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Developmental patterns in the associations between instructional practices and children's math trajectories in elementary school

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ABSTRACT

Although procedural and conceptual math instruction have been linked to children's math achievement in elementary school, the extant research provides an inconsistent developmental picture of how children respond to a variety of instructional inputs from kindergarten through 5th grade. Using data from a large, longitudinal sample, the ECLS-K (n = ~7600), this study considered how within-child changes in exposure to procedural and conceptual approaches are additively and interactively linked to corresponding changes in children's math achievement across elementary school. Specifically, this investigation examined whether these instructional associations with math achievement change as children progress from kindergarten to 5th grade. Significant two- and three-way interactions between instructional approach and longitudinal time were detected. Although an emphasis on procedural instruction was most positively linked to achievement for kindergarteners, a combination of both conceptual and procedural instruction was more beneficial for 5th graders' achievement. Implications for practice are discussed.

Students experience significant growth in their mathematical skills during elementary school (Fuson, Kalchman, & Bransford, 2005). Yet considerable heterogeneity exists in the way mathematics is taught during this period, and debate over the optimal instructional content and approach has been intense (Gamoran, 2001; Shrouse, 2001). Procedural instruction emphasizes basic skill acquisition and calculation activities to convey math facts (Gamoran, 2001; Shrouse, 2001), while conceptual instruction emphasizes the development of analytic and reasoning skills (Fuson et al., 2005; Griffin, 2005). Though both have been associated with math learning (Fuson et al., 2005), less is known about how associations between math instruction and achievement change as children develop across elementary school. Instead, the previous literature typically examines these associations within grades (e.g., 1st grade) rather than across grades (e.g., K–5th grade). As a result, the literature paints an inconsistent picture of how children respond to instructional input as they progress through elementary school. There is also uneven consideration both for how teachers combine procedural and conceptual instruction, and no studies have formally assessed how this combination shifts as children develop more skills and the work becomes more advanced and problem-based. Accounting for how procedural and conceptual instruction are interactively associated with math development across elementary school therefore represents an important next step.

The purpose of the present study is to consider how additive and interactive associations between math instruction and math achievement change as children develop across elementary school. This investigation follows children from kindergarten through 5th grade, and specifically focuses on within-child associations to track how change in exposure to conceptual and procedural instruction is associated with change in individual children's math achievement over time. The study uses a large, longitudinal, and nationally representative dataset, the Early Childhood Longitudinal Study — Kindergarten cohort (ECLS-K) to investigate associations (U.S. Department of Education, National Center for Education Statistics, 2006). As students' math skills grow from kindergarten through 5th grade, understanding how instruction can be leveraged to promote growth is central to understanding how children acquire mathematical skills and competency throughout the elementary school years (NMAP, 2008).

A developmental perspective on elementary math instruction

Contemporary thinking about developmentally appropriate instructional input has been heavily influenced by Piagetian and Vygotskian theories of learning and development. Piagetian theory argues that children must obtain and then master a basic body of facts, procedures, and skills before extending or applying such skills to more advanced mathematics. This approach is reflected by instruction in procedural math, which focuses upon calculation and basic number concepts as important tools for math achievement (Gamoran, 2001; Rosenshine & Stevens, 1986). In contrast, Vygotskian theory argues for the utilization of higher-order problem-solving and reasoning skills inherent in conceptual instruction (Goodman, 1989; Vygotsky, 1978; Xue & Meisels, 2004). Although it is less clear how Piagetian or Vygotskian

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perspectives may apply as children move through middle childhood, it may be that instruction in math facts and computation skills are more beneficial for younger children who have not yet acquired the basic math skills needed for more advanced application and problem-solving (Piaget, 1977). In contrast, conceptual instructional approaches that emphasize applied and problem-solving skills may be more effective for older children who are increasingly adept at thinking symbolically and representationally (Burns & Sibley, 2001). As reviewed below, the empirical evidence supporting either approach is limited and mixed.

Empirical associations between pedagogical approach and math achievement

Several studies suggest that procedural instruction is beneficial for children's math development during the early years of elementary school (Bodovski & Farkas, 2007a; Byrnes & Wasik, 2009; Georges, 2009). For example, kindergarteners whose teachers spent more time on procedural skills such as advanced counting, addition and subtraction facts, single-digit operations, worksheet, and chalkboard activities demonstrated greater achievement gains across the school year than those whose teachers spent less time on these activities (Bodovski & Farkas, 2007a; Georges, 2009). Byrnes and Wasik (2009) demonstrated that these early positive associations continued through 3rd grade, with the strongest associations detected in kindergarten. However, examinations of procedural instruction and achievement in later elementary-school are more mixed. For example, Crosnoe et al. (2010) found that more procedural instruction in 3rd and 5th grade was not significantly associated with children's math achievement trajectories. Moreover, several correlational studies suggest that procedural instruction is negatively associated with student achievement once children reach 5th grade (Crosnoe et al., 2010; Hamilton, McCaffrey, Klein, Stecher, Robyn & Bugliari, 2003; Klein, Hamilton, McCaffrey, Stecher, Robyn & Burroughs, 2000; Le et al., 2006).

Exposure to conceptual math instruction is also inconsistently associated with children's math achievement throughout elementary school. For instance, studies conducted in the early years of elementary school (e.g., Pre-K–3) find that greater (rather than lesser) amounts of conceptual instruction are associated with math achievement, but with very small (Bodovski & Farkas, 2007a; Georges, 2009; Mashburn et al., 2008) or non-significant (Byrnes & Wasik, 2009; Howes et al., 2008; Le et al., 2006) effect sizes. Others have found negative associations for conceptual strategies that utilize manipulatives in early elementary school (Bodovski & Farkas, 2007a; Georges, 2009). In contrast, greater amounts of conceptual instruction in 4th and 5th grade are more consistently positively associated with children's math skills than are lower amounts (e.g., Hecht & Vagi, 2010, 2012). For example, Crosnoe et al. (2010) found that 3rd and 5th graders who experienced high amounts of conceptual instruction showed greater growth than their peers with low levels of conceptual instruction, though only when instruction was accompanied by non-conflictual teacher–child relationships. Experimental evidence also revealed that 4th graders who received conceptual instruction were just as likely to develop basic skills and were more adept at applying and extending their knowledge to novel situations than those who received procedural instruction (Rittle-Johnson & Alibali, 1999). These mixed findings leave an unclear picture of how procedural and conceptual instruction are associated with math achievement through elementary school.

Balanced, dynamic, and generalizable associations across elementary school

In addition to the mixed empirical support for conceptual and procedural math instruction from kindergarten through 5th grade, three issues remain understudied. First, the extent to which the combination of conceptual and procedural instruction promotes math achievement remains unclear. Evidence from a large, nationally-representative sample finds that a combination of instructional styles, defined as high amounts of both conceptual and procedural instruction, are more strongly linked to children's math achievement in kindergarten, 1st, and 3rd grade than disproportionate reliance upon either conceptual or procedural instruction alone (Byrnes & Wasik, 2009). However this investigation only considered additive effects of teachers who used primarily conceptual, primarily procedural, and both forms of instruction, and no formal tests of moderation have been conducted. Since synergistic instructional effects may be operating to enhance both domains of math competence, accounting for naturalistic variation in instruction is an important step.

Second, there are no studies to date that follow children throughout elementary school to examine how associations between instructional exposure and math achievement trajectories may change in meaningful ways over time. Although math proficiency involves both procedural and conceptual abilities (Fuson et al, 2005), children's math reasoning becomes more sophisticated and problems become more challenging and complex as they approach 5th grade. In contrast, young children who are learning basic skills and routines may benefit from an emphasis on procedural rather than conceptual instruction. While several studies are suggestive of developmental patterns for conceptual, procedural, and balanced instruction (e.g., Bodovski & Farkas, 2007b; Byrnes & Wasik, 2009; Georges, 2009), these investigations only considered additive associations over 2 to 4 years and did not procedurally test two- or three-way interactions between exposure to pedagogical approaches as children move through elementary school. Thus, considering how different combinations of instruction differentially promote achievement in early versus late elementary school is also a major interest of this investigation.

Third, much of the work on conceptual and procedural instruction is subject to external validity and endogeneity concerns. For instance, the majority of the extant research has been conducted on small or regional samples, which limits the generalizability of past findings. Previous research has also relied on between-child comparisons that may be affected by complex selection processes that could bias associations (Byrnes & Wasik, 2009; Desimone & Long, 2010; Georges, 2009). In contrast, within-child analyses make it possible to examine whether children's math achievement is higher at times when their teachers use relatively higher procedural or constructivist math instruction. These processes effectively control for all time-invariant child, family, teacher, and school characteristics and results in a fairly conservative model. Investigating within-child associations would therefore provide a more robust assessment of causal inference when examining additive, balanced, and dynamic associations between instruction and achievement across elementary school.

The present study

To address these important considerations, the present study uses data from a large, longitudinal, and nationally representative dataset, the Early Childhood Longitudinal Study, Kindergarten Cohort (ECLS-K) to examine how procedural and conceptual math instruction are associated with children's math achievement in elementary school. This investigation makes use of the ECLS-K's rich longitudinal design and hierarchical linear modeling (HLM) to examine within-child differences in exposure to instructional approach and corresponding math achievement from kindergarten through 5th grade. This approach holds constant time-invariant characteristics of children and their environments that may bias estimates (Singer & Willett, 2003) while controlling for important time-varying characteristics of schools, families, and children.

This investigation has two primary goals. The first is to identify how differences in exposure to procedural and conceptual instruction across elementary school are additively and interactively linked to change in individual children's math achievement during this time. Given