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Which preschool mathematics competencies are most predictive of fifth grade achievement?

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ABSTRACT

In an effort to promote best practices regarding mathematics teaching and learning at the preschool level, national advisory panels and organizations have emphasized the importance of children's emergent counting and related competencies, such as the ability to verbally count, maintain one-to-one correspondence, count with cardinality, subitize, and count forward or backward from a given number. However, little research has investigated whether the kind of mathematical knowledge promoted by the various standards documents actually predict later mathematics achievement. The present study uses longitudinal data from a primarily low-income and minority sample of children to examine the extent to which preschool mathematical competencies, specifically basic and advanced counting, predict fifth grade mathematics achievement. Using regression analyses, we find early numeracy abilities to be the strongest predictors of later mathematics achievement, with advanced counting competencies more predictive than basic counting competencies. Our results highlight the significance of preschool mathematics knowledge for future academic achievement.

1. Introduction

Public concern about children's mathematics achievement is abundant and growing. In an increasingly technology- and information-based society, young children's mathematical development and proficiency has become an important predictor of later labor market success (Ritchie & Bates, 2013; Rose, 2006). Mathematical competencies are needed for a growing number of professional tasks, and jobs currently require higher mathematical proficiency than ever before (National Mathematics Advisory Panel (NMAP), 2008). Empirical work suggests that children's early competencies set the course for their later achievement, with the mathematics competencies children demonstrate at school entry being the strongest predictors of their later school achievement (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Bailey, Siegler, & Geary, 2014; Claessens & Engel, 2013; Claessens, Duncan, & Engel, 2009; Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Watts, Duncan, Siegler, & Davis-Kean, 2014). National panels (National Association for the Education of Young Children (NAEYC) and the National Council of Teachers of Mathematics (NAEYC & NCTM, 2002); NCTM, 2007; NMAP, 2008) have responded to this growing body of research by calling for comprehensive mathematics curricula targeted at preschool-aged children.

The motivation for the current interest in early predictors of mathematics achievement is straightforward: if strong predictors of later success are found, and if these factors can be successfully targeted by practitioners early in school, then perhaps the education system can prevent at-risk children from falling further behind (Gersten, Jordan, & Flojo, 2005). Unfortunately, students from low-income backgrounds have been shown to start school well behind their higher-income peers in mathematics, and these gaps appear to only grow wider as they progress through school (Burchinal et al., 2011; Case & Okamoto, 1996; Fryer & Levitt, 2004; National Research Council (NRC), 2009). It is likely that the differences seen in early mathematics ability between low- and high-income children are related to early exposure, or lack thereof, to mathematics (Baroody, 2003; Case, Griffin, & Kelly, 1999). This presents challenges for educational practitioners, as low-income children typically enter school ill-prepared for the increasingly academic content taught in early-grade classrooms (Bassok, Latham, & Rorem, 2016; Clements, Sarama, & DiBiase, 2004; Starkey, 2007).

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Not only is it important to know what the key competencies are for these students, but also it is important to know what competencies predict later mathematics success for two reasons. First, assessing these competencies can help researchers and practitioners identify children likely to struggle with math, so that we can target more services toward these children. Second, if there are skills found to be predictive of later mathematics achievement and we have strong theoretical reasons to believe these skills are important, then we may be able to design interventions to teach these skills.

In the present study, we investigated various domains of preschool mathematical knowledge and their relation to fifth grade mathematics achievement. We were particularly interested in testing the hypothesis that advanced counting skills among preschool children is uniquely predictive of their overall mathematics achievement. We took a closer, finer-grained approach that can contribute to our theoretical understanding of the developmental relationships between different sets of children's mathematical competencies and thus help practitioners considerably improve early mathematics education.

2. Background

2.1. Early mathematics knowledge among low-SES children

Children's mathematics achievement trajectories are established early in elementary school and tend to persist in later grades (NRC, 2009). Many of these children are likely to be from low-income and disadvantaged backgrounds, as children from low-SES families begin school with less mathematical knowledge than their peers from higher SES families (Jordan, Huttenlocher, & Levine, 1992; Reardon & Portilla, 2015; Starkey, Klein, & Wakeley, 2004; Starkey & Klein, 2008) owing in part to the fact that their home learning environments are less rich mathematically (Blevins-Knabe & Musun-Miller, 1996; Siegler, 2009). As a result, SES-related gaps in mathematical knowledge appear early and widen during early childhood (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Sarama & Clements, 2009).

Children's early mathematical experiences in the home, such as the complexity of numeracy activities, differ by the family socioeconomic background. For example, Levine et al. (2010) that mothers from low-SES backgrounds provide more input about simple verbal counting, whereas parents from high-SES backgrounds emphasize more advanced number sense skills (such as numerical magnitude estimation and connecting counting to cardinality). Although it is important to identify reasons as to why and how children from low-SES families are behind in their early mathematical abilities compared with their high-SES counterparts, it is equally as important to pinpoint the early competencies low-SES children need to have prior to entering elementary school that will provide them with the foundation for academic success in school.

2.2. Early mathematics competencies and standards

To identify key competencies for early childhood mathematics, a likely starting point can be found within the pre-established standards documents which detail the important and necessary mathematical skills and concepts at the preschool level. Such documents include the *National Research Council Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity* (NRC, 2009), *Principles and Standards for School Mathematics* (2000) issued by the NCTM, and *Early Childhood Mathematics: Promoting Good Beginnings* (NAEYC & NCTM, 2002), a joint position statement issued by NCTM and NAEYC. These reports reflect the growing interest of researchers and practitioners in promoting high-quality mathematics education during preschool. For example, the NRC lists numbers, relations and operations and geometry, spatial thinking, and measurement as key competencies. Though the labeling of the domains vary to a slight degree across documents, children's competencies in number and operations, geometry and spatial sense, measurement, patterning and algebraic thinking, and displaying and analyzing data have been identified as inherently critical skill areas for their mathematical development.

States have used a number of these reports from national advocacy organizations to guide the development of their early learning standards in mathematics (Neuman & Roskos, 2005; Stipek, 2006). Although states have long played a crucial role in K-12 education, only in recent years have standards gained traction in early childhood education. Standards documents provide a framework for both research and practice and typically have two primary goals: to describe how mathematics should be taught and which topics should be taught. More specifically, standards are intended to shape the development of curriculum and assessment tools, and therefore they have the potential to serve as a bridge between what empirical research says about children's learning and the kinds of teaching and learning that occur in the classroom (NRC, 2009). Further, the impact of standards on children's learning depends greatly on the content and learning goals that are laid out. The inclusion and widespread support of these standards in preschool demonstrates the varied mathematics knowledge children develop in the early years and warrants further investigation.

2.3. Early counting competencies

Across all the standards documents for preschool mathematics, counting competencies have been emphasized more than any other mathematical topic. In particular, the various standards documents (the NRC report in particular) emphasize that counting competence is of primary importance for children's development of mathematical proficiency (NAEYC & NCTM, 2002; NCTM 2000, 2007; NMAP, 2008; NRC, 2009). Counting competence is often defined as the ability to recognize that numbers represent quantities and have magnitudes, as well as mastery of one-to-one correspondence (understanding that each element in one set is paired with exactly one element from the other set), fixed order (number names and numerals are in a fixed order), and cardinality (the last number names the set and indicates the size of the set) (Clements & Sarama, 2014; Gelman & Gallistel, 1978). The NRC report (2009) goes as far as categorizing numbering (i.e., counting) as its own distinct domain. There has also been strong support for the development of counting and cardinality competencies in early childhood among researchers—Clements and Sarama (2007) emphasize that children's ability in this competency area serves as the "capstone of early numerical knowledge, and the necessary building block for all further work with number and operations" (p. 467).

It is not difficult to imagine why counting skills would be important for future mathematics learning. Basic counting, such as verbal counting, or counting fingers and other objects, provides a natural scaffold for calculation (Fuson, Richards, & Briars, 1982; Jordan et al., 2008; Purpura, Baroody, & Lonigan, 2013) and expands children's quantitative understanding beyond very small numbers (Baroody, 1987; Ginsburg, 1989; Griffin and Case, 1997). For example, fingers may be most helpful to children when they are first learning to compute with small number sets (i.e., totals of ten or less) but they become less useful after time when mathematics becomes more advanced and other strategies might be more advantageous, such as counting with cardinality, counting forward or backward from a given number, and conceptual subitizing (Clements, 1999; Sarnecka & Carey, 2008; Secada, Fuson, & Hall, 1983). It is also possible for children to rely on memory-based strategies (Siegler & Shipley, 1995). This is what makes counting