaviors that disrupted the counting session like getting out of their seat to walk around the classroom or talking about things that were unrelated to the counting task (e.g., “I’m going to be Cinderella for Halloween,” or “My dad had surgery on his arm.”). A consequence of disruptions such as these is that it makes it more difficult for the instructor to present a given trial in the highly structured way (i.e., labeling set and then immediately counting
in close temporal continuity with no interruptions) that benefits children’s understanding of cardinality.

Objects with lower representational status not only draw attention away from the task at hand, but they also draw attention to themselves (DeLoache, 2002; Uttal et al., 1997). In support of this idea, children from the current study were more likely to carry out more task-irrelevant behaviors (e.g., stomping the toy animals on the table and growling, pretending to eat the toy strawberries, driving the toy bus on the table and making “beep beep” noises) with the materials in the object condition than with the materials in the picture condition. Children’s greater amount of non-number related set exploration might have focused their attention on other aspects of the sets at the expense of them noticing cardinality as an important attribute of the sets.

These results lend support to the growing literature suggesting that perceptually rich materials may hinder learning outcomes (Goldstone & Sakamoto, 2003; Kaminski, Sloutsky, & Heckler, 2008; Kaminski & Sloutsky, 2009; Son, Smith, & Goldstone, 2008; Son, Smith, & Goldstone, 2011). This research suggests that knowledge gained from learning with perceptually rich materials may not be easily transferred to new contexts because the superficial details of the materials may detract from the intended relational structure of the task (Kaminski, Sloutsky, & Heckler, 2008). Son et al. (2008) suggest that perceptually rich objects might be especially difficult for young children to use in a learning context because young children focus especially on object details. Young children’s focus on superficial perceptual features may increase their likelihood of encoding unnecessary features. For example, a young child counting objects that are perceptually rich may focus on the fact that they are gold or shaped like stars instead of
the fact that there are three of them. In summary, pictures are less detailed, and thus have higher representational status. Counting sets that have higher representational status should benefit children’s understanding of cardinality because children should be less distracted by the objects themselves and more likely to focus on the relevant aspect of the set (i.e., set size).

It is important to note that some research suggests that the detrimental effects of perceptually rich objects may diminish over time as children gain experience using those specific objects in a representational manner (Son, Smith, & Goldstone, 2011; Stevenson & Stigler, 1992). The rationale behind this idea is that by using the same objects repeatedly, and across different learning situations, children gain knowledge of them as representations of other things (Son, Smith, & Goldstone, 2011). Stevenson and Stigler (1992) imply that one possible reason for Asian children’s relative success in mathematics compared to children from other countries is that they tend to use the same set of learning materials across lessons and across grades. They suggest that this practice is much less confusing than the typical American practice of introducing many different learning materials in mathematics lessons. However, the results from the current study do not support this idea. Although children in the current study generally used the same types of objects (e.g., they always counted small toy food, vehicles, and animals during every session) across the counting practice sessions, the objects they used did not become less distracting to them over time, and did not help them to construct a better understanding of cardinality.

One possible reason why the objects children counted in the current study never became more representational to them, even after several practice sessions, is that the
objects selected for the current study were too familiar and interesting for children to ignore them as objects in their own right (cf. Petersen & McNeil, 2013). Perhaps if children had counted things that are a little less interesting to them, like simple household items, they would have been able to think of the objects they counted as more representational over time. As evidence for this point, Stevenson and Stigler (1992) reported that the learning materials Asian instructors bring into their classroom are typically plain items. Thus, it is possible that objects that are both perceptually rich and familiar to children outside of a school setting are never helpful for learning situations, even after repeated use of them.

Because objects with higher representational status, like pictures, have been shown to decrease children’s focus on the individual objects as objects in their own right and increase children’s focus on the objects as members of categories, I hypothesized that pictures would also be more likely than objects to focus children’s attention on the set during the counting practice sessions. I reasoned that this attention to the set would help children improve their understanding of cardinality, thus serving as another potential benefit of using pictures for counting. However, the current study did not provide evidence to support this idea. To measure attention to the set, I coded children’s response to the experimenter’s first prompt on each trial of the counting practice for counting or stating the set size. I found that children in the picture condition were no more likely to respond on the basis of set size than were children in the object condition. These results are somewhat surprising given that previous research has shown that preschool-aged children are more likely to talk categorically about pictured objects than physical objects (Gelman et al., 2005). On the other hand, these results are expected given Levine and
colleagues’ (2010) finding that children who are learning to count are more likely to talk about math in the context of counting than they are to talk about math in the context of stating set size. Therefore, it is possible that the results of this study would have revealed some differential attention to the set between children in the two conditions if I had used another metric to gauge it, such as children’s eye movements or use of the plural form when referring to the objects.

It is also possible that differences in terms of attention to set were small because my object condition was too “set-like.” Great care was taken to make sure the two conditions were equated on all potentially confounding variables, including set-ness that was outside of the picture versus object manipulation. For example, the objects were always presented to children on a white work mat, which contained the objects into a set. Gelman and colleagues (2005) suggested that in containing the objects they used in their study in a plastic box, they made those objects more representational than when they were free. Thus, placing the objects on a white work mat perhaps increased the salience of the set more than it would have if I had simply presented the objects on the table for each trial.

Additionally, the objects in the current study were all presented as homogenous groups. Children always saw, for example, five lions or three strawberries as opposed to a group of five composed of two lions, two hippos, and an elephant, or a group of three composed of one strawberry, one lion, and one boat. Mix and colleagues’ research suggests that children understand homogeneous groups as countable sets before they recognize the same in heterogeneous groups (Mix, 1999; Mix, Huttenlocher, & Levine, 1996, 2002; Mix, Sandhofer, & Baroody, 2005; Siegel, 1994). Thus, because the objects
presented in the current study were presented only in homogeneous groups, this presentation perhaps enhanced the salience of the set more than if the objects were presented in heterogeneous groups.

Finally, practice was scripted in a way that encouraged children, regardless of condition, to label the set first. During every trial across the five counting practice sessions, the experimenter always modeled the set by reporting the set size (e.g., “Look, there are 3 boats.”) and then counting. Since children in both conditions always practiced in this manner, it is perhaps not surprising that they did not differ in terms of making set responses after the experimenter’s first prompt. Even if children in the object condition would naturally pay less attention to the set than children in the picture condition, all children’s attention was likely drawn to the set at the outset because the experimenter always labels the set first.

Thus, both conditions presented the to-be-counted items in a contained fashion, and as homogenous groups. Additionally, the experimenter encouraged children in both conditions to count by first labeling the set. Thus, all three of these features of the counting practice interventions in the current study likely served to draw children’s attention to the to-be-counted items as a set. Therefore, the representational status of pictures might have only modestly increased children’s attention to the set above and beyond the effects of those other manipulations. The difference in children’s attention to the set may have been much stronger if the objects in the object condition had not been contained by the work mat. Furthermore, it is possible that the picture book condition would have been much more important for helping children focus on the set if the to-be-counted sets were heterogeneous. Finally, if the instructor had not encouraged children to
count by first labeling the set, it is possible that children who practiced counting in picture books would have been more likely to make spontaneous set responses than children who practiced counting using physical objects.

In summary, the current study has provided some evidence that the representational status of to-be-counted items in a set is an important manipulation of children’s counting experience that influences their understanding of cardinality. Children are less likely to be distracted by objects with higher versus lower representational status, and they are less likely to focus on objects with higher versus lower representational status as objects in their own right.

4.1 Limitations and future directions

The results from the current study suggest that educators’ money may be better spent on counting books than on physical counters. Counting books have the advantages over physical counters of teaching children the concept of cardinality and helping children to stay focused on the counting lesson while also improving children’s counting skill as much as physical counters. It is important to note, however, that the picture books that were used in the current study were created for this study and not simply selected from among popular existing counting books. Existing counting books differ in many respects. For example, existing counting books differ not only in terms of the presentation of the objects, but also in terms of whether the book contains a story, or number words. These various aspects of picture books may make them more or less effective as materials for counting practice. The picture books used in the current study contained pages that featured only the set with no other pictorial details, words, or Arabic numerals. Thus, the effectiveness of these picture books may not generalize to all
counting books. Future studies should analyze existing counting books for both superficial (e.g., whether the book contains scenes or objects on their own) and numerical (e.g., the range of the numbers practiced) aspects that may differentially benefit children’s understanding of cardinality and their counting skill.

The benefits of counting book practice from this study were impressive given that children only received five short practice sessions. It is possible that gains in understanding of cardinality would be even more impressive over continued practice with counting books. A question for future research is whether differences in actual counting practice in the home and preschool environments might account for differences in children’s understanding of cardinality. In the future, I plan to observe counting practice at preschools and homes to see if the amount of picture book counting practice children receive relates to their understanding of cardinality.

4.2 Conclusion

Overall, the current study contributes to our understanding of the malleable factors in the early learning environment that affect children’s understanding of a foundational mathematical concept, cardinality. More generally, the current study adds to the growing evidence that seemingly small variations in the materials children use in learning situations affects the knowledge they construct. These results can also provide information to educators who must decide which materials they should bring into their classrooms to best teach their students the concept of cardinality.
APPENDIX A:

FIGURE A.1

Figure A.1. Adjusted ratio of counting errors to total trials performed during counting practice across sessions and by condition.
Figure A.2. Adjusted mean performance on the Give-a-number task at pretest and posttest by condition.
Figure A.3. Adjusted mean performance on the “What’s on this card?” task at pretest and posttest by condition
Figure A.4. Adjusted mean performance on the Count disks task at pretest and posttest by condition
Figure A.5. Ratio of set responses to total trials performed during counting practice across sessions and by condition
Figure A.6. Ratio of total distractions to total trials possible during counting practice across sessions and by condition (including irrelevant movement of stimuli)
Figure A.7. Ratio of total distractions to total trials possible during counting practice across sessions and by condition (not including irrelevant movement of stimuli)
Figure A.8. Adjusted ratio of counting errors to total trials performed during counting practice across sessions and by knower-level as assessed by the Give-a-number task at pretest.
Figure A.9. Stimuli used in experiment

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REFERENCES


