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Using assessment to individualize early mathematics instruction

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A R T I C L E I N F O

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A B S T R A C T

Accumulating evidence suggests that assessment-informed personalized instruction, tailored to students' individual skills and abilities, is more effective than more one-size-fits-all approaches. In this study, we evaluate the efficacy of Individualizing Student Instruction in Mathematics (ISI-Math) compared to Reading (ISI-Reading) where classrooms were randomly assigned to ISI-Math or ISI-Reading. The literature on child characteristics X instruction or skill X treatment interaction effects point to the complexities of tailoring instruction for individual students who present with constellations of skills. Second graders received mathematics instruction in small flexible learning groups based on their assessed learning needs. Results of the study (n = 32 teachers, 370 students) revealed significant treatment effects on standardized mathematics assessments. With effect sizes (d) of 0.41–0.60, we show that we can significantly improve 2nd graders' mathematics achievement, including for children living in poverty, by using assessment data to individualize the mathematics instruction they receive. The instructional regime, ISI-Math, was implemented by regular classroom teachers and it led to about a 4-month achievement advantage on standardized mathematics tests when compared to students in control classrooms. These results were realized within one school year. Moreover, treatment effects were the same regardless of school-level poverty and students' gender, initial mathematics or vocabulary scores.

1. Introduction

Children who develop strong mathematics skills in their early school years generally experience greater long term academic achievement than do their peers with poor numeracy skills (Duncan et al., 2007; Siegler et al., 2012), which in turn predicts later school completion and occupational success, (Geary, Hoard, Nugent, & Bailey, 2013; National Mathematics Advisory Panel, 2008; Ritchie & Bhatia, 1999; Rivera-Batiz, 1992; Siegler et al., 2012). However, according to the National Assessment of Educational Progress (NAEP, 2015), only about 40% of United States 4th graders attain proficiency in mathematics, and this percentage drops to 24% for children living in poverty. These rates represent an enduring problem, because achievement levels have held fairly steady over the last decade (NAEP 2005 to 2015). This means that a significant number of current and future U.S. students will enter school on a path towards underachievement in mathematics. At issue, then, is the need to identify ways to reverse this path and to do so as

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early as possible because early mathematics underachievement does not simply correct itself with time (Aunola, Leskinen, Onatsu-Arvilommi, & Nurmi, 2002; Mazzocco & Myers, 2003). One way, we hypothesize, is to improve the early mathematics instruction students receive, so that it is better aligned with their individual learning strengths and weaknesses in general, and their mathematical knowledge and skills specifically. However, the features of such individualized learning needs and instruction (as they pertain to early mathematics) are not yet well understood, and identifying them has been proposed as one of the current "grand challenges" of mathematical cognition research (Alcock et al., 2016, p. 23). In this paper, we describe an approach to mathematics instruction that uses assessment results to individualize (i.e., personalize, differentiate) the instruction students receive. We then test the efficacy of this instructional approach in a randomized controlled trial with teachers randomly assigned to individualized student instruction in either mathematics or reading.

1.1. *Influences on early mathematics achievement*

Accumulating evidence suggests that differences in mathematics achievement levels are related to multiple sources of influence (Berch & Mazzocco, 2007; Bronfenbrenner & Morris, 2006) including family, community, and student characteristics. These sources of influence are also likely to influence mathematics development and children's kindergarten entry quantitative skills, which are highly predictive of later mathematics achievement (e.g., Nunes, Bryant, Evans, & Barros, 2015; Purpura, Baroody, & Lonigan, 2013). Although early mathematical skills include spatial and geometric skills, much of the research on early mathematical thinking focuses on number (e.g., Mazzocco & Räsänen, 2013), and number is a primary focus for early mathematics in the Common Core State Standards (CCSS, Common Core State Standards Initiative, 2010). There is evidence of individual differences emerging from studies of very basic, primitive measures of magnitude judgment (Halberda, Mazzocco, & Feigenson, 2008) to highly formalized representations of number relations and the ability to fluently execute simple operations (Nunes et al., 2015). For instance, kindergartner's understanding of enumeration, symbolic numbers, and the relations between numbers are strong predictors of their math achievement level at the end of third grade (Mazzocco & Thompson, 2005) or fourth grade (Jordan, Glutting, & Ramineni, 2010; Morgan, Farkas, & Wu, 2009). Their ability to compose and decompose numbers at school entry predicts numeracy levels in high school (Geary et al., 2013). Moreover, individual differences persist throughout the school age years, when they may manifest as qualitative errors (e.g., place value errors, atypical computational errors; Mazzocco, Murphy, Brown, Rinne, & Herold, 2013; Mazzocco, Myers, Lewis, Hanich, & Murphy, 2013) or differences in fluency versus accuracy (Petrill et al., 2012; Price, Mazzocco, & Ansari, 2013). Importantly, these differences are apparent in early childhood (e.g., Desoete, Ceulemans, De Weerdt, & Pieters, 2012; Murphy, Mazzocco, Hanich, & Early, 2007), which means that we cannot assume children arrive at school with equivalent foundational mathematics skills.

Even if children do enter school with solid foundational mathematics skills, the path to their mathematics competence may not be maintained throughout primary school. Moreover, efforts to promote mastery are likely to support achievement only for those children who have not yet achieved it, and efforts to maintain mastery will do little to advance mathematics achievement of students who have already attained age-appropriate early mathematics skills (Engel, Claessens, & Finch, 2013). This dilemma is the logical outcome of the heterogeneity in mathematics skills seen in early childhood, which continues through elementary school and beyond. Hence for this study, we chose second grade as an important grade for improving mathematics achievement and for testing the causal influence of children's individual differences on mathematics achievement (i.e., child X instruction interactions).

1.1.1. *Theoretical framework*

In addition to early mathematics skills, accumulating research suggests that other child characteristics including cognitive, linguistic, and social-emotional processes, may interact reciprocally and synergistically with instruction to impact how students respond to instruction (Connor et al., 2016). Based on bio-ecological theories (Bronfenbrenner & Morris, 2006) and dynamic systems (Yoshikawa & Hsueh, 2001), the lattice model (Connor, 2016) has been applied to literacy achievement. We have adapted this model for mathematics achievement as depicted in Fig. 1. Although there are important distinctions between mathematics and reading skills, the rationale for applying this framework to mathematics emerges from evidence for shared variance among early literacy and numeracy (Davidse, De Jong, & Bus, 2014), from findings that select literacy measures predict later mathematics achievement (Purpura, Hume, Sims, & Lonigan, 2011), and for well documented comorbidity of mathematics and reading disorders (Willcutt & Pennington, 2000). Applying the lattice framework to studies of early mathematics interventions may shed additional light on shared and non-shared aspects of early learning in mathematics and reading. This also justifies including other sources of influence on children's mathematics development including gender, language skills, and socio-economic status in our models.

In the lattice model, proficient mathematics achievement relies on developing mathematics-specific processes, such as numerical processing (Mazzocco, Feigenson, & Halberda, 2011a, 2011b), other numeracy skills (Geary et al., 2013), number knowledge (Purpura et al., 2013), linguistic skills (LeFevre et al., 2010; Purpura et al., 2011), and social-emotional skills (Jones, Brown, & Aber, 2011; Rimm-Kaufman, Curby, Grimm, Nathanson, & Brock, 2009). These skills may interact with any one of a wide range of factors but particularly with instruction. For example, whereas we would not expect gender differences between boys and girls based on biological, linguistic, cognitive, or math-specific processes; it may be the case, that social-emotional attitudes and anxiety might indirectly contribute to gender differences (Beilock, Gunderson, Ramirez, & Levine, 2010). This may be one reason that gender differences do not emerge consistently on measures of the early and later numeracy and other basic mathematics skills (e.g., Geary et al., 2013; Halberda et al., 2008; Purpura et al., 2013) – the influence of gender on mathematics is indirect.

The key to our conceptual framework is that it is dynamic. That is, children bring a constellation of skills, aptitudes, attitudes, and beliefs to the process of learning mathematics and to the instructional environment. This means that what is effective mathematics