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Beyond numeracy in preschool: Adding patterns to the equation☆

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ABSTRACT

Patterns are a pervasive and important, but understudied, component of early mathematics knowledge. In a series of three studies, we explored (a) growth in children's pattern knowledge over the pre-K year ($N = 65$), (b) the frequency of pattern activities reported by parents ($n = 20$) and teachers ($n = 5$) relative to other mathematical activities, and (c) changes in 4-year-old children's pattern knowledge after brief experience generating or receiving explanations on patterns ($N = 124$). Together, these studies illustrate the types of experiences preschool children are receiving with patterns and how their pattern knowledge changes over time and in response to explanation. Young children are able to succeed on a more sophisticated pattern activity than they are frequently encouraged to do at home or at school.

Introduction

"It's a pattern!" Young children, parents, teachers, and educational TV and games all emphasize patterns in the world. Patterns are a predictable sequence, and the first patterns young children usually interact with are repeating patterns (i.e., linear patterns that have a unit that repeats, such as the colors blue–blue–red–blue–blue–red). Exploring pattern and shape was the most common mathematical activity observed during the play of 4- and 5-year-olds, accounting for 20–40% of the observed time in U.S. preschools (Ginsburg, Inoue, & Seo, 1999; Ginsburg, Lin, Ness, & Seo, 2003). Preschool teachers also view pattern activities as important (Clarke, Clarke, & Cheeseman, 2006; Economopoulos, 1998), and educational games and TV shows often incorporate them.

In addition to being a common topic for young children, patterns are considered a central idea in mathematics (Charles, 2005; Sarama & Clements, 2004; Steen, 1988). Identifying, extending, and describing predictable sequences in objects or numbers are core to mathematical thinking. For example, counting and arithmetic principles describe generalizations of predictable sequences, such as the next number name in the count sequence represents a magnitude that is exactly one more than the previous number name (the successor function). Similarly, functional relationships capture predictable input–output relations between two variables (e.g., $y = 2x + 5$). Working with repeating patterns provides early opportunities to identify and describe predictable sequences, and many early mathematics education researchers consider patterns to be central to early mathematics thinking, particularly algebraic thinking (Burton, 1982; Fox, 2005; Lee & Freiman, 2006; Mulligan & Mitchelmore, 2009; Papic, Mulligan, & Mitchelmore, 2011; Papic, 2007; Sarama & Clements, 2004; Warren & Cooper, 2006).

New research on patterns provides strong evidence that pattern knowledge is central to mathematics achievement. In a six-month intervention, struggling first-grade students were randomly assigned to learn about patterns, numeracy, reading, or social studies. Across two studies, children who received pattern instruction performed as well or better on several standardized mathematics assessments relative to children who received numeracy instruction, and systematically better than children who received reading or social studies instruction (Kidd et al., 2013, 2014). A specialized

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preschool pattern intervention that focused on the unit of repeat in repeating patterns supported greater knowledge of both repeating and growing patterns in Kindergarten (Papic et al., 2011) and knowledge of repeating patterns has been used to support thinking about ratios (Warren & Cooper, 2007). Further, pattern knowledge in elementary school is predictive of algebraic proficiency a year later (Lee, Ng, Bull, Pe, & Ho, 2011). Thus, multiple studies indicate that understanding patterns is important for mathematics achievement.

Despite the importance of patterns, a vast majority of research on early mathematics focuses exclusively on numeracy (Sarama & Clements, 2004). To help address our limited knowledge of early development of pattern knowledge, the goals of the current paper were to explore growth in repeating pattern knowledge over the pre-K year (Study 1), describe exposure to pattern activities reported by parents and teachers (Study 2), and explore the impact of explanations in learning to abstract patterns (Study 3). In the next section, we review what is known about early development of pattern knowledge.

From duplicating and extending to more sophisticated pattern tasks

The most common and popular pattern tasks for preschoolers are creating, duplicating, and extending repeating patterns (Economopoulos, 1998). For example, children are shown an ABBABB pattern and asked to make an exact replica of the pattern (duplicate) or to continue the pattern (extend, see top row of Fig. 1). This is in line with the NAEYC Standard 2.F.08: "Children are provided varied opportunities and materials that help them recognize and name repeating patterns" (NAEYC, 2014, p. 17). Many 4-year-old children can duplicate repeating patterns and some can extend patterns (Clements, Sarama, & Liu, 2008; Papic et al., 2011; Starkey, Klein, & Wakeley, 2004).

However, duplicating and extending patterns can be completed using object-matching strategies and may not stand up to mathematical considerations (Threlfall, 1999). Mathematical patterns rest on generalizing and abstracting relationships that go beyond object matching. As Economopoulos (1998) noted, "To generalize and predict, children must move from looking at a pattern as a sequence of 'what comes next' to analyzing the structure of the pattern, that is, seeing that it is made of repeating units" (p. 230). Thus, children must learn to identify the pattern unit: the part of the pattern that repeats (Clements & Sarama, 2009; Papic et al., 2011).

We propose that *pattern abstraction* helps young children learn to focus on the pattern unit, making it a more mathematically relevant task than duplicating and extending patterns. Pattern abstraction requires making the *same kind of pattern* using new objects. For example, children might be shown a blue–yellow–yellow–blue–yellow–yellow pattern and be asked to create the same kind of pattern using orange squares and circles (see Fig. 1). This abstraction requires children to pay attention to the overall structure of the pattern rather than its surface features. Pattern abstraction cannot be executed using an object-matching strategy, and it emphasizes the need to abstract the relationships beyond specific objects. This task has been recommended by some educators, but without empirical evidence on the difficulty, validity, or value of the task (Clements & Sarama, 2009; Mulligan & Mitchelmore, 2009; Warren & Cooper, 2006).

Children also learn to explicitly recognize the pattern unit (*pattern unit recognition*), such as identifying the set of elements that repeat. For example, children have been asked to say or to circle the part of the pattern that is repeating (Papic et al., 2011; Warren & Cooper, 2006) or to use the smallest number of objects to make their own pattern while keeping the pattern the same as in the model pattern (Sarama & Clements, 2010). A less explicit measure is to ask children to reproduce a pattern from memory with the same number of units as the model pattern (Papic et al., 2011). Children who are successful on this task typically verbalized the pattern unit and noted how many times it repeated.

In a recent study, we found that a substantial minority of 4-year-old children was able to abstract patterns (Rittle-Johnson, Fyfe, McLean, & McEldoon, 2013). Children participated in the Fall of their pre-K year (the year before starting Kindergarten), and most children could duplicate patterns and about half could extend patterns. Pattern abstraction was more difficult than duplicating and extending patterns, but was achievable by some preschool children. Very few 4-year-old children were successful with explicit pattern unit recognition. This study led to a four-level construct map for repeating pattern knowledge, which was an extension of the learning trajectory for patterns and structure proposed by Clements and Sarama (2009). A *construct map* represents the continuum of knowledge through which people are thought to progress, but it is not comprised of distinct stages as knowledge progression is continuous and probabilistic (Wilson, 2005). At Level 1, children can duplicate patterns, and at Level 2, they can extend patterns. At Level 3, children can abstract the underlying pattern well enough to generate a pattern using different materials. At this level, children must be able to represent the pattern at a non-perceptual level to recreate the pattern with new materials. Finally, at Level 4, children can explicitly recognize the smallest unit of a pattern. Thus, Levels 3 and 4 of our construct map go beyond basic skills with repeating patterns and assess children's understanding of pattern units. See Fig. 1 for sample items from each level.

Current study

In the current study, we extend this prior research by evaluating growth in repeating pattern knowledge over the pre-K year (Study 1) and describing exposure to pattern activities reported by parents and teachers (Study 2). This is meant to provide background information on knowledge change and potential sources of this change. The final study explores the impact of explanations in learning to abstract patterns (Study 3).

Study 1

In the Fall of their pre-K year, we found large individual differences among 4-year-old children in their repeating pattern knowledge, spanning across the four knowledge levels hypothesized in our construct map (Rittle-Johnson et al., 2013). We reassessed the same children near the end of their pre-K year to evaluate growth in their pattern knowledge.

Method

Participants. Sixty-five of the 66 children from the initial study participated at follow-up (36 females). One child had moved away. Children attended one of six pre-K classes at four preschools. Three of the preschools served primarily Caucasian, middle- and upper-middle-class children ($n = 47$), and the other preschool had a publicly funded pre-K program serving primarily African American, low-income children (i.e., all children qualified for free- or reduced-lunch; $n = 18$). Approximately 35% of the participants were racial or ethnic minorities (26% African American), and their average age was 5.2 years (range = 4.7–5.9 years).

Materials. We used the same 10-item assessment administered in our previous study, which had been adapted from previous assessments (Papic et al., 2011; Sarama & Clements, 2010; Starkey et al., 2004). As shown in Table 1, there was one Level-1 item (duplicate a pattern), two Level-2 items (extend a pattern), four Level-3 items (abstract a pattern) and three Level-4 items (pattern unit