Early Childhood Research Quarterly 36 (2016) 358–365

Contents lists available at ScienceDirect

Early Childhood Research Quarterly

Geometric toys in the attic? A corpus analysis of early exposure to geometric shapes

Ilyse Resnick[a,*], Brian N. Verdine[a], Roberta Golinkoff[a], Kathy Hirsh-Pasek[b]

[a] *University of Delaware, United States*
[b] *Temple University, United States*

A R T I C L E I N F O

Article history:
Received 5 July 2015
Received in revised form
24 November 2015
Accepted 16 January 2016

Keywords:
Spatial thinking
Shapes
Category learning
Input
STEM

A B S T R A C T

Preschoolers' experiences with shapes are important because geometry is foundational to aspects of mathematics and it is now part of the Common Core for school-readiness. Exposure to shapes also provides experiences that are key to developing spatial thinking more broadly. Yet achieving a strong conceptual understanding of geometric categories can extend well into elementary school (Satlow and Newcombe, 1998) despite a general sense that many kindergarten children "know their shapes." The extended time period may be partially a product of the nature of the spatial input to which children are exposed. This study characterizes the geometric input preschoolers receive from three sources: shape books, sorters, and interactive digital content. These shape materials were examined for the types of shapes they include. Shapes were further classified as canonical (e.g., equilateral triangles) vs. non-canonical (e.g., isosceles or scalene), and whether the shape was presented as a geometric form vs. everyday object and in isolation vs. embedded in a scene. The quantity of shape terms was documented for each shape material. The level of sophistication of associated shape language was assessed by tracking the presence of geometric adjectives and explicit definitions. Findings suggest that children are exposed to a limited number of shape categories and very few non-typical variants within those categories. Shapes were typically labeled with only a single generic identifier (e.g., *triangle*) and few of the materials provided explicit definitions, geometric adjectives (e.g., *scalene*), or identified similarities and differences across shapes. Findings suggest a need for more thoughtful design of shape learning materials to provide variety and evoke discussion of their defining properties.

1. Introduction

Identifying, visualizing, and manipulating geometric forms (i.e., shapes) builds a foundation for understanding a wide range of mathematical concepts, including measurement, part-whole relations, cardinal knowledge, composition, decomposition, and the number line (Cross, Woods, & Schweingruber, 2009; Casey, Nuttall, Pezaris, & Benbow, 1995; Sarama & Clements, 2004; Gunderson, Ramirez, Beilock, & Levine, 2012). Exposure to shapes has been identified as a particularly valuable opportunity for children to practice the mental manipulation of spatial information (Cross et al., 2009). Spatial thinking in childhood, in turn, is predictive of science, technology, engineering, and mathematic (STEM) achievement (Kyttälä & Lehto, 2008; Mix & Cheng, 2012; Newcombe, Levine, & Mix, 2015; Wai, Lubinski, & Benbow, 2009), a link that is observed as early as preschool and kindergarten (Grissmer et al., 2013; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Verdine, Lucca, Golinkoff, Newcombe, & Hirsh-Pasek, in press). Preschool and kindergarten mathematics standards now emphasize early geometry knowledge and understanding of related spatial terminology (National Governors Association Center for Best Practices, 2010; Office of Head Start, 2011). For example, the Common Core Standards state that children should be able to: 1) "describe objects in the environment using names of shapes"; 2) "correctly name shapes regardless of their orientations or overall size"; and 3) "analyze and compare two- and three-dimensional shapes, in different sizes and orientations, using informal language to describe their similarities, differences, parts..." Thus, shape knowledge is vital for school readiness.

Yet children can have difficulty learning geometric forms well into elementary school (Satlow & Newcombe, 1998). It is not clear how children eventually induce the key properties that define geometric forms from their experiences interacting with shapes.

---

[*] Corresponding author at: University of Delaware, School of Education, Willard Hall, Newark, DE, 19716, United States. Fax: +1 302 831 4110.
E-mail address: iresnick@udel.edu (I. Resnick).

http://dx.doi.org/10.1016/j.ecresq.2016.01.007

Language corpora exist for the study of language input, but no studies have systematically explored the nature of the shape exposure children receive. Given that parents' spatial language (including shape terms) is uniquely predictive of children's spatial ability (Pruden, Levine, & Huttenlocher, 2011), one potential source of shape input is parents' and possibly teachers' spatial and shape language. Unfortunately, parents and early childhood teachers infrequently use geometric terms. For example, geometric terms (e.g., *triangle*, *circle*) comprised only 0.11% of all words produced by parents in everyday speech with children aged 20–27 months (Verdine et al., in press). However, exposure to shape input is likely important in shape learning at even earlier ages; children already can discriminate between shapes by two and half months (Schwartz, Day, & Cohen, 1979). Further, only 1.2% of the mathematics-related words used by teachers with children ranging from birth to five years of age are about geometric forms (Rudd, Lambert, Satterwhite, & Zaier, 2008). The minimal time teachers do spend on geometry is focused on identification of shapes and not on the core or defining properties of shape categories (Sarama & Clements, 2004). Children are typically asked to identify a shape (e.g., a triangle) but no further explanation of shape properties is provided (e.g., a triangle has three sides and three angles). As children learn through play – especially in these preschool years (Hirsh-Pasek & Golinkoff, 2008) – promising sources of geometric input include books and play materials, such as toys and interactive digital content. Shape sorters and books have traditionally been used for learning about shapes. More recently, a new educational medium has become prevalent: touchscreen applications or "apps" (Hirsh-Pasek, Zosh et al., 2015).

The aim of this study is to characterize preschool children's exposure to geometric form input. Given that parents and teachers rarely talk about shapes (Rudd et al., 2008; Verdine et al., in press), we have identified an alternative source of geometric input: shape learning materials in the form of books, sorters, and apps. To characterize the shape input children receive from these sources we ask three related questions: (1) what shapes are presented; (2) how are these shapes depicted; and (3) what (if any) additional information is provided regarding the shapes that might help children learn them? The examination of shape input is analogous to the characterization of language input. Without knowing how children are exposed to shapes (or to language) we cannot know how the environment supports young children's inductions about shapes or about the language(s) they are learning (Gathercole & Hoff, 2008).

It is important to note that there may be factors other than input that may also contribute to shape learning, which are not assessed in the current study. For example, perceptual features of the shapes, such as the relative length of sides or the orientation in which they are presented, may make the shapes more difficult to discriminate. When an equilateral triangle, for instance, is presented on its side, instead of with the point at the top, identifying it may be challenging (Wohlwill & Wiener, 1964). Additionally, cognitive processes such as executive function may also play a role in shape learning in that, for example, failing to inhibit an incorrect response to a rectangle may make it harder for children to learn its true name. However, if the properties of shape materials observed in this analysis align with reported shape learning difficulties, it suggests that these shape learning materials play an important role in shape understanding. For example, while 3-to-6-year-olds are fairly accurate in identifying circles (96% accuracy, Clements, Swaminathan, Zeitler Hannibal, & Sarama, 1999), they are far less accurate with other shapes (e.g., 54% accuracy in identifying rectangles; Clements et al., 1999). Is it the case that shape books and toys do not typically include *rectangles* and often include *circles*?

1.1. What types of geometric forms are included in shape materials?

A wide variety of classic geometric shapes (e.g., triangle, square) and iconic shapes (e.g., star, cross) can be presented in children's shape materials, and these shapes can be canonical or non-canonical variants. Canonical shapes are the "standard" or "archetype" version of that shape, typically possessing equilateral properties. Non-canonical shapes, then, are unusual shape variants, typically with sides and angles of varying sizes. For example, an equilateral triangle or a square would both be considered canonical variants of their shape categories (triangle and quadrilateral, respectively), whereas any other triangle (e.g., scalene triangles: triangles with three sides of different lengths) and any other quadrilateral (e.g., trapezoids: quadrilaterals with sides of different lengths) would both be considered non-canonical. These distinctions are informative because accurate classification of non-canonical shapes is difficult for young children by comparison to canonical versions (Clements et al., 1999; Verdine et al., in press). For example, while equilateral triangles are identified by children as *triangles*, scalene triangles are often not (Satlow & Newcombe, 1998; Fisher, Hirsh-Pasek, Golinkoff, Singer, & Berk, 2011).

Given how long it takes children to appreciate the properties of geometric forms (Satlow & Newcombe, 1998), it may be the case that young children are not exposed to a diverse set of shapes within a superordinate shape category. Research indicates that exposure to varied instances of a category helps children appreciate the parameters of that category (Gentner & Namy, 1999; Goldenberg & Sandhofer, 2013; Tversky, 1977). Thus, seeing ten equilateral triangles is likely not as valuable for learning that triangles have three sides, as it would be to see ten triangles of varying types (e.g. *scalene*, *isosceles*, *right*). The properties of equilateral triangles – such as sides of equal length – do not define all *triangles*, and may unintentionally mislead. Inducing shape properties based on exposure to canonical instances alone is akin to learning the term *dog* exclusively from pictures of Chihuahuas; the learner might focus on common properties of Chihuahuas (e.g., small size) that do not define all dogs. Subsequently, the learner may have trouble understanding, for example, that Great Danes are also in the *dog* category and that small house cats are not. In both learning animals and shapes, inducing properties from a limited number of similar instances increases the chance of making induction-based errors.

1.2. How are the shapes depicted?

Shapes can be presented as geometric forms (e.g., a line drawing of a rectangle) or as everyday objects (e.g., a door as a rectangle), either in isolation (e.g., an image of just a door) or embedded in a scene (e.g., a front door of a house). Identifying shapes from within a complex scene, however, can be difficult for young children (Coates, 1972; Karl & Konstadt, 1971; for review see Busch, Watson, Brinkley, Howard, & Nelson, 1993), a finding that is used as the basis for the Embedded Figures test (Goodenough & Eagle, 1963). Verdine et al. (in press) also found that 30-month-olds had more difficulty identifying shapes presented as isolated everyday objects compared to isolated geometric forms.

Identifying shapes instantiated in everyday objects may be made more difficult for children due to mutual exclusivity, an assumption children make when learning words that a given object can only have one label (Markman, 1989). Mutual exclusivity makes it likely that children will resist new shape labels (e.g., *rectangle*) for common objects in their environment for which they already have a name (e.g., a door). Young children have also not yet mastered dual representation (DeLoache, 2000), which is required to understand that an object can simultaneously be an object itself *and* a symbol

Table 1
Exhaustive list of shapes present in the shape learning materials and their definitions.

Overarching Shape	Subcategories of Shape	Definitions of subcategory
Ellipse	Oval	A closed line forming a closed loop, where the sum of the distances from two points (foci) to every point on the line is constant
	Circle	A round plane whose boundary (the circumference) consists of points equidistant from the center
Triangle	Equilateral	A 3-sided flat shape with equal sides and angles (60 degrees)
	Right	A 3-sided flat shape with one interior angle is a right angle (90 degrees)
	Isosceles	A 3-sided flat shape with two equal sides and two equal angles
	Scalene	A 3-sided flat shape with no equal sides and no equal angles
Quadrilateral	Isosceles trapezoid	A 4-sided flat shape with straight sides that has a pair of opposite sides parallel; the sides that aren't parallel are equal in length and both angles coming from a parallel side are equal
	Rectangle canonical	A 4-sided flat shape where every angle is a right angle (90 degrees); Opposite sides are parallel and equal in length. Canonical rectangles follow golden rule. Multiply long side by .5714 and again by .6666. If short side falls into this range, then rectangle is canonical. If short side falls out of this range, then it is non-canonical
	Rectangle non-canonical	A 4-sided flat shape where every angle is a right angle (90 degrees); Opposite sides are parallel and equal in length. Rectangles that do not follow the golden rule. Multiply long side by .5714 and again by .6666. If short side falls into this range, then rectangle is canonical. If short side falls out of this range, then it is non-canonical
	Square	Has 4 equal sides and every angle is a right angle (90 degrees)
	Rhombus	A 4-sided flat shape with straight sides where all sides have equal length. Opposite sides are parallel and opposite angles are equal.
Pentagon	Equilateral	A flat 5-sided shape with equal sides (and equal angles)
Hexagon	Equilateral	A flat 6-sided shape with equal sides (and equal angles)
	Scalene	A flat 6-sided shape with unequal sides and angles
Octagon	Equilateral	A flat 8-sided shape with equal sides (and equal angles)
Star	5-point star canonical	A pentagon with extended edges (5 points). Extended edges are all equal in length and angles are all the same
	5-point star non-canonical	A pentagon with extended edges (5 points). Extended edges are not equal in length and angles are different
	6+ star	A polygon with 6+ extended edges.
Iconic Shapes	Crescent	
	Cross	
	Heart	
	Arrow	
	Semi-circle	

for something, in this case the category *rectangle*. An additional barrier to identifying embedded shapes is that younger children have reduced cognitive control, resulting in them being easily distracted (Lavie, 2010). Thus, having to find a shape within a scene may actually provide the prospective learner with many alternative objects and colors to examine.

1.3. What (if any) additional information is provided regarding the shapes?

Rare parental talk about shapes emphasizes a potential role for books, sorters, and apps. These shape materials could offer labels, descriptions of defining properties, and relationships between shapes. When a *rectangle* and a *square* are presented together, for example, do the shape materials highlight that the two shapes are similar in that they both have four sides? Such distinctions may serve as a foundation for learning the hierarchical organization of shape terminology and may facilitate the learning of definition-based concepts for geometric forms as the quality and quantity of word exposure leads to greater proficiency in understanding (Hirsh-Pasek et al., 2015). Indeed, kindergarteners demonstrated an understanding more typical of older children after completing geometry activities that included explicit comparison of shapes for ‘sameness’ (Bruce, Sinclair, Moss, Hawes, & Caswell, 2015).

1.4. The current study

To study the issues presented above, the types of shapes included in books, sorters, and apps were identified. Shapes were classified as being canonical vs. non-canonical as well as whether the shape was a geometric form vs. everyday object and presented in isolation vs. embedded in a scene. Finally, we also examined the quantity of shape terms by documenting the shape labels provided, and the level of sophistication of associated shape language by tracking the presence of explicit definitions and geometric adjectives (e.g., scalene, isosceles).

Given the importance of geometry knowledge for school readiness within the Common Core standards, and the long-term impacts of spatial and mathematical skills in the STEM disciplines, it is essential to understand how children induce the geometric properties from their interactions with shapes. Here we focus on children's exposure to geometric forms through shape materials (books, sorters, and apps). Findings from this analysis are a crucial first step in understanding the opportunities children have to develop geometric and spatial skills.

2. Methods

2.1. Data acquisition

An analysis was conducted on 29 shape books (books), 20 physical shape sorter toys (sorters), and 20 shape-focused digital touchscreen applications (apps). To obtain these materials, we found them in the same way a parent might, by searching in libraries and online marketplaces, providing ecological validity to our study. The books were identified through an exhaustive search for preschool-aged shape books from public libraries within a 15-mile radius of the authors' institution. While these books were found at local libraries, all the books were also available for sale on Amazon.com, suggesting they are not regionally specific. Sorters were identified on Amazon.com (one of the largest retailers in the United States; Jopson, 2011) using the search term “shape sorting toys” in the “Toys & Games” department. The apps were identified using iTunes online, a near-exhaustive clearinghouse of available apps for phones and tablets, using the keywords “preschool”; “shape”; “toddler”; and “learning” in the “Educational” section. Using Amazon. com’s and iTunes. com’s algorithm for sorting searches based on popularity; we found the 20 most popular sorters and apps being sold on these sites. Although some children may be exposed to different toys with different characteristics; selecting the most popular shape materials; with many coming from readily recognizable brands and publishers; makes it likely that the majority of preschool children engaged with shape materials are similar to those described in our analysis. Online supplemental materials presents a list of all products analyzed in this study.

2.2. Data coding and analysis

The books, sorters, and apps were all analyzed in the same way. All geometric and iconic shapes included in the toys and books were identified. Geometric shapes included traditional shapes, such as circles, triangles, or n-sided shapes like pentagons and octagons. Iconic shapes included shapes that are symbolic of other things, such as stars, crescents, hearts, arrows, etc. Shapes were coded with the most specific term. For example, triangles were coded as “equilateral”, “isosceles”, or “scalene” triangles, and not coded as just “triangles.” Under this coding scheme, squares and rectangles are considered separate shapes.

Shapes were also coded as either canonical or non-canonical exemplars. Recall that canonical refers to the “standard” or “archetype” version of a shape category, and that non-canonical refers to unusual shape variants. Equilateral variants of a shape category were considered the canonical version. Shapes were measured using a ruler and protractor to determine if they were equilateral (even sides and angles). Indeed, many of the exemplars that were non-canonical actually appear to have been intended to be canonical versions but were either drawn with slightly different side lengths or different angles, especially among embedded forms which were sometimes drawn with cues to show 3-dimensional perspective. To prevent coder disagreements and interpretation of the intention of the material creators such shapes were considered non-canonical. For this reason, if anything, the coding system over-estimates the instances of non-canonical shapes. Shape sorters differed from books and apps in that they included three-dimensional figures that represent two-dimensional shapes; thus shapes in the shape sorters were identified using the two-dimensional outline of the hole that the shape pieces were inserted.

Shapes could be depicted in one of four ways (see Fig. 1): as an *isolated geometric form*—a single line drawing; an *embedded geometric form*—a single line drawing incorporated within a scene, such as a red circle representing a clown’s nose; an *isolated object*—a real world object that represents a geometric form, such as a door that represents a rectangle; or an *embedded object*—a real world object that represents a geometric form within a scene, such as a rectangular door on the front of a house. Shapes were coded for these depiction types.

Shape terms were any nouns or adjectives used to refer to a geometric (e.g., *circle*, *square*) or iconic (e.g., *star*, *heart*) shape. These included both proper mathematical terms (e.g., *rhombus*) and colloquial words for shapes (e.g., *diamond*). The coding scheme also tracked geometric adjectives that increased the specificity of the shape categories (e.g., *isosceles*, *scalene*, *obtuse*, *acute*, etc.), but most were exceedingly rare or nonexistent. A shape definition was coded when there was a description of a shape present in the materials (e.g., “a square has equal sides” or “a square has four corners”). Two undergraduate interns were trained on how to code the shape materials by the postdoctoral researcher overseeing this study and 20% of the shape materials were double coded. Comparison of the double coded materials by the postdoctoral research found that agreement between the two coders was 100% (i.e., kappa = 1), indicating a high degree of reliability in adult categorization of the shapes in the materials.

3. Results

3.1. What types of geometric forms are included in shape materials?

Table 1 provides an exhaustive list of the geometric shapes (e.g., triangle) and the iconic shapes (e.g., star) that were found in the shape materials. Table 2 shows the percentage of books, sorters, and apps containing each shape variant. A descriptive analysis revealed that the most common shape included across the books, sorters, and apps is circle (in 93% of books, 85% of sorters, and 95% of apps), while rectangle is included to a significantly lesser extent (in 72% of books, 20% of sorters, and 65% of apps). Circles were significantly more likely to be presented across shape learning materials compared with rectangles ($\chi 2 = 8.06$, $p = .006$, $\Phi = .342$). This finding is consistent with children’s knowledge of shapes from Clements et al. (1999) and Verdine et al. (in press), as both found that young children (3–6 years old and 2.5 years old, respectively) are relatively good at recognizing circles and much less accurate in recognizing rectangles.

All of the books, sorters, and apps focused on a small number of the same categories of shapes (see Fig. 2). There was a significant difference between books, sorters, and apps on the average number of shape categories presented in each product ($F(2, 66) = 9.22$, $p < .001$). Individual comparisons were assessed using a Tukey post hoc test to control for multiple comparisons. Apps ($t(66) = 4.29$, $p < .01$) and books ($t(66) = 2.43$, $p = .02$) had significantly more unique shapes compared to sorters. Apps and books were not significantly different from either after the Tukey correction (apps: $t(66) = 2.24$, $p > .05$).

The books, sorters, and apps also significantly differed on how many non-canonical shapes were included (see Fig. 2; $F(2, 66) = 19.19$, $p < .001$). Although the inclusion of non-canonical shapes was not common, a Tukey post hoc test of individual comparisons indicate books were most likely to include them. The number of non-canonical shapes in apps were intermediate between books and sorters, which had the least (books vs. apps: $t(66) = 2.7$, $p < .001$; books vs. sorters: $t(66) = 4.2$, $p < .01$; apps vs. sorters: $t(66) = 6.10$, $p < .01$).

3.2. How are the shapes depicted?

Only books and apps were analyzed for how shapes were depicted because the nature of the shape sorter required all of the shapes to be isolated geometric forms. See Table 3 for the number and percentage of books and apps that present shapes as geometric forms or as everyday objects (e.g., a door is a rectangle), either in isolation or embedded in a scene (e.g., the door in a house). Apps were more likely than books to present isolated geometric forms ($p = .029$; Fisher’s Exact Test); though a majority of both types of materials present shapes in this way. Books were more likely than apps to present shapes as an embedded object ($p < .001$; Fisher’s Exact Test). There is no statistical difference between books and apps on the presentation of the embedded geometric forms nor is there on the presentation of isolated objects. However, books depict

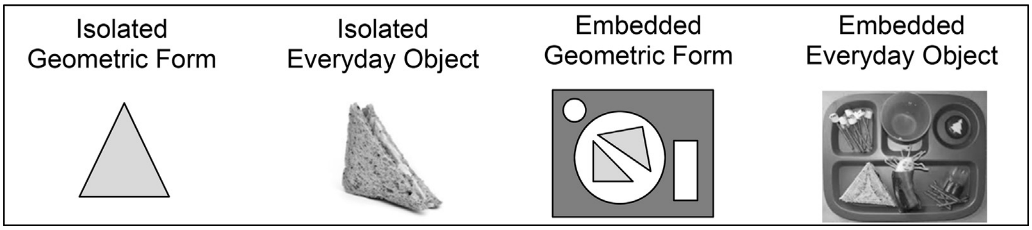

Fig. 1. Four ways shapes were depicted the shape learning materials.
Note: In order to determine the geometric forms intended by the shape learning materials, accompanying text was used to identify what kind(s) of shapes were included. In the example in this figure, for each depiction type, text may read, "Can you find any triangles?"

shapes in both of these ways approximately two times more often than apps. Taken together, these results suggest that books present shapes in a greater variety of ways compared to apps. When shapes are embedded in a scene, typically only one or two shapes are identified per page. One book also provided shape outlines transposed on top of the embedded everyday objects.

3.3. What (if any) additional information is provided regarding the shapes?

The format of shape sorters, due to the nature of the sorting activities, precluded the use of shape terms or shape definitions, and all of the shapes were isolated geometric forms. Of the books and apps that included the following shapes, all of them also used the following shape terms: *square*, *rectangle*, *triangle*, *pentagon*, *hexagon*, *octagon*, and *star*. Only one app refers to shapes using a greater level of specificity by using geometric adjectives such as *scalene*, *isosceles*, *equilateral*, and *right-angle*.

Colloquial terms were also sometimes used instead of the mathematical terms for shapes. For books and apps that presented a *rhombus*, 45% of apps (9 of 20) and 55% of books (16 of 29) used the term *diamond;* none of the books and only 10% of apps (2 of 20) actually used the proper geometric term *rhombus*. While 95% of apps (19 of 20) and 86% of books (25 of 29) used the term *circle*, interestingly two books (7%) used the term *round* to identify *circle* and never included the term *circle* anywhere. There were also three instances of *moon* compared to nine instances of *crescent*.

The language used to describe the geometric forms could provide more sophisticated information beyond simply naming shapes. While 51% of books provided explicit definitions of shape properties, sorters and apps did not include any definitions ($p < .001$; Fisher's Exact Test). Only one app used geometric adjectives (e.g., *scalene*, *equilateral*, *isosceles*) to describe types of a given shape. This same app was also the *only* shape material of the 69 coded to show the category membership of individual shapes within larger encompassing categories (e.g., *square* and *rectangle* as *quadrilaterals*). Thus, the vast majority of shape materials do not provide any explicit information about the properties of shape categories or the relationships between them. For example, shape materials could define rectangles as having "four straight sides and four right angles" and squares as having the same properties but also as having four equal sides.

4. Discussion

Early experiences with shape materials, and the geometry and spatial knowledge they foster, help form the bedrock on which later STEM-related skills are built. Thus, surveying the current landscape of shape-related materials is a crucial first step in finding ways to provide the most relevant experiences to preschoolers. The data in this corpus analysis drew its inspiration from studies of exposure in the language literature (Hoff, 2003; Hoff & Naigles, 2002; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991); just as children cannot induce the properties of language without sufficient language exposure, children cannot learn about the properties of geometric forms unless they encounter them. Although not exhaustive, our findings represent a significant cross section of the materials available for teaching shapes. It is important to

Table 2
Percentage of books, sorters, and apps containing each shape variant.

Shape category	Shape type	%of **Books** containing each shape type (N = 29)	%of **Sorters** containing each shape type (N = 20)	%of **Apps** containing each shape type (N = 20)
Ellipse	Circle	93	85	95
	Oval	55	15	80
Triangle	**Equilateral triangle**	48	85	90
	Non-canonical triangle	90	0	45
Quadrilateral	**Square**	90	85	90
	Rectangle	72	20	65
	Non-canonical quad.	83	25	60
Pentagon	**Equilateral pentagon**	0	35	50
	Non-canonical pentagon	0	0	0
Hexagon	**Equilateral hexagon**	10	30	35
	Non-canonical hexagon	4	0	0
Octagon	**Equilateral octagon**	0	15	40
	Non-canonical octagon	0	0	0
Iconic Shapes	**Star (5-point)**	10	60	50
	Non-canonical star	35	0	15
	Heart	31	0	55
	Crescent	28	0	25
	Other	10	50	35

Note 1: **Bold** shapes are the canonical variants of their overall shape category.
Note 2: "Other" includes quatrefoil (cross), trifoil (clover), half-circle, arrow, and spiral.
Note 3: Quasi-geometric shapes were not calculated in the average for the non-canonical shapes.

Table 3
Percentage of books and apps that depict shapes as geometric forms or as everyday objects (e.g., a door is a rectangle), either in isolation or embedded in a scene (e.g., the door in a house).

	Isolated Geometric Form	IsolatedEveryday Object	Embedded Geometric Form	Embedded Everyday Object
Books	20 of 20 (100%)	15 of 29 (52%)	15 of 29 (52%)	23 of 29 (79%)
Apps	22 of 29 (76%)	5 of 20 (25%)	5 of 20 (25%)	3 of 20 (15%)

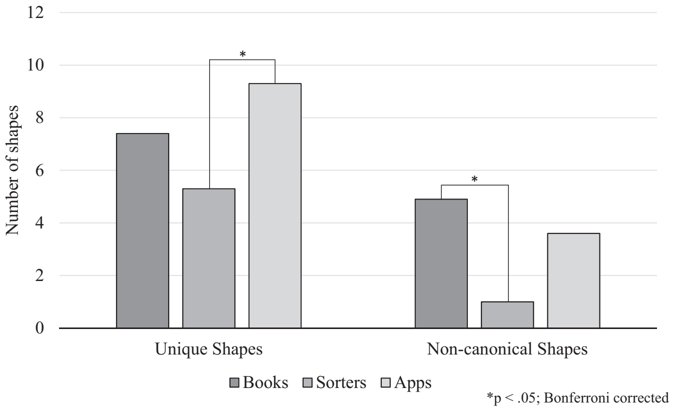

Fig. 2. Mean number of unique shapes and non-canonical shapes included in each toy type.

note that our analysis focused on shape learning materials for preschool children; as children get older, shape learning materials may differentiate from preschool materials in meaningful ways. One limitation of the study is that it is not clear in what settings these materials are being used: are parents, teachers, or both using these or other shape materials? Additionally, while searches of websites for other countries showed that a majority of these materials are also sold elsewhere, our analysis focused on materials widely available within the United States. The possibility exists that other cultures use shape materials that differ in interesting ways. Below we align our observational findings with findings from cognitive development, education, and the literature on parent–child interactions. We suggest educational approaches to teaching shape.

4.1. *What types of geometric forms are included in shape materials?*

Shape materials on the market tended to include only a small set of similar shapes; most materials focused on *circle*, *square*, *triangle*, and *star*. Strikingly, one of these four common shapes, the star, is only an iconic shape unlikely to be encountered in a mathematics class. There are many other shapes that could be included instead, such as n-sided polygons (e.g., hexagon, heptagon, etc.) or rectangles, which are relatively rare. While books provided more instances of non-canonical shape variants than apps and sorters, overall the shape materials did not frequently do so. For example, while 85% of shape sorters included an equilateral triangle, none of them included other kinds of triangles such as scalene or isosceles. These findings suggest that young children are exposed to a very limited number of shape categories through their shape materials and within those categories they tend to see only canonical variants.

The educational quality of shape materials would likely benefit from the incorporation of a wider variety of shapes, especially the inclusion of non-canonical shape variants within shape categories, because varied instances would be expected to allow children to extract the defining properties of shape categories (Verdine et al. in press). This is not to say that canonical shapes should be replaced; rather, where appropriate, shape materials might include both typical and atypical shapes in a way that invites comparison. In addition, when presented with varied examples, adults are more likely to use labels that identify category membership (Shipley, Kuhn, & Madden, 1983). For example, a scalene triangle might elicit a comment such as, “It may not look like one, but this is a triangle too!” Comments like this, in turn, invite comparison between shapes, both within and between categories, and might contribute to children forming more accurate, definition-focused categories (Liu, Golinkoff, & Sak, 2001; Shipley et al., 1983; Waxman, 1990). Thus, shape materials that incorporate varied instances of shapes would be expected not only to change the shapes to which children are exposed, but also to fundamentally impact the amount and quality of information that parents and early educators naturally communicate about them. This issue is one we are currently investigating in our research.

4.2. *How are the shapes depicted?*

The most common way shapes were depicted across all shape materials was as isolated geometric forms. While books frequently presented shapes in other ways (e.g., embedded everyday objects), interestingly, apps depicted shapes the same way as shape sorters: only as isolated geometric forms. Hirsh-Pasek, Zosh et al. (2015) argued that apps for young children are in the “first wave” and are essentially just transferring materials available in physical formats into a digital medium. Our results are in line with that conclusion. However, given that apps are digital, they are not constrained by some of the practical limitations of a physical medium (e.g., limited pages), and could be designed to present shapes with nearly limitless variety. Perhaps in the “second wave” app developers will be guided by this research and the science of learning to create more variety in the depiction styles and shapes they incorporate.

Identifying shapes instantiated within everyday objects, as children’s books often do, may require overcoming hurdles of mutual exclusivity (Markman, 1989) and dual representation (DeLoache, 2000). When learning the word for a new object, children tend exhibit a whole-object bias, interpreting the new word as referring to the whole object and not as a component part (Hollich, Golinkoff, & Hirsh-Pasek, 2007; Landau, Smith, & Jones, 1988). Children already know some of the functions and labels for many of the objects we use to teach shapes (e.g., door). Therefore, they may resist the novel shape label (e.g., “this is a rectangle”) or struggle to ignore the primary purpose of the object to appreciate it as a valid symbol for a class of shapes. Indeed, in one study (Verdine et al. in press), when asked to identify a particular shape from a set of two different shapes, 30-month-olds were more accurate identifying isolated geometric objects (e.g., rectangle) compared to isolated everyday objects depicting a shape (i.e., door).

When presenting shapes instantiated within objects, it may help the child to identify the object first and then direct the child’s attention to the shape as an attribute of the object (Verdine et al. in press). A similar approach has been used to teach children the term *angle*. When shown intersecting lines depicting an *angle*, 4- and 5-year-old children often erroneously believe *angle* references the figure as a whole and not the degree of intersection between the lines (Gibson, Congdon, & Levine, 2014). Providing children with a label for the overall figure *first*, however, helps them to interpret the term correctly (Gibson et al., 2014; Hall, Waxman, & Hurwitz, 1993; Markman & Wachtel, 1988). Analogously, for shape learning, first identifying the object with its familiar label (e.g., door), and then describing the object's shape (e.g., "the door is in the shape of a rectangle") may help the child develop the correct reference frame. However, this practice was not observed in this data set.

4.3. What (if any) additional information is provided regarding the shapes?

Most shape materials did not provide information beyond labeling the shape; they did not provide information about the properties of shapes or highlight the relationships between shapes, essentially requiring children to induce the properties of shape categories with little guidance that would scaffold their learning. Providing explicit information about shape categories in play materials may help children in attending to important features, especially for children with weaker language or induction skills (Penno, Wilkinson, & Moore, 2002). Another important aspect of including information about shape properties in shape materials is that it may emphasize to parents the relevance of such information. Even well trained preschool teachers rarely discuss shape properties (Sarama & Clements, 2004) so highlighting the important defining features could be especially useful for prompting shape talk. The design of children's shape materials can potentially influence how children play with these materials and the interactions they have with adults (Christie & Roskos, 2006; Ferrara, Golinkoff, Hirsh-Pasek, Lam, & Newcombe, 2011; Fisher et al., 2011). Traditional paper books, for example, foster more dialogic reading and a greater focus on content compared to battery-operated electronic books (Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, & Collins, 2013). In parallel fashion, the use of traditional shape toys without batteries fosters more spatial language and varied speech compared to electronic shape sorters that name shapes for children (Zosh et al., 2015). Describing the specific sub-categories of shapes or the hierarchical relationships between shapes along with the materials may provide parents with relevant shape language and promote the discussion of geometric properties with their children.

Future research should examine the influence of increasing shape variety in different shape learning materials (e.g., book, sorter, or app) on parent-child interactions. Specifically, how might parents' language differ as a function of the shape materials used, and how might different types of interactions relate to children's understanding of geometric properties? Ferrara et al. (2011), for example, found that while playing with blocks naturally elicits parents' use of spatial language, providing parents with instructions ("guided play"; Weisberg et al., 2013) significantly increased the frequency of spatial terms.

It seems apparent that parents, educators, and other experienced play partners *can* play an important role in early geometry knowledge. However, to optimize their impact on helping children learn about the properties of shapes, shape materials need to be designed to elicit the appropriate scaffolding from adults. Even quick explanations, with relatively little detail, are helpful for children learning novel words (Weizman & Snow, 2001). Additionally, children as young as four years of age develop more sophisticated and definition-focused shape concepts when they learn about the defining features of shapes through guided play (Fisher et al., 2013).

4.4. Conclusions

Perhaps not surprisingly, the shapes appearing in these materials seem to align with children's early geometry knowledge. The limited variety they contain may help to explain the extended timeframe necessary to understand the defining features of shapes (Clements et al., 1999; Satlow & Newcombe, 1998; Verdine et al. in press). While these findings do not reduce the possible influence of alternative factors (such as shape orientation) that may contribute to shape understanding, our results suggest that the available materials influence shape learning. More research is needed to examine other factors that may contribute to shape learning, and how the design of shape materials can be altered to optimize preschoolers' knowledge. Research is also needed to understand how the design of materials influences shape-based interactions between parents and children. Thus, the careful design of shape materials and tasks appear likely to influence the quality of the shape exposure children receive.

Regardless, the shape materials currently on the market appear woefully inadequate in providing the within and between category variety necessary for children to induce the defining properties of shapes that they are expected to know by early grade school. This is true even of material types that have fewer physical limitations on the variety of shapes that *could be* presented. For example, a book's pages have more "space" to include shapes than sorters. And apps could easily be designed to automatically generate a nearly limitless variety of both canonical and non-canonical variants of shapes.

Compounding problems with the variety of shapes presented, the materials that are available appear unlikely to elicit behaviors from adults that would support children's learning of shape properties. Most current designs do not invite comparison and contrast of different versions of shapes from the same categories, fail to provide adjectives (e.g., scalene, isosceles) to further delineate shapes within a category, and do not accommodate highlighting of the hierarchical nature of shape categories. To provide enriching early mathematical experiences to preschoolers it may be time to stow the current crop of geometric toys in the attic. We should design new ones that are more aligned with current research and that will naturally foster adult-child interactions that serve as a force-multiplier for learning.

Author Note

This research was supported by the National Science Foundation via the Spatial Intelligence and Learning Center (grant number SBE-1041707), National Institutes of Health Stimulus Grant 1RC1HD0634970-01, and Institute of Education Sciences (grant number R305B130012).

The authors would like to thank Madeline Lopez, Madison McCaffery, and Kelsey Lucca, for their research assistance and consultation on this project.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecresq.2016.01.007.

References

Bruce, C. D., Sinclair, N., Moss, J., Hawes, Z., & Caswell, B. (2015). Spatializing the curriculum. In B. Davis, & The Spatial Reasoning Study Group (Eds.), *Spatial Reasoning in the Early Years: Principles, Assertions, and Speculations*. New York, NY: Routledge.

Busch, J. C., Watson, J. A., Brinkley, V., Howard, J., & Nelson, C. (1993). Preschool embedded figures test performance of young children: age and gender differences. *Perceptual and Motor Skills*, *77*, 491–496.

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test-scores across diverse samples. *Developmental Psychology*, *31*, 697–705.

Christie, J. F., & Roskos, K. (2006). Standards, science, and the role of play in early literacy education. In D. Singer, R. M. Golinkoff, & K. Hirsh-Pasek (Eds.), *Play = learning: how play motivates and enhances children's cognitive and social–emotional growth* (pp. 57–73). New York, NY: Oxford University Press.

Clements, D. H., Swaminathan, S., Zeitler Hannibal, M. A., & Sarama, J. (1999). Young children's concepts of shape. *Journal for Research in Mathematics Education*, *30*, 192–212.

Coates, S. (1972). *Preschool embedded figures test: PEFT*. Palo Alto, CA: Consulting Psychologists Press.

Cross, C. T., Woods, T. A., & Schweingruber, H. (Eds.). (2009). Mathematics learning in early childhood: paths toward excellence and equity. In. Washington, DC: The National Academies Press.

DeLoache, J. S. (2000). Dual representation and young children's use of scale models. *Child Development*, *71*, 329–338.

Ferrara, K., Golinkoff, R. M., Hirsh-Pasek, K., Lam, W., & Newcombe, N. S. (2011). Block talk: spatial language during block play. *Mind Brain and Education*, *5*, 143–151.

Fisher, K., Hirsh-Pasek, K., Golinkoff, R. M., Singer, D., & Berk, L. E. (2011). Playing around in school: implications for learning and educational policy. In A. Pellegrini (Ed.), *The Oxford handbook of the development of play* (pp. 341–360). NY: Oxford University Press.

Fisher, K. R., Hirsh-Pasek, K., Newcombe, N., & Golinkoff, R. M. (2013). Taking shape: Supporting preschoolers' acquisition of geometric knowledge through guided play. *Child Development*, *84*, 1872–1878. http://dx.doi.org/10.1111/cdev.12091

Gathercole, V. C. M., & Hoff, E. (2008). Input and the acquisition of language: three questions. In E. Hoff, & M. Shatz (Eds.), *Blackwell handbook of language development* (2007) (pp. 107–127). Blackwell Publishing Oxford. http://dx.doi.org/10.1002/9780470757833, ch6

Gentner, D., & Namy, L. (1999). Comparison in the development of categories. *Cognitive Development*, *14*, 487–513.

Gibson, D. J., Congdon, E. L., & Levine, S. C. (2014). The effects of word-learning biases on children's concept of angle. *Child Development*, *86*, 319–326.

Goldenberg, E. R., & Sandhofer, C. M. (2013). Same, varied, or both?: contextual support aids young children in generalizing category labels. *Journal of Experimental Child Psychology*, *115*, 150–162.

Goodenough, D., & Eagle, C. J. (1963). A modification of the embedded-figure test for use with young children. *Journal of Genetic Psychology*, *103*, 67–74.

Grissmer, D. W., Mashburn, A. J., Cottone, E., Chen, W. B., Brock, L. L., Murrah, W. M., et al. (2013, April). Play-based after-school curriculum improves measures of executive function, visuospatial and math skills and classroom behavior for high risk K-1 children. In *Paper Presented at the Society for Research in Child Development*.

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: the role of the linear number line. *Developmental Psychology*, *48*, 1229–1241.

Hall, D. G., Waxman, S. R., & Hurwitz, W. M. (1993). How two- and four-year-old children interpret adjectives and count nouns. *Child Development*, *64*, 1651–1664.

Hirsh-Pasek, K., Adamson, L., Bakeman, R., Owen, M., Golinkoff, R., Pace, A., et al. (2015). The contribution of early communication quality to low-income children's language success. *Psychological Science*, http://dx.doi.org/10.1177/0956797615581493

Hirsh-Pasek K., Golinkoff R. M., (2008). Why play = learning. In A. Petitclerc (Ed.), Encyclopedia on early childhood development.

Hirsh-Pasek, K., Zosh, J., Golinkoff, R., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in educational apps: lessons from the science of learning. *Psychological Science in the Public Interest*, *16*, 3–34.

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*, 1368–1378.

Hoff, E., & Naigles, L. (2002). How children use input in acquiring a lexicon. *Child Development*, *73*, 418–433.

Hollich, G., Golinkoff, R. M., & Hirsh-Pasek, K. (2007). Young children associate novel words with complex objects rather than salient parts. *Developmental Psychology*, *43*, 1051–1061.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: relation to language input and gender. *Developmental Psychology*, *27*, 236–248.

Jopson, B. (2011). *Amazon urges California referendum on online tax*. Financial Times. July 12.

Karl, S. A., & Konstadt, N. (1971). Children's embedded figures test. In H. A. Witkin, K. Oltman, E. Raskin, & S. A. Karp (Eds.), *A manual for the embedded figures tests* (pp. 21–26). Consulting Psychologists Press: Palo Alto CA.

Kyttälä, M., & Lehto, J. E. (2008). Some factors underlying mathematical performance: The role of visuospatial working memory and non-verbal intelligence. *European Journal of Psychology of Education*, *23*, 77–94.

Landau, B., Smith, L. B., & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development*, *3*, 299–321.

Lavie, N. (2010). Attention, distraction and cognitive control under load. *Current Directions in Psychological Science*, *19*(3), 143–148.

Liu, J., Golinkoff, R. M., & Sak, K. (2001). One cow does not an animal make: young children can extend novel words at the superordinate level. *Child Development*, *72*(6), 1674–1694.

Markman, E. (1989). *Naming and Categorization in Children*. MIT Press.

Markman, E. M., & Wachtel, G. F. (1988). Children's use of mutual exclusivity to constrain the meanings of words. *Cognitive Psychology*, *20*, 121–157.

Mix, K. S., & Cheng, Y. L. (2012). The relation between space and math: developmental and educational implications. In B. Janette Benson (Ed.), *Advances in child development and behavior* (vol. 42) (pp. 197–243). Burlington: Academic Press.

National Governors Association Center for Best Practices, Council of Chief State School Officers (2010). *Common Core State Standards for Mathematics.* Washington D.C.: National Governors Association Center for Best Practices, Council of Chief State School Officers.

Newcombe, N. S., Levine, S. C., & Mix, K. S. (2015). Thinking about quantity: The intertwined development of spatial and numerical cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(6), 491–505. http://dx.doi.org/10.1002/wcs.1369

Parish-Morris, J., Mahajan, N., Hirsh-Pasek, K., Golinkoff, R. M., & Collins, M. F. (2013). Once upon a time: parent–child dialogue and storybook reading in the electronic era. *Mind Brain, and Education*, *7*, 200–211.

Penno, J. F., Wilkinson, I. A. G., & Moore, D. W. (2002). Vocabulary acquisition from teacher explanation and repeated listening to stories: do they overcome the Matthew effect? *Journal of Educational Psychology*, *94*, 23–33.

Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: does talk about the spatial world matter? *Developmental Science*, *14*, 1417–1430. http://dx.doi.org/10.1111/j.1467-7687.2011.01088.x

Rudd, L. C., Lambert, M., Satterwhite, M., & Zaier, A. (2008). Mathematical language in early childhood settings: what really counts? *Early Childhood Education Journal*, *36*(1), 75–80.

Sarama, J., & Clements, D. H. (2004). Building blocks for early childhood mathematics. *Early Childhood Research Quarterly*, *19*, 181–189.

Satlow, E., & Newcombe, N. (1998). When is a triangle not a triangle?: young children's developing concepts of geometric shape. *Cognitive Development*, *13*, 547–559.

Schwartz, M., Day, R. H., & Cohen, L. B. (1979). Visual shape perception in early infancy. *Monographs of the Society for Research in Child Development*, *44*(7), 1–63. http://dx.doi.org/10.2307/1165963

Shipley, E. F., Kuhn, I. F., & Madden, E. C. (1983). Mothers' use of superordinate category terms. *Journal of Child Language*, *10*, 571–588.

Tversky, A. (1977). Features of similarity. *Psychological Review*, *84*, 327–352.

Verdine, B. N., Lucca, K. R., Golinkoff, R. M., Newcombe, N. S., & Hirsh-Pasek, K. (2016). The shape of things: the origin of young children's knowledge of the names and properties of geometric forms. *The Journal of Cognition and Development*, http://dx.doi.org/10.1080/15248372.2015.1016610. Advanced online publication

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. S. (2014). Finding the missing piece: blocks, puzzles, and shapes fuel school readiness. *Trends in Neuroscience and Education*, *3*, 7–13.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*, 817–835.

Waxman, S. R. (1990). Linguistic biases and the establishment of conceptual hierarchies: evidence from preschool children. *Cognitive Development*, *5*, 123–150.

Weisberg, D. S., Hirsh-Pasek, K., & Golinkoff, R. M. (2013). Guided play: Where curricular goals meet a playful pedagogy. *Mind, Brain, and Education*, *7*, 104–112. http://dx.doi.org/10.1111/mbe.12015

Weizman, Z. O., & Snow, C. E. (2001). Lexical input as related to children's vocabulary acquisition: effects of sophisticated exposure and support for meaning. *Developmental Psychology*, *37*, 265–279.

Wohlwill, J. F., & Wiener, M. (1964). Discrimination of form orientation in young children. *Child Development*, *35*(4), 1113–1125. http://dx.doi.org/10.2307/1126858

Zosh, J. M., Verdine, B. N., Filipowicz, A., Michnick Golinkoff, R., Hirsh-Pasek, K., & Newcombe, N. S. (2015). Talking shape: parental language with electronic versus traditional shape sorters. *Mind, Brain, and Education*, *9*(3), 136–144. http://dx.doi.org/10.1111/mbe.12082