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Taking Shape: Supporting Preschoolers' Acquisition of Geometric Knowledge Through Guided Play

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Shape knowledge, a key aspect of school readiness, is part of early mathematical learning. Variations in how children are exposed to shapes may affect the pace of their learning and the nature of their shape knowledge. Building on evidence suggesting that child-centered, playful learning programs facilitate learning more than other methods, 4- to 5-year-old children ($N = 70$) were taught the properties of four geometric shapes using guided play, free play, or didactic instruction. Results revealed that children taught shapes in the guided play condition showed improved shape knowledge compared to the other groups, an effect that was still evident after 1 week. Findings suggest that scaffolding techniques that heighten engagement, direct exploration, and facilitate "sense-making," such as guided play, undergird shape learning.

There is growing national concern around improving education. Many children lack key academic competencies prior to school entry, particularly in core subjects such as math (e.g., Cross, Woods, & Schweingruber, 2009). Although it is clear that young children need exposure to rich curricular content (Pianta, Barnett, Burchinal, & Thornburg, 2009), educators and researchers have long debated how best to deliver that content (Fisher, Hirsh-Pasek, & Golinkoff, 2012). Didactic instructional methods have gained popularity based on the belief that didactic teaching is efficient and facilitates children's learning (Stockard & Engelmann, 2008). Many developmental experts, on the other hand, contend children actively construct knowledge as they explore and engage with their environment (e.g., Vygotsky, 1978).

Evidence suggests that child-centered, playful learning programs promote sustained academic performance compared to more traditional, academically focused programs, although few studies have rigorously compared the two approaches (e.g., Diamond, Barnett, Thomas, & Munro, 2007; Lillard & Else-Quest, 2006; Marcon, 2002). Moreover, there are considerable discrepancies concerning how play-based pedagogies are conceptualized and implemented, ranging from free play to guided play (Chein et al., 2010; Wood, 2009). *Free play* generally refers to self-directed activities that are fun, engaging, voluntary, and flexible have no extrinsic goals, and often contain an element of make-believe (Sutton-Smith, 2001). *Guided play* is a discovery-learning approach intermediate between didactic instruction and free play (Golbeck, 2001). Teachers are seen as collaborative partners who create flexible, interest-driven experiences that encourage children's natural curiosity, active engagement, and "sense-making" processes (e.g., Fisher et al., 2012). In such contexts, adults scaffold children's learning by commenting on discoveries, coplaying with the children, and creating games or activities with well-planned curricular materials.

The attributes that facilitate children's mathematics learning in play-based experiences are understudied. Some evidence suggests that children naturally engage in math-related activities during free play (e.g., Bjorklund, 2008; Ginsburg, Pappas, & Seo, 2001), and that certain forms of play are associated with math achievement (e.g., Ramani & Siegler, 2008). However, some argue that adult guidance is critical in the development of children's complex knowledge (Brown, McNeil, & Glenberg, 2009).

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Sarama and Clements (2009) contend that when children play with math-related objects by themselves, it is unlikely that the play will facilitate the *intended* concept. For example, playing with shapes may not lead to discovery of their definitional properties (e.g., all triangles have three angles). Particular forms of adult guidance, such as dialogic inquiry or "exploratory talk," may be beneficial in fostering children's learning during guided play (Ash & Wells, 2006). Recent reviews reveal that the level of adult guidance directly influences discovery-learning outcomes (Honomichl & Chen, 2012; Kirschner, Sweller, & Clark, 2006). Alfieri, Brooks, Aldrich, and Tenenbaum (2011), for example, in a meta-analysis, found that didactic instruction had greater impact on children's learning outcomes than unassisted discovery. However, enhanced discovery methods (e.g., asking questions, prompting exploration) proved superior to other instruction forms. While the meta-analysis collapsed across age including children up to age 12 years, its findings suggest that enhanced discovery methods, such as those found in guided play, may be beneficial to preschool children.

We investigated the differential impact of playful learning and didactic pedagogies on preschool children's shape knowledge, considered a foundational area for later geometric thinking (Cross et al., 2009). Children's knowledge of shapes involves a concrete-to-abstract shift, as they initially categorize shapes based on visual similarity and orientation irrespective of definitional properties (Keil, 1996). In the elementary years, children shift to rule-based or definitional classification systems that rely on the *number* of sides or angles for shape identification (Satlow & Newcombe, 1998). Less clear is whether this shift from perceptual similarity to definitional criteria is due to children's limited exposure to atypical shapes, current educational pedagogies, or developing cognitive ability (Keil, 1996).

If children's developing shape concepts are malleable via instruction, the natural question is whether varying *pedagogical approaches* are differentially effective. We hypothesized that children in guided play, more than children in didactic instruction or free play, would show improved understanding of the standard features of shapes rather than merely relying on typical appearances.

Method

Participants

A total of 70 children were recruited from a Philadelphia suburban area. Four- and 5-year-olds were chosen because they typically display relatively concrete concepts of shapes, relying heavily on visual similarity. In addition, they also have the capacity to recognize and count shape features, key factors for learning the definitional properties of shapes. Data from 10 children were discarded due to inattentiveness (e.g., did not fixate on task during training or left training area; 5 children), inability to count (3), and experimenter error (2), leaving 60 children for data analysis. Children were predominantly Caucasian and upper middle-class, and divided equally among three conditions: guided play ($M_{\text{age}} = 56.77$ months, $SD = 6.09$; 10 males), didactic instruction ($M_{\text{age}} = 57.11$, $SD = 6.77$; 11 males), and free play ($M_{\text{age}} = 55.83$, $SD = 5.91$; 10 male children).

Materials

Shape training stimuli. Four geometric shape categories (triangles, rectangles, pentagons, and hexagons) were chosen because: (a) previous research established a concrete-to-abstract shift; (b) two shapes were familiar, simple shapes and two were less familiar, complex shapes; and (c) the shapes' properties were within preschoolers' counting range. Two typical and two atypical exemplars of each shape were created using Serif DrawPlus 4.0 software (16 total exemplars) based on Satlow and Newcombe (1998). Each exemplar was displayed individually on a 5 × 5 in. laminated card. Typical exemplars were shapes with canonical properties, displayed in upright orientations, and medium in size (e.g., equilateral). Atypical shapes were equally valid shapes forms but less commonly seen (e.g., scalene, obtuse). Velcro on the back of exemplar cards allowed them to be displayed on an 11 × 11 in. green felt board. For the free play condition, shapes were cut along their outer edges.

Shape construction sticks and diagram. Small (2.5 in.), medium (4 in.), and large (6 in.) wax-covered sticks were used to construct shapes during training conditions. Sticks were placed in a general shape form (e.g., a triangle with approximately 1-in. gaps between the sticks). A diagram only visible to the experimenter and outlining eight shape designs (two atypical shapes per category), was created to ensure the same scaffolding experiences across conditions.

Sorting task stimuli. Novel exemplars of the four target shapes were created for the sorting task based on stimuli used by Satlow and Newcombe (1998): Three typical, three atypical, and four nonvalid exemplars of each shape were printed individually on 5 × 5 in. laminated cards, yielding 10

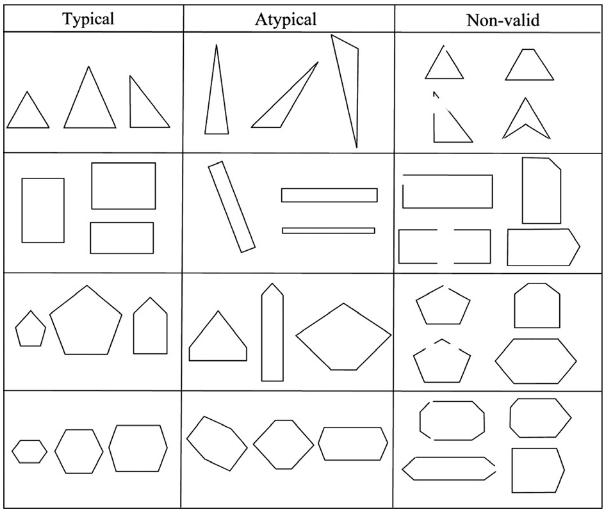

Figure 1. Stimuli for the shape-sorting task.

exemplars of each shape (see Figure 1). Two non-valid shapes had a lack of closure and two had an incorrect number of sides.

Pedagogical Conditions

Detailed descriptions of the pedagogical conditions are available in the online supporting information.

Guided play. Participants were taught definitional properties for each shape in a playful, exploratory manner. The experimenter asked the child "Did you know all shapes have secrets? Today I need your help in discovering the secret of the shapes" and both donned make-believe detective hats. For each shape category, the experimenter affixed four exemplar cards (two typical, two atypical) on the felt board in front of the child, pointed to the exemplars, and said that all of the shapes were "real" shapes, although they looked different. The experimenter then asked the child to help her figure out the shapes' secret—what makes them "real" shapes. After approximately 10 s of exploration, the experimenter helped the child "discover" each shape's distinguishing features through questions and by encouraging the child to touch or trace shapes as they examined the exemplar cards. After training, the construction sticks were laid out in the prescribed shape forms, one at time. The child was asked to construct two new shapes and to describe how these new shapes were similar to those on the training cards. This process was repeated for each shape.

Didactic instruction. The experimenter introduced the child to the experiment using similar wording and vocal intonations as the guided play condition. During training, the experimenter acted as "the explorer" while the child passively watched and listened through each step of training. The guided play and didactic instruction conditions provided the same content and exposure to shape stimuli, differing only in the child's engagement.

Free play. Prior to the start, the experimenter organized the cards in one large group next to the felt board. The cards were organized by their respective shapes within this larger group (e.g., triangle cards together) to enhance children's natural, within-category comparison when examining the cards. Children were given 7 min to play with the shapes and 6 min to play with the construction sticks in any way that they wished. Children were exposed to the shape stimuli for approximately the same amount of time as the pedagogical conditions.

Shape-Sorting Task

Each participant was introduced to Leelu the Ladybug, "a very picky bug who loves shapes, but only *real* shapes." The child was asked to place all *real shapes* in a box while all *fake shapes* were placed in a trashcan. For each shape, the child was first shown one typical instance (not identical to any of the original training or test items) and told that it was just one example of that particular shape. The model was then attached to the box and remained on display. Next, the experimenter drew one test card, face down, from a pile and displayed the image for approximately 10 s in front of the child (the experimenter could not see the item displayed). She stated, "Look at this carefully. Is this a real triangle or a fake triangle? Why do you think so?" Children's comments confirmed that they understood the procedure and attended to the details of each figure (e.g., "This is fake because it is broken here … so it goes in the trashcan"). The sorting task proceeded through all four shapes (randomized order within a type) using the same instructions.

Procedure

The study was conducted in a private room free from distractions at two separate locations in the same geographic area (see the Preliminary Analyses section). All children participated in an experimental condition followed by the shape-sorting task. One experimenter worked individually with each child. Fifty-one children returned 1 week after initial training and assessment (M = 7.19 days, SD = 1.05). During the second assessment (T2), children were prompted to recall the activities from the first session and then asked to sort the shapes again.

Manipulation Fidelity

The experimenter made special efforts to maintain child-friendly affect across all conditions during training. Even so, slight differences in training affect could have subtly influenced the outcome. We examined whether perceived friendliness and warmth differed among conditions by having 40 adults rate fifteen 5-s audio clips of the instruction periods from available audio data. Five clips were made for each condition. Clips were played in *reverse* so raters would not be influenced by the content of the speech. Participants rated the speaker's level of friendliness and warmth on 7-point, Likert scales (1 = *low*, 5 = *moderate*, 7 = *high for each dimension*) for each clip. Mean friendliness and warmth scores were computed for each condition.

Repeated measures analysis of variance (ANOVA) revealed a significant effect of condition on perceived friendliness, $F(2, 78) = 6.79$, $p = .01$, $\eta_p^2 = .15$; paired t tests showed free play ($M = 4.74$, $SD = 1.01$) was rated higher than didactic instruction ($M = 4.33$, $SD = .81$) or guided play ($M = 4.36$, $SD = .79$), $ps < .01$. Similarly, perceived warmth ($M = 4.56$, $SD = .89$) was higher in free play than didactic instruction ($M = 4.02$, SD .76) or guided play ($M = 4.15$, $SD = .71$), $ps < .01$, $F(2, 78) = 13.55$, $p = .001$, $\eta_p^2 = .26$. The fact that free play was viewed as more friendly and warm suggests that emotional support is probably part of the construct of free play. Importantly, this finding suggests that an outcome in favor of guided play cannot be attributed to differential support in that condition. Furthermore, didactic instruction and guided play did not differ from one another on either friendliness or warmth ($ps < .17$), suggesting that the experimenter's affect was consistent across training conditions.

Results

Data analyses were conducted in two steps. First, multivariate ANOVAs were performed to determine the impact of pedagogy on children's definitional learning of shapes at T1 and T2. Second, a series of mixed ANOVAs was performed to determine whether shape category had an impact on children's shape learning.

Data Reduction

Children who relied on perceptual similarity to classify shapes would identify typical shapes in the sorting task as "real" but reject atypical and nonvalid shapes. Conversely, those who developed more abstract, geometric concepts of shape would rely on definitional properties, identifying typical *and* atypical shapes as "real" while rejecting nonvalid shapes. Thus, the key comparison was children's rejection of *atypical* shapes. To determine the extent to which children's sorting behaviors were guided by visual similarities versus definitional concepts in the shape-sorting task, we collapsed across shape and calculated acceptance rates across exemplar type (typical, atypical, nonvalid). We also calculated acceptance rates for typical, atypical, and nonvalid exemplars within each of the four shape categories.

Preliminary Analyses

We examined data distributions for normality and parametric assumptions. For within-subject variables that violated sphericity, we conducted multivariate analyses to determine main effects and interactions and the Greenhouse-Geisser adjusted F test was reported (Tabachnick & Fidell, 2007). Bonferroni corrections were applied when conducting multiple post hoc comparisons.

Age and gender. A preliminary 3 (pedagogy: guided play, didactic instruction, free play) × 2 (gender) × 2 (age, median split) multivariate analysis of variance (MANOVA) was performed to determine whether factors such as gender or age affected children's acceptance of typical, atypical, and nonvalid shape exemplars. No main effects of gender or age, or interactions between these factors, were found. Thus, age and gender were not considered in further analyses.

Setting and blind assessment. The experiment was conducted in two locations, in the lab and in a school where a second experimenter—blind to the condition—administered the shape-sorting task assessment for approximately one third of the sample ($n = 23$). Supplemental analyses noted mean differences in children's responses between the two settings, but these did not differentially vary by pedagogy. When controlling for setting, the results paralleled those reported next (see online supporting information for additional analyses).

Does Pedagogy Influence Children's Definitional Shape Knowledge?

A MANOVA revealed that pedagogy had a significant effect, Wilks's Lambda, $F(6, 110) = 6.83$, $p < .001$, $\eta_p^2 = .27$, influencing children's acceptance of typical shapes, $F(2, 57) = 8.24$, $p < .001$,

$\eta_p^2 = .22$, and atypical shapes, $F(2, 57) = 19.61$, $p < .001$, $\eta_p^2 = .41$, but not nonvalid shapes, $F(2, 57) = 1.18$, $p = .32$, $\eta_p^2 = .04$. Post hoc tests (Figure 2) revealed that children in guided play identified more typical (ps < .05) and atypical (ps < .001) shapes as "real" compared to children in the didactic and free play conditions. Didactic instruction appeared to have a marginal effect on shape knowledge; children accepted more atypical shapes than those in free play ($p = .06$), but there was no difference for typical shapes.

To assess whether effects on children's shape concepts were maintained over a 1-week period, a 3 (pedagogy) × 2 (time: T1, T2) MANOVA was conducted on acceptance rates for typical, atypical, and nonvalid shape exemplars. Children did not show a significant change in shape knowledge from T1 to T2, Wilks's Lambda, $F(3, 46) = 0.24$, $p = .87$, $\eta_p^2 = .02$. The Pedagogy × Time interaction was also not significant, Wilks's Lambda, $F(6, 92) = 1.20$, $p = .31$, $\eta_p^2 = .07$, suggesting that children's retention of shape concepts did not fluctuate by the type of instruction they received.

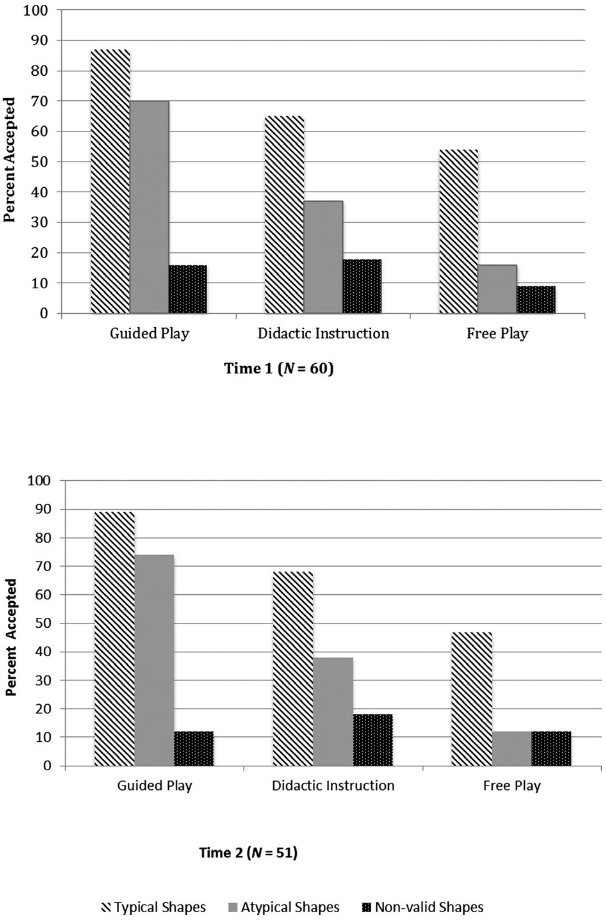

Figure 2. Mean percent of shapes accepted during Time 1 and Time 2 in shape-sorting task.

Does Shape Category Influence Children's Shape Learning?

Three mixed ANOVAs were performed to determine whether children's acceptance rates fluctuated across shape category for typical, atypical, and nonvalid exemplars during T1. For each analysis, shape category was the within-subjects factor and pedagogy was the between-subjects factor. The main effect of shape category on typical exemplar acceptance rates was not significant, $F(2.35, 134.14) = 1.13$, $p = .33$, $\eta_p^2 = .02$; however, a marginal interaction between shape category and pedagogy was observed, $F(4.71, 134.14) = 2.21$, $p = .06$, $\eta_p^2 = .07$. The cubic contrast was significant for the interaction, $F(2, 57) = 2.21$, $p < .01$, $\eta_p^2 = .20$, suggesting that children's response patterns across shapes varied by pedagogy (see Table 1). Children in guided play and didactic instruction maintained consistent acceptance rates across triangles, rectangles, pentagons, and hexagons (paired t tests $p > .27$). However, children in free play showed distinct variation in their shape-by-shape acceptance rates. Paired t tests revealed significant mean differences between triangles and rectangles, $t(19) = 2.63$, $p = .02$, as well as rectangles and pentagons, $t(19) = 3.34$, $p = .003$.

Table 1

Mean Percent of Shapes (Standard Deviation) Accepted During the Sorting Task

	Shape category			
	Triangles	Rectangles	Pentagons	Hexagons
Typical exemplars				
Guided play	.85 (.25)	.87 (.27)	.92 (.21)	.85 (.28)
Didactic instruction	.60 (.35)	.65 (.38)	.67 (.34)	.68 (.38)
Free play	.55 (.36)	.68 (.38)	.40 (.41)	.52 (.33)
Atypical exemplars				
Guided play	.68 (.38)	.70 (.42)	.77 (.38)	.67 (.36)
Didactic instruction	.43 (.43)	.33 (.42)	.33 (.42)	.38 (.36)
Free play	.10 (.22)	.22 (.31)	.17 (.28)	.17 (.32)
Nonvalid exemplars				
Guided play	.18 (.27)	.16 (.19)	.16 (.22)	.15 (.19)
Didactic instruction	.14 (.27)	.19 (.25)	.19 (.28)	.23 (.28)
Free play	.10 (.17)	.06 (.14)	.10 (.17)	.11 (.25)

Note. The values represent mean percentages of instances accepted as "real shapes" in the sorting task during Time 1. Values in parentheses are standard deviations.

Conversely, the main effect of shape category on atypical exemplar acceptance rates was not significant, $F(2.68, 152.82) = 0.06$, $p = .98$, $\eta_p^2 = .001$; nor was the interaction between shape category and pedagogy, $F(5.36, 152.82) = 0.85$, $p = .52$, $\eta_p^2 = .03$. Similarly, the main effect of shape category on children's acceptance of nonvalid shapes, $F(2.46, 140.14) = 0.45$, $p = .68$, $\eta_p^2 = .001$, and its interaction with pedagogy was not significant, $F(4.92, 140.14) = 0.75$, $p = .58$, $\eta_p^2 = .03$ Children's response patterns did not appear to vary substantially from shape to shape for atypical or nonvalid shapes. In particular, children in the guided play and didactic instruction conditions demonstrated consistent acceptance rates across triangles, rectangles, pentagons, and hexagons within each exemplar domain.

Discussion

This study demonstrates that children's shape knowledge is malleable and influenced by pedagogical experience. After approximately 15 min of shape training, children displayed very different shape knowledge across guided play, free play, and didactic instruction conditions. Children in guided play demonstrated improved definitional learning of shapes. They accepted more valid instances (typical and atypical) of shapes while rejecting the majority of nonvalid instances. Learning was relatively robust, showing no decline over a 1-week period. Conversely, children in didactic instruction displayed relatively concrete knowledge of shapes, with a high rate of rejection across atypical as well as nonvalid shapes. While didactic instruction may have appeared to direct children's attention to the defining features of the shapes, children did not seem to extract the relevant geometric principles. For example, when asked whether a triangle was "real" or "fake," several children trained didactically counted sides and corners randomly (e.g., "it's a fake triangle because it has 1…2…3…4…5…6…"). In effect, these children appeared to learn *that* counting was important, but not *why* it mattered for determining the shapes' properties. Thus, it appears that guided play helps direct children's attention to key defining shape features and prompts deeper conceptual processing.

Children in free play showed highly rigid shape concepts, accepting approximately 50% of typical shapes and only 15% of atypical shapes. This parallels previous findings (e.g., Uttal, O'Doherty, Newland, Hand, & DeLoache, 2009) suggesting that children may fail to extract key concepts when engaging in free play behaviors—even with enriched materials. During free play, children chose to create designs or tell stories with the shapes and construction sticks rather than sorting or comparing shapes. Thus, children were less likely to notice the definitional features because these features were irrelevant to the child's chosen play task.

This research takes an initial step in discovering the potential mechanisms underlying the effectiveness of guided play. Specifically, the research shows how appropriate scaffolding through dialogic inquiry and engagement facilitate geometric shape learning. Free play alone does not provide sufficient information to help children form specific shape concepts. These experimental findings suggest that scaffolding techniques that heighten children's engagement, direct their attention and exploration, and facilitate their "sense-making" processes undergird learning and academic readiness (Alfieri, 2010; Honomichl & Chen, 2012).

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Mean Percent of Shapes (*SD*) Accepted During T1 Sorting Task Using Different Experimenters/Settings.

Appendix S1. Pedagogy Instructional Scripts.

Appendix S2. Experimenter/Setting Analyses.