How Important is Where You Start? Early Mathematics Knowledge and Later School Success

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Abstract

Children's early skills and knowledge are essential for their later success in school. Research, policy, and educational practice have tended to focus on early literacy rather than early numeracy. Two recent studies using large scale longitudinal datasets highlight the importance of early mathematics knowledge, relative to other skills, for later elementary school achievement (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007). We know surprisingly little about the particular mathematics knowledge and skills young children typically have and how these early skills affect later academic outcomes. This study examines which early math skills predict later school success using a nationally representative sample of kindergartners. We explore how early math skills relate to achievement from kindergarten through eighth grade across reading, math, and science test score outcomes, as well as grade retention. Preliminary results show that children's math skills in pattern recognition and measurement are the most predictive early academic skills for eighth grade reading, math, and science success. All basic mathematics skills are important for reducing the likelihood of grade retention. The importance of these early math skills increases or is maintained over the course of elementary school. Differences for subgroups of children are explored.

How Important is Where You Start? Early Mathematics Knowledge and Later School Success

Children's early skills and knowledge are essential for their later success in school. Research, policy, and educational practice have tended to focus on early literacy rather than early numeracy. Recently, key advocacy groups for both early childhood and mathematics education, the National Association for the Education of Young Children (NAEYC) and the National Council for Teachers of Mathematics (NCTM), have issued position statements on the importance of early mathematics (NAEYC, 2002; NCTM, 2007). Further, the National Mathematics Advisory Panel (NMAP), formed in 2006, focuses on mathematics learning in Grades PreK-8 (NMAP, 2008). Both NAEYC (2002) and NCTM (2007) suggest that mathematics education for 3- to 6-year-old children is essential to promoting future mathematics achievement. The position statements, along with the final report from the NMAP, indicate that very young children are ready to learn a broad array of mathematics content that will give them a solid base for future learning. Beyond the growing interest from advocacy groups and experts, researchers in both psychology and education (Baroody, 2003; Ginsburg & Amit, 2008) have focused their attention on the importance of mathematics education in early childhood. Two recent studies using large scale longitudinal datasets have also pointed to the importance of early mathematics knowledge, relative to other skills, for later elementary school achievement (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007).

Despite the fact that both advocates and researchers have increased their focus on the importance of early math skills, we know surprisingly little about the mathematics knowledge and skills young children typically have, or how these early skills affect later academic achievement and school success. More research is needed to uncover how early math skills relate to later school success across diverse groups of students, and which particular early math skills should be the focus in early childhood and kindergarten classrooms. This study aims to address these gaps in the extant research by investigating which early math skills predict later school success using a nationally representative sample of kindergartners. Specifically, we explore how early math skills relate to achievement from kindergarten through eighth grade and across reading, math, and science test score outcomes, and how early math skills relate to grade retention. We also investigate the importance of specific early math skills for subgroups of children including socioeconomically disadvantaged students, African American and Hispanic students, English language learners, girls, and those students most at risk of math difficulties and school failure.

Prior Research

Theoretical Framework

Children's early skills are linked to subsequent success because they provide the foundation for positive adaptation (Entwisle et al., 2005; Cunha et al., 2005). A child's predispositions, knowledge, and skills contribute to his own learning and to the environment in which he operates; in turn the child receives feedback from others in the environment (Meisels, 1999). This complex interaction between the child and his environment affects his developmental trajectory (Bronfenbrenner & Ceci, 1994; Bronfenbrenner & Morris, 1998). For example, a child who enters kindergarten with high levels of mathematics skills may build upon this knowledge with additional instruction, receive reinforcement from the teacher, or be placed in a higher-ability group.

Research on children's math skills acquisition highlights the importance of specific academic skills, but also indicates that more general cognitive skills, particularly oral language and conceptual ability, may grow in importance for mastery of increasingly complex academic tasks. Foundational concepts of numbers allow for deeper understanding of more complex mathematical problems and flexible problem-solving techniques (Baroody, 2003; Ferrari & Sternberg, 1998; Hiebert & Wearne, 1996). Children begin school with different skills and abilities, and these initial abilities, along with skills developed over the first years of schooling are important for later success.

Early Mathematics Skills

Children begin school with varied early math skills, and low-income children and children in urban schools have particularly low levels of these academic skills (Magnuson & Duncan, 2006; Magnuson, Ruhm, & Waldfogel, 2007; Phillips, Crouse, & Ralph, 1998). Across all levels of income, some children have very high levels of early math achievement, while others are much less proficient (Baroody, 1987; Bodovski & Farkas, 2007a; Brannon & Van de Walle, 2001; Clements, 2004; Crosnoe et al., 2010; Huttenlocher et al., 1994; Levine et al., 1992; Mix et al., 2002; Morgan et al., 2009; Wynn, 1990). Math achievement measured around kindergarten entry has been found to be highly predictive of subsequent achievement (Aubrey et al., 2006; Claessens et al., 2009; Duncan et al., 2007; Jordan et al., 2009; Stevenson & Newman, 1986). However, little is known about how important early math skills are for middle school success and which early math skills are most important.

Two recent studies linked school-entry math skills to elementary school achievement in both math and reading (Claessens et al., 2009; Duncan et al., 2007). These studies found that school entry math achievement predicted later math and reading achievement test scores and teacher reports. Both studies found that early math skills were more important for later math and reading achievement than school-entry reading skills. However, these studies only focused on reading and math outcomes and did not follow children beyond fifth grade. Neither study examined which early math skills were most important for later achievement.

Specific Early Mathematics Skills

Studies focused specifically on early math skills show that number sense, number competence, and counting in preschool or kindergarten predict subsequent elementary school math achievement test scores (Aunola et al., 2004; Bodovski & Farkas, 2007a; Jordan et al., 2007, 2009). Children who have difficulty counting tend to have later difficulties in math (Geary et al., 1999). These foundational math skills—number sense and competence—are important for both later levels and gains in mathematics in elementary school (Aunola et al., 2004; Jordan et al., 2006, 2007, 2009). Yet, other evidence suggests that the vast majority of children can count at or prior to school-entry (Clements & Sarama, 2004; Mix, Huttenlocher, & Levine, 2002; NRC, 2009). Taken together, these findings suggest that focusing on number sense could be an important avenue for improving later achievement, but that by school entry most children have mastered this foundational skill.

Both theory and research have shown that very young children, including infants, process quantitative information before they have an understanding of conventional mathematical skills and symbols (Clements & Sarama, 2004; Mix et al., 2002). Over the course of early and middle childhood, children's conventional mathematics skills develop and these skills might be essential for later, increasingly more complex mathematical skills. Conventional mathematical skills include the basic foundational skills of number such as counting, number facts, and base-ten structure and more advanced skills such as calculations and measurement (Mix et al, 2002). The direction of the relationship between mathematical concepts and mathematical conventions is the subject of much debate (Clements & Sarama, 2004; Gelman, 1991; Mix et al., 2002), but these skills are inter-related. For example, children acquire the words of counting almost from the time they begin to speak (Fuson, 1988), before they have the one-to-one correspondence of conventional mathematics skills. Conversely, conventional units are key for a child's ability to represent quantity, and learning these conventional skills might expand children's understanding of measurement.

Although counting and number sense have been linked to later math achievement test scores, we know little about the relative importance of specific early math skills such as basic and advanced counting, shapes, relative size, ordinality, sequence, and patterns. Recent studies have focused on the importance of early math skills relative to other early academic and socioemotional skills (Claessens et al., 2009; Duncan et al., 2007). However, understanding how specific mathematics skills relate to later school success has important implications for education policy and practice. Theory and research suggest that children might not have the information processing capacity very early on to be proficient at the more advanced early mathematical skills such as comparisons of size and quantity and simple calculations (Clements & Sarama, 2004). These more advanced skills require the use of working memory to compare different objects of varying size or different sets of varying quantity. Very young children might not have developed sufficient skills in processing this complex quantitative information. However, studies do suggest that by kindergarten entry, or around age 5, children have sufficient processing skills to do such calculations or comparisons (Clements & Sarama, 2004).

Given that theory and research indicate that by age 5 children have processing skills that will allow them to learn a range of mathematics skills, understanding which skills are most beneficial for later school outcomes has important implications for early mathematics education. Understanding which early math skills are most important for their later success in school has the potential to lead to the development of targeted interventions focused on those specific early math skills that are most important for subsequent success in school. For example, if early ability to identify relative size and patterns is more important for subsequent achievement outcomes than counting, then, early childhood and kindergarten teachers should emphasize these early math skills. In contrast, if counting ability is particularly important for later outcomes, then a focus on counting might be warranted and more important than a focus on more complex early skills.

Differences Across Groups

On average, boys get poorer grades and have higher rates of academic difficulties (e.g., grade retention, special education placement, and drop out) than girls (Dauber, Alexander, & Entwisle, 1993; McCoy & Reynolds, 1999), and these gender differences are especially pronounced among African American and low-income children. However, there is still much debate about when and how sex differences in math skills develop (Geary, 1996). Men are more likely than woman to pursue careers in math and technology (National Science Foundation [NSF], 2001). Children from low-income backgrounds are also less likely to enter these careers (NSF, 2001).). A large body of literature has documented race and income gaps in school entry academic skills, including math (e.g. Bodovski & Farkas, 2007a; Fryer & Levitt, 2004; Magnuson & Duncan, 2006; Magnuson et al., 2007; Phillips et al., 1998).

Low-income and minority children are at particular risk for underachievement in mathematics (Jordan et al., 2007, 2009; Siegler, 2009; Siegler & Ramani, 2008; Starkey, Klein, & Wakeley, 2004). Children from disadvantaged backgrounds appear to lag behind their more advantaged peers on several measures of early mathematics skills (Griffin & Case, 1997; Jordan et all., 1992; Saxe et al., 1987; Starkey & Klein, 1992). Children from low-income families have more varied mathematics skills than middle income children (Wright, 1991). Evidence suggests that all children learn basic counting skills, although at different rate, but that there are wide income gaps in more advanced early mathematics skills such as sequencing, shapes, and comparisons of shape (Clements & Sarama, 2004; Sarama & Clements, 2008).

The Present Study

Using a large-scale, nationally representative longitudinal study of kindergarteners, we examine the relationship between specific measures of school entry mathematics skills and subsequent success in school. We focus on how early math skills relate to reading, math, and science achievement and grade retention across elementary school and into middle school, which early mathematics skills are most important for later success, and how this varies across children at-risk for school failure. We hypothesize that early math skills will be important for middle school reading and math achievement, as found in prior research (Claessens et al., 2009; Duncan et al., 2007). We also expect that early math skills will be important predictors of other measures of school success including science achievement and grade retention. We expect that particular early math skills, such as counting and number, will be critical to later school success, as found in prior studies (Aunola et al, 2004, Bodovski & Farkas, 2007a; Jordan, et al. 2009, 2007, 2006). We contribute to this body of research by using a nationally representative sample of children with measures of school success through eighth grade and by focusing on a range of specific early mathematics skills.

Method

Data

The data used in this study come from the Early Childhood Longitudinal Study—Kindergarten (ECLS-K) cohort. The ECLS-K is a nationally representative sample of children followed from the fall of kindergarten through eighth grade. Designed to focus on early school experiences, the study follows 21,260 children who were in kindergarten in the 1998-99 school year. Data from the fall and spring of kindergarten and spring of first, third, fifth, and eighth grades are used. Data are collected from multiple sources, including direct cognitive assessments of children in math, reading, and beginning in third grade, science; interviews with parents; and teacher surveys.

Beyond direct child assessments, the ECLS-K includes information about grade retention. The sample used in the present study is the 7,655 children who have complete data on fall of kindergarten and spring of eighth grade achievement tests. Table 1 shows the differences between the analytic sample and the full sample of approximately 20,000 kindergartners.[1] A

[1] Sample sizes vary on individual variables due to missing data.

second analytic sample includes those students who are lower achieving in mathematics at kindergarten entry, relative to the full sample, and for whom we have complete data on both fall of kindergarten and spring of eighth grade achievement tests. We define this sample as students who are not proficient on mathematics subscale 2 at kindergarten entry. This sample is comprised of 2,551 students, and is about 1/3 of the full analytic sample.

Measures

Achievement Tests

Children were given achievement tests in a range of subjects from kindergarten through 8th grade. Children were tested in general knowledge in the fall and spring of kindergarten and spring of first grade. In third, fifth, and eighth grades, children were given tests in science. Children were tested in language and literacy (reading) and math at the fall and spring of kindergarten and spring of first, third, fifth, and eighth grades. All of the ECLS-K assessments were designed using Item Response Theory (IRT) to allow for the examination of growth over time (Tourangeau et al., 2009). The ECLS-K provides proficiency scores for subscales in both reading and math achievement. Ten subscales in reading and nine in math were created. We use the subscale measures of proficiency in mathematics to measure mastery rates both overall and within population subgroups (Tourangeau et al., 2009).

Math Test. The ECLS-K math assessment measured children's conceptual and procedural knowledge and problem solving skills, and the IRT-based scores range in reliability from .89 to .94 (Tourangeau et al., 2009). The nine proficiency areas in math are identifying some one-digit numerals, recognizing geometric shapes, and one-to-one counting up to ten objects (subscale 1); reading all one-digit numerals, counting beyond ten, recognizing a sequence of patterns, and using nonstandard units of length to compare objects (subscale 2); reading two-digit numerals, recognizing the next number in a sequence, identifying the ordinal position of an object, and solving a simple word problem (subscale 3); solving simple addition and subtraction problems (subscale 4); solving multiplication and division problems and recognizing more complex number patterns (subscale 5); place value (subscale 6); rate and measurement (subscale 7); fractions (subscale 8); and area and volume (subscale 9).

These subscales are measured using proficiency probability scores, which range from 0 to 1, and have reliabilities from .30-.66 in the fall and spring of kindergarten. In kindergarten, subscale scores are available for subscales one through five. However, because only 5 percent of the analytic sample is proficient on subscales 4 and virtually no students are proficient at subscale 5 at kindergarten entry (see Table 1), we include only subscales one through three in our analyses.

Reading Test. The reading test measured children's basic skills, vocabulary, and comprehension, and the reliability of the IRT based scores ranges from .91-.96 (Tourangeau et al., 2009). The reading assessments from kindergarten to eighth grade cover a total of ten different proficiency levels: identifying letters, identifying beginning sounds and ending sounds, reading words by sight and in context, literal inference, extrapolation, evaluation, evaluating nonfiction, and evaluating complex syntax. The reading subscales have reliabilities between .60 and .83 in the fall and spring of kindergarten.

Science Test. Students were given a direct assessment of science in third, fifth, and eighth grades. The science test placed equal emphasis on life science, earth and space science, and physical science. Children needed to demonstrate understanding of the physical and natural world, draw inferences, and comprehend relationships. In addition, they needed to interpret scientific data, formulate hypotheses, and identify the best plan to investigate a given question. The test-retest reliabilities range from .84-.87. The test includes no subscales or proficiency levels.

General Knowledge Test. The test, administered in fall and spring of kindergarten and spring of first grade, assessed knowledge of science and social studies and evaluated children's conception and understanding of the social, physical, and natural world and their ability to draw inferences and comprehend implications. It also measured children's skills in establishing relationships between and among objects, events, or people and to make inferences and comprehend the implications of verbal and pictorial concepts. The reliability of the general knowledge test ranges from .85-.88. We use children's fall of kindergarten scores on the general knowledge test as a control for cognitive ability in our models as was done by both Claessens et al., (2009) and Duncan et al., (2007).

School Success

This study also includes measures of school success that are not achievement test scores. These measures of school success include retention in grade and teacher rated achievement. For *retention in grade*, the ECLS-K provides a measure of the child's current grade level for each data collection wave. We created measures of retention for different points in time across elementary and middle school.

Surveyed teachers reported on sample children's achievement using the *Academic Rating Scale (ARS).* The ARS asks teachers to rate the child's skills, knowledge, and behaviors within two areas of academic learning: (1) Language and Literacy, and (2) Mathematical Thinking in kindergarten through fifth grade. ARS questions use examples to help the teacher think of the range of situations in which a specific child may demonstrate similar skills and behaviors. Each questionnaire assesses skills, knowledge, and behaviors that are appropriate for each grade level in school. The reported reliabilities for the Language and Literacy scales are .94 - .95 and .91-.92 for Mathematical Thinking. The ARS is not used in eighth grade, but different measures of teacher rated school performance were collected. Teacher ratings of a student's written expression skills, oral expression skills, math skills, and science skills with test-retest reliabilities of .93 to .96 are used.

Child Characteristics

Characteristics of the child that are likely correlated with initial and later measures of mathematics skills and achievement are included in this analysis. We use measures of the sample child's sex and race/ethnicity as well as information about child health, birth weight, birth date, and whether or not the child was premature. Parents also reported on their child's preschool and child care experiences. This information was collected at the fall of kindergarten.

Home and Family Background

This study also includes a wide range of family and home characteristics that might influence a child's initial skill levels and subsequent outcomes. These measures include family structure capturing parental marital status and number of siblings. We also use maternal and paternal demographic characteristics such as age, education, work status, and income. In addition, we account for measures of home language, immigrant status, and poverty. The ECLS-K also asks questions of parents about the number of books in the home, and the frequency with which they engage in reading with the child. A complete list of all of these control variables is included in Appendix Table A.

Analytic Plan

To answer our primary research question, we relate the math subscale skills measured at kindergarten entry to children's achievement test scores and other measures of school success measured in eighth grade (and at other points throughout elementary school). School-entry skills are measured in the fall of kindergarten ("FK") while outcomes are measured in the spring of eighth grade ("8th"). The estimating equation is as follows:

$$(1) \quad SO_{i8th} = a_1 + ß_1 Math1_{iFK} + ß_2 Math2_{iFK} + ß_3 Math3_{iFK} + ß_4 Reading_{iFK} + ß_5 GenKnow_{iFK} + ß_6 Fam_i + ß_7 Child_i + e_i$$

where SO_{i8th} is the school outcome measure of child i in the spring of eighth grade, $Math1_{IFK}$, $Math2_{IFK}$, and $Math3_{IFK}$ are the math achievement subscale scores 1-3 for child i at kindergarten entry, $Reading_{iFK}$ and $GenKnow_{iFK}$ are measures of child i's reading and general knowledge assessed by achievement tests in the fall of kindergarten. We include these measures to control for initial reading skills and cognitive ability. Fam_i and $Child_i$ are sets of family background and child characteristics included to control for individual differences that might influence math achievement before and after school entry; a_1 is a constant and e_i is a stochastic error term.

Our interest is in estimating $ß_1$, $ß_2$, and $ß_3$ which, if correctly modeled, can be interpreted as the relationship between particular math skill sets at kindergarten entry and subsequent school outcomes. A key challenge in this approach is ensuring that we have accounted for the possibility of omitted variable bias, which occurs if family or child characteristics are correlated both with children's early math skills and their later achievement and are omitted from our model. Our strategy for securing unbiased estimation of $ß_1$- $ß_3$ is to estimate a model of the form of equation (1) that includes as many prior measures of relevant child and family characteristics as possible. Given that the ECLS-K data are nested in classrooms at the fall of kindergarten, we provide estimates that adjust standard errors for this non-independence or clustering in the fall of kindergarten.

Preliminary Results

Table 1 shows descriptive statistics for the background characteristics and kindergarten achievement test scores for the full sample of kindergartners (n=21,409), column 1, the analytic sample (n=7,655), column 2, and the analytic sample of children who are low achievers in fall of kindergarten mathematics (n=2,551), column 3. This subgroup is defined as children who are not proficient in math subscale 2 at the fall of kindergarten. As shown in Table 1, column 2, fully 96 percent of children in the main analysis sample are proficient on subscale 1 – identifying some one-digit numerals, recognizing shapes, and one-to-one counting ten objects – at kindergarten entry. Even among the subsample of students who are lower performing in mathematics, the average score in fall of kindergarten on subscale 1 is .86 out of 1, and 88 percent are proficient at subscale 1. Students in the analysis sample had an average score of .63 on subscale 2, and .26 on subscale 3. In terms of proficiency or mastery, 66 percent of the full analytic sample is proficient at subscale 2 – reading all one-digit numerals, counting beyond ten, recognizing patterns and using nonstandard units for measurement – at kindergarten entry, and 26 percent are proficient at subscale 3, which tests ability to read two-digit numerals, ordinality, and solving simple word problems. As can be seen in Table 1, a very small fraction of the sample was proficient on subscale 4, 5%, with an average score of only .05. Thus, we include only subscales 1 through 3 in our analyses below. Further, as can be seen in the table, students in the analytic sample who were lower achieving in mathematics (column 3), by definition, were not proficient on subscale 2, with an average score of .24. For analyses with this subgroup, we use only mathematics subscales 1 and 2, as there is no variation for these students on subscale 3, with an average score of only .01.

Not surprisingly, as Table 1 shows, the analytic sample – those with valid achievement data at both the fall of kindergarten and the spring of eighth grade, appears to be more advantaged than the full sample of children in the fall of kindergarten (column 2 compared to column 1). Results of tests of the statistical significance of the mean differences between these two groups are shown in column 4. The analytic sample is two-thirds white (66%), compared with only 55 percent in the full sample, and more likely to live in the suburbs (26% compared with 20%). In addition, 71 percent of the analytic sample children lived in a two-parent married family in the fall of kindergarten, compared with only 56 percent in the full sample. The analytic sample is also less likely to be non-English speaking. The analytic sample also has higher household income, more maternal education, and older mothers, on average, compared with the full sample at kindergarten entry (see Appendix A).

Comparing the full analytic sample and the analytic sample of children who are low math achievers in the fall of kindergarten (columns 2 and 3) shows that the lower achieving children are less advantaged. The results of tests of the mean differences between these two groups are shown in column 5. Children with low math skills are less likely to be white, 52 percent, and nearly 40% are either black or Hispanic, compared with 24 percent of the full analysis sample. These children are also less likely to live in a two-parent household at kindergarten entry. In addition, they are more likely to be non-English speakers, have mothers' with lower education, and are more likely to be low income (see Appendix A).

Table 2 presents the descriptive statistics for the outcomes of interest for the primary analytic sample and for the group of children with low mathematics skills. As shown in Table 2, achievement test scores increase over time for students in both groups, as we would expect. Unlike achievement test scores, teacher rated achievement does not increase monotonically over time. Looking at grade retention, we see that the retention rate increases over time. While only three percent of the sample had been retained by 1st grade, that number tripled to nine percent by the eighth grade year. Turning to the sample of students who were not proficient on math subscale 2 at kindergarten entry, we see that they consistently score lower than the full analytic sample on all outcomes of interest, both achievement test scores and teacher ratings of academic achievement. The lower achieving sample is also about twice as likely to have experienced grade retention in any given year, with fully one-fifth of the sample having been retained by eighth grade.

Table 3 presents results for the full analytic sample using fall of kindergarten math subscale scores to predict eighth grade achievement test scores in reading, mathematics, and science. Results indicate that fall of kindergarten math skills are important for eighth grade test scores. The first column for each dependent variable (columns (1), (6), and (11)) shows the bivariate relationship between each of the three math subscale scores and that outcome. As shown in Table 3, all three math subscales are highly correlated with subsequent achievement test scores, with coefficients ranging from .40 to .54 for eighth grade reading test scores, .45 to .60 for eighth grade math achievement, and .41 to .55 for eighth grade science test scores. Table 3 also provides estimates of various specifications of the relationship between early mathematics skills and eighth grade reading, math, and science test scores. All variables have been standardized by full-sample standard deviations so that coefficients can be compared across models and interpreted as standard deviation increments. Columns (2)-(4) for reading and (7)-(9) for math show the coefficients for individual math subscale scores controlling for reading, general knowledge, and child and family background characteristics. As Table 3 indicates, including control variables reduces the magnitude of coefficients, in some cases by as much as one half to two thirds. Interestingly, the pattern of results for these models shows that kindergarten entry math subscale scores are more predictive of math, reading, and science achievement in eighth grade than the full reading test score at kindergarten entry.

Columns (5), (10), and (12) provide the full-control models, including all three math subscales, reading, general knowledge and child and family background controls. Results indicate that kindergarten entry math skills are more predictive than early reading skills for all three achievement test score outcomes. Coefficient estimates on math subscales range in size from .04 to .17 for reading test outcomes, .11 to .26 for math test scores, and .07 to .16 for science achievement, all in standard deviation units. Results also suggest that kindergarten entry scores on subscales one and two are particularly predictive of eighth grade achievement in reading, math, and science. Post-estimation tests of the differences between the coefficients show that for eighth grade math test score outcomes, fall of kindergarten math subscale 2 is the most predictive compared to both subscales 1 and 3 and to fall of kindergarten reading achievement. In addition, for both reading and science outcomes, math subscales 1 and 2 are more predictive than subscale 3 or reading tests.

Table 4 shows results, again for the full analytic sample, using fall of kindergarten math subscale scores to predict teacher reported reading and math and whether the student was retained in grade by eighth grade. Models are specified identically to those in Table 3 for the three additional outcome measures. The pattern of results for teacher reported achievement is similar to that shown in Table 3. The full models, reported in columns (5), (10), and (12) indicate that kindergarten entry scores on all three early math subscales independently predict both teacher reported reading and math ability. Math subscale 2 is more predictive of teacher rated reading at eighth grade than both subscales 1 and 3 and reading test scores. Coefficients from models predicting teacher reported math are somewhat larger, with subscale 2 having an effect that is 1/5 of a standard deviation in magnitude.

As columns (11) and (12) show, scores on all three math subscales predict whether or not a child has been retained in grade by the end of eighth grade. These are coefficients and standard errors from logistic regression models, with odds ratios provided to the right of coefficients. As would be expected, we find a negative relationship, with lower test scores indicating a higher likelihood of having been retained.

Tables 5 and 6 show results for the same set of analyses shown in Tables 3 and 4, for the subgroup of children who were not proficient on subscale 2 at kindergarten entry. One important difference between these analyses and those described above is that math subscale 3 is omitted from all models. Children who are not proficient on subscale 2 are essentially scoring zero on subscale 3 (mean=.01, standard deviation=.02). The lack of variation on that subscale for these students with lower math scores resulted in our having to omit it from the analyses for this sample. Results for subscales 1 and 2, however, are similar to those presented for the full sample, with coefficients on the subscales ranging in size from .12 to .31 in the full-control models (columns (5), (10), and (12)) for test score outcomes reported in Table 5. Table 6 shows results for teacher reports and grade retention. Kindergarten entry scores on the mathematics subscales are, again, highly predictive of eighth grade teacher reports of reading and mathematics knowledge. Interestingly, fall of kindergarten measures of math subscale 2 are more predictive of both teacher rated math and math achievement test scores in eighth grade (column (8), Tables 5 and 6) than fall of kindergarten math subscale 1 or reading achievement test scores. Results for grade retention show a similar pattern for this subgroup of children with lower mathematics test scores at kindergarten entry. Scores on math subscales 1 and 2 and reading achievement scores all independently predict later grade retention in the expected direction.

Tables 3-6 presented results examining a variety of eighth grade school outcomes. We also examine how particular early math skills predict shorter-run outcomes, and whether their importance for school success changes over time. Tables 7 -10 present the fully controlled models using fall of kindergarten measures of achievement to predict test scores, teacher reports of achievement, and retention at spring of kindergarten, first, third, and fifth grade. We examine these models for the full analytic sample (Tables 7 & 8) and for the group of children who are low math achievers at school entry (Tables 9 & 10).

Table 7 presents results for reading, math, and science (when available) test score outcomes at various points throughout elementary school. Turning first to the reading achievement test score outcomes (columns (1)-(5)), Table 7 shows that all three math subscales are consistently predictive of subsequent reading outcomes, except subscale 2 at the spring of kindergarten (column (1)). After spring of kindergarten, subscales 1 and 2 are more predictive of subsequent reading test scores than subscale 3, with coefficients ranging from .11 to .20. For math achievement test score outcomes, the pattern is somewhat similar, although math subscale 3 is particularly important for spring of kindergarten and first grade math achievement, but its importance falls over time from .41 for the spring of kindergarten outcomes to .11 for eighth grade math test scores (columns (6) to (10)). Math subscale 2 gains in importance across elementary school going from .14 for the spring of kindergarten math outcomes (column (6)) to .26 for eighth grade test scores (column (10)). For science test score outcomes, all three math subscales are equally important for third grade science, but for fifth and eighth grade, subscales 1 and 2 are more predictive.

Interestingly, the pattern of results for reading achievement for both later reading and math achievement shows that it decreases in importance over elementary school. While fall of kindergarten reading achievement is highly predictive of spring reading test scores, with a coefficient of .75, by eighth grade it has fallen to only .05. The relationship between early reading skills and later math achievement shows a similar pattern. For spring of kindergarten math achievement, fall of kindergarten reading skills is strongly predictive, .16, but by third grade, the coefficient drops to .04.

Table 8 presents the results for teacher rated achievement and grade retention measured across elementary school using fall of kindergarten math achievement subscales. The pattern of results in Table 8 is quite similar to results shown in Table 7. However, for reading outcomes (columns (1)-(5)) in the spring of kindergarten and first grade, subscales 1 and 2 are the most predictive of the three math subscales, with coefficients ranging from .14 to .27. By third and fifth grades, subscale 2 is the most predictive of teacher rated reading skills. Fall of kindergarten reading achievement is consistently predictive of teacher reported reading. However, the magnitude of the coefficient falls over time from .29 to .10 by eighth grade. The pattern for teacher rated math achievement indicates that all three math subscales are consistently predictive of teacher reported math skills from first to eighth grade. For first grade teacher reports of math, subscales 1 and 2 are more predictive than 3, but all three are equally predictive until eighth grade, where subscale 2 emerges as the most important. Finally, the results for ever being retained in grade are consistent over time, and nearly identical to those shown in column (14) for eighth grade.

Tables 9 and 10 present the results from the same models shown in Tables 7 and 8, but for the sample of children who had low levels of math achievement at kindergarten entry. The pattern of results for the low math achieving children is similar to the pattern shown for the full sample. Interestingly, both subscales 1 and 2 are consistently predictive of reading achievement test scores for this group of children across elementary school. The coefficient estimates range from .07 to .17. In addition, as shown with the full sample, fall of kindergarten reading achievement becomes less important for subsequent reading outcomes across elementary school, falling from .56 in the spring of kindergarten to a statistically insignificant .08 in eighth grade. For math outcomes the pattern is again similar to the full sample, both subscales 1 and 2 consistently predict subsequent math achievement. However, while math subscale 1 is consistently predictive, subscale 2 is at least twice as large in magnitude.

Table 10 shows the results for teacher reports of reading and math achievement as well as ever having been retained in grade for this sample of low math achievers at kindergarten entry. Math subscales 1 and 2 are consistently predictive of teacher reports of reading achievement. The magnitude for both coefficients stays relatively constant across elementary school and into eighth grade. Fall of kindergarten reading achievement shows a similar pattern as in Table 9, its importance for teacher reports of reading achievement across elementary school falls from .48 to .08. For teacher reports of math achievement, the pattern shown in Table 10 is similar to the pattern for teacher rated reading achievement. Subscales 1 and 2 are predictive of teacher rated math achievement, but subscale 2 is consistently larger in magnitude. The results for retention in grade are similar to those shown in previous models.

Subgroups

Given that particular groups of children are more at-risk of later school failure and that these same groups have lower school-entry skills, we examined differences in the importance of specific school entry math skills for later school success for subgroups of students by income, gender, race/ethnicity, home language, family structure (single parent), and low maternal education. In preliminary runs, we find no systematic differences in the relationship between early math skills and later outcomes across these groups of children (results not shown). These findings suggest that early mathematics skills, in particular those measured on subscales 1 and 2, are consistently important for children's school success as measured by achievement test scores, teacher reports, and grade retention.

Note: We plan to look at the relationship between gains on math subscales over kindergarten and later achievement, but were not able to complete those analyses for this draft. We also plan to add special education placement as an additional outcome.

Discussion

Using a nationally representative sample of kindergartners, this study explored which early math skills were most important for later school success. We examined reading, math, and science achievement test score outcomes at several points across elementary school and into middle school. We focused first on the eighth grade school-related outcomes which are the latest data point available, and also examined shorter-run outcomes. We also examined teacher rated achievement outcomes and retention in grade at each available data collection wave.

Across all the models, except spring of kindergarten and first grade, children's early math skills were more important predictors of later achievement than their early reading skills. Further, math subscale 2 which measures a child's ability to *read all one-digit numerals, count beyond ten, recognize a sequence of patterns, and use nonstandard units of length to compare objects*, is typically the most consistent and important predictor of later achievement test scores in both reading and math across elementary school and is more important for eighth grade math achievement than subscale 1 which is a measure of a child's ability to *identify some one-digit numerals, recognize geometric shapes, and count one-to-one up to ten objects*. Both subscales 1 and 2 are equally important for eventual reading and science achievement test scores. For teacher rated achievement, mathematics subscale 2 is the most important predictor by eighth grade. As would be expected, early mathematics achievement as well as early reading achievement predict grade retention, with higher scores on all three math subscales and reading negatively related to the likelihood of being retained.

Consistent with other studies of early math skills and later achievement (Aunola et al., 2004; Bodovski & Farkas, 2007a; Jordan et al., 2007, 2009), the present study found that fall of kindergarten math skills were important for subsequent elementary school math achievement test scores. The prior studies found evidence that number sense and competence were important for later math achievement. In the current study, we find that number recognition, counting, shapes and patterns are key to success at various points in elementary school. Unlike the prior studies, this study also looked at outcomes beyond subsequent math test scores, showing that early math skills are important for a broad range of measures of school success including reading, science, and grade retention.

We find an intriguing, suggestive pattern of results when we look across the primary grades. While math subscale 2 is the most important predictor of eighth grade math achievement, it gained in importance across elementary school. Although both subscales 1 and 2 were important for eventual reading and science achievement, again, math subscale 2 gained or maintained its importance over time, while subscale 3 typically decreased in magnitude across elementary school. Further, fall of kindergarten reading achievement was initially important for the shorter-run measures of achievement test scores, but its importance waned over the course of elementary school.

Why might different math subscales be important at different points in time?

Both theory and research in mathematics suggest that over the course of early and middle childhood, children's conventional mathematics skills develop and these skills might be essential for later, increasingly more complex mathematical skills. We find suggestive evidence that particular early math skills are important for later success while basic foundational skills in number knowledge predict success across all time points. The present study shows that most children already have basic knowledge in counting and shapes prior to school entry, but that children's skills at pattern recognition and measurement vary substantially when they begin formal schooling. Here, we find that children's basic skills predict both short and longer term school success, but that more complex skills are predictive of longer run outcomes, particularly in mathematics. This might be due to the changing nature of the content taught in school over the course of elementary school and into middle school. For example, while the primary years of school might be focused on foundational reading and mathematics skills, by eighth grade the focus in reading and mathematics may have shifted to an emphasis on abstraction and extrapolation. These more advanced skills likely require children to use more abstract thinking, and in turn, math subscale 2, which taps skills in patterns and measurement, might be measuring the antecedents of these later skills.

Another reason the importance of specific math skills might change over time may be related to children's cognitive processing skills. Theory and research suggest that children might not have the information processing capacity very early on to be proficient at the more advanced early mathematical skills such as comparisons of size and quantity and simple calculations (Clements & Sarama, 2004). These more advanced skills require the use of working memory to compare objects of varying size or different sets of varying quantity. Very young children might not have developed sufficient skills in processing this complex quantitative information. In the present study, children who are more advanced in terms of cognitive processing skills and working memory might be better at math achievement subscale 2, and these cognitive processing skills and working memory might be particularly important for eighth grade achievement when the content of the tests is more difficult and requires more abstract thinking. Thus, subscale 2 may be measuring children's processing skills and working memory more than other measures included in the analyses.

Do math skills matter more for disadvantaged students?

We find a similar pattern of results for children who enter kindergarten with lower mathematics achievement, as well as for a wide range of subgroups broken down by gender, race/ethnicity, income, education, and English language learners. The similar pattern of results across groups strongly supports the notion that these foundational mathematics skills are important predictors of academic achievement and grade retention for all students. In future work, we plan to examine the relationship between content exposure during the kindergarten year and gains in these key early mathematics skills. We also plan to examine the extent to which exposure to mathematics content in general, as well as to the particular mathematics content that we find here predicts later achievement varies across these subgroups. We anticipate that content exposure will vary substantially, with more disadvantaged children typically being exposed to less mathematics overall, and less of the math skills measured on subscale 2.

Limitations

The results presented here are preliminary and not without limitations. First, the data used here are non-experimental; and thus, all of the results are correlational and subject to concerns about selection and omitted variable bias. In addition, although the tests used here were highly reliable as a full scale, the individual subscales have relatively low reliability. The measurement error in the subscales might be biasing our results, although the direction of bias is likely downward. Finally, the math achievement subscales available in the data do not allow us to further deconstruct early math skills. For example, we would prefer to examine pattern recognition and measurement separately, but these are combined in one subscale measure. Finding data with more reliable measures of children's early math skills with longer-run outcomes will be crucial to replicating and confirming the preliminary results found here.

Conclusion

The results reported here have implications for education policy regarding mathematics curricula in the earliest years of schooling. Findings that early mathematics knowledge and skills are the most important academic skill for predicting not only later math achievement, but achievement in other content areas and grade retention indicates that math should be a primary area of academic focus during the kindergarten year. These findings, which confirm earlier work (Claessens, et. al., 2009; Duncan, et. al., 2007) indicate that particular early math skills grow in importance as children progress through school. Thus, our findings support a greater emphasis on mathematics than is currently the case in many kindergarten classrooms, and also suggest that emphasizing skill development in pattern recognition and measurement might develop skills that will benefit students in the later years of schooling across multiple subject areas.

Findings reported here provide new information about the mathematics knowledge of a representative sample of children at school entry, and how that early knowledge predicts later school success. Our findings indicate that the development of early mathematics skills is important not only for later math outcomes, but for later reading and science achievement, and to reduce the likelihood of grade retention as well. We also find that these early math skills, including foundational knowledge of numbers and counting as well as the ability to recognize patterns, are important for all children regardless of background characteristics.

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Table 1. Descriptive Statistics for Background Characteristics for Full and Analytic Samples

	Full Sample n=21,409 (1)		Analytic Sample n=7655 (2)		Low Math Skills Analytic Sample n=2551 (3)		Mean Diff. Col. 1 & 2 (4)	Mean Diff. Col. 2 & 3 (5)
	Mean	S.D	Mean	S.D	Mean	S.D		
Fall of Kindergarten Math Skills								
Subscale Scores								
Subscale 1	0.92	0.18	0.95	0.13	0.86	0.20	***	***
Subscale 2	0.55	0.35	0.63	0.33	0.24	0.19	***	***
Subscale 3	0.21	0.30	0.26	0.32	0.01	0.02	***	***
Subscale 4	0.04	0.12	0.05	0.14	0.00	0.00	***	***
Subscale 5	0.00	0.03	0.00	0.03	0.00	0.00	*	***
Proficiency (dummy, 1=profficient)								
Subscale 1	0.92	0.27	0.96	0.20	0.88	0.32	***	***
Subscale 2	0.57	0.50	0.66	0.47	0.00	0.00	***	***
Subscale 3	0.20	0.40	0.26	0.44	0.00	0.00	***	***
Subscale 4	0.04	0.19	0.05	0.22	0.00	0.00	***	***
Subscale 5	0.00	0.06	0.01	0.07	0.00	0.00	**	***
Full Scale IRT Test Scores								
Math	25.91	9.10	27.78	9.27	19.35	3.27	*	***
Reading	35.21	10.20	36.23	10.03	29.69	4.73	*	***
General Knowledge	22.23	7.51	23.59	7.47	18.75	6.34	*	***
Baseline Child Characteristics								
Race								
White	0.55	0.50	0.66	0.47	0.52	0.50	***	***
Black	0.15	0.36	0.11	0.31	0.17	0.38	***	***
Hispanic	0.18	0.38	0.13	0.33	0.19	0.39	***	***
Asian	0.06	0.24	0.05	0.21	0.04	0.19	***	**
Other	0.06	0.23	0.06	0.24	0.08	0.27		***
Female	0.49	0.50	0.50	0.50	0.47	0.50	*	**
Age (in months at Fall Assessment)	68.41	4.35	68.56	4.23	67.43	4.16	***	
Geographic Controls								
Urban	0.41	0.49	0.35	0.48	0.35	0.48	***	
Rural	0.39	0.49	0.39	0.49	0.33	0.47		***
Suburban	0.20	0.40	0.26	0.44	0.32	0.46	***	***
Home Environment								
Number of Siblings	1.46	1.19	1.43	1.09	1.53	1.22	**	***
Two bio. parents (cont. married)	0.56	0.50	0.71	0.45	0.60	0.49	***	***
Adopted	0.01	0.11	0.01	0.11	0.01	0.12		
Live with guardian	0.02	0.14	0.02	0.13	0.03	0.16		***
Single biological parent	0.19	0.39	0.16	0.37	0.23	0.42	***	***
Bio. parent and other parent	0.07	0.25	0.06	0.23	0.07	0.25	***	***
Two bio. prnts (not cont. married)	0.15	0.36	0.04	0.19	0.06	0.23	***	***
Eng. not primary home language	0.14	0.35	0.07	0.26	0.11	0.31	***	***

Sample sizes for individual variables vary due to missing data.
* p<.05; ** p<.01; *** p<.001 for t test

Table 2. Descriptive Statistics for Test Scores, Teacher Reported Achievement, and Retention Outcomes Over Time for Analytic Samples

	Full Analytic Sample				Analytic Sample with Low Math Skills			
	Mean	S.D	Min	Max	Mean	S.D	Min	Max
Test Scores								
Math								
Grade 8	143.81	21.22	66.26	172.20	130.55	22.99	68.35	172.20
Grade 5	127.38	23.53	50.86	170.66	111.32	23.97	50.86	168.01
Grade 3	103.11	23.88	34.56	166.25	86.52	21.15	34.56	164.22
Grade 1	64.59	17.94	13.53	132.49	52.20	13.44	13.53	117.09
Sping Kindergarten	38.72	12.05	12.68	112.51	29.77	7.27	12.68	61.38
Reading								
Grade 8	173.18	26.40	86.63	208.90	157.72	28.78	86.63	208.44
Grade 5	154.82	24.74	65.22	203.22	138.39	24.77	65.22	198.38
Grade 3	132.29	26.54	51.61	200.75	114.29	24.65	51.61	181.40
Grade 1	80.93	23.53	25.69	184.05	65.63	17.04	25.69	135.78
Sping Kindergarten	47.97	14.01	22.35	156.85	39.64	7.81	22.35	99.62
Science								
Grade 8	86.17	15.19	28.21	107.90	77.43	16.60	28.21	107.90
Grade 5	67.62	14.70	23.01	103.23	58.84	14.59	23.01	95.44
Grade 3	53.45	14.55	17.68	95.37	44.76	13.01	17.68	90.93
Teacher Reports								
Math								
Grade 8	3.15	0.93	1.14	4.94	2.74	0.88	1.14	4.94
Grade 5	3.48	0.70	1.00	5.00	3.13	0.66	1.00	5.00
Grade 3	3.16	0.72	1.00	5.00	2.82	0.66	1.00	5.00
Grade 1	3.58	0.85	1.00	5.00	3.09	0.84	1.00	5.00
Sping Kindergarten	3.66	0.81	1.00	5.00	3.19	0.80	1.00	5.00
Reading								
Grade 8	3.13	1.02	1.03	4.97	2.62	0.96	1.03	4.97
Grade 5	3.53	0.82	1.00	5.00	3.13	0.79	1.00	5.00
Grade 3	3.42	0.85	1.00	5.00	2.94	0.81	1.00	5.00
Grade 1	3.57	0.88	1.02	5.00	3.01	0.84	1.02	5.00
Sping Kindergarten	3.48	0.77	1.00	5.00	3.00	0.67	1.00	5.00
Retention								
Grade 8	0.09	0.28	0.00	1.00	0.20	0.40	0.00	1.00
Grade 5	0.07	0.26	0.00	1.00	0.17	0.38	0.00	1.00
Grade 3	0.06	0.24	0.00	1.00	0.15	0.35	0.00	1.00
Grade 1	0.03	0.16	0.00	1.00	0.06	0.23	0.00	1.00

Sampel sizes for individual variables vary due to missing data.

Table 3. Regression Coefficients and Standard Errors from Models Predicting Eighth Grade Achievement Test Scores with Fall Kindergarten Achievement

	Reading					Math					Science	
Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Fall Kindergarten												
Math Test Score												
Subscale 1[abc]	.52***	.21***			.13***	.57***	.30***			.18***	.53***	.15***
	(.02)	(.02)			(.02)	(.02)	(.02)			(.02)	(.02)	(.02)
Subscale 2[bde]	.54***		.26***		.17***	.60***		.42***		.26***	.55***	.16***
	(.01)		(.01)		(.02)	(.01)		(.01)		(.02)	(.01)	(.02)
Subscale 3[adf]	.40***			.12***	.04***	.45***			.24***	.11***	.41***	.07***
	(.01)			(.01)	(.01)	(.01)			(.01)	(.01)	(.01)	(.01)
Reading Test Score[cef]		.13***	.06***	.09***	.05***		.16***	.05***	.08***	.03**		.03***
		(.01)	(.01)	(.01)	(.01)		(.01)	(.01)	(.01)	(.01)		(.01)
Genral Knowledge		X	X	X	X		X	X	X	X		X
Control Variables		X	X	X	X		X	X	X	X		X
Observations	7645	7645	7645	7645	7645	7645	7645	7645	7645	7645	7644	7644
R squared		.45	.46	.44	.47		.43	.47	.42	.48		.50

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001

First column for each dependent variable (columns 1, 6, & 11) shows coefficients from bivariate regressions.

Controls include gender, age, birth weight, race/ethnicity, geographic controls, home environment, parental education, family income, preschool child care arrangement, neighborhood characteristics, parental expectations. Missing dummies included for controls. Complete list of controls in Table 1 or Appendix A.

All variables are standardized by full, weighted sample standard deviations.

[a]Coeffient for subscale 1 significantly different from coefficient for subscale 3 in columns (5), (10), and (12), p<.05.

[b]Coeffient for subscale 1 significantly different from coefficient for subscale 2 in column (10), p<.05.

[c]Coeffient for subscale 1 significantly different from coefficient for reading test in columns (5), (10), and (12), p<.05.

[d]Coeffient for subscale 2 significantly different from coefficient for subscale 3 in columns (5), (10), and (12), p<.05.

[e]Coeffient for subscale 2 significantly different from coefficient for reading test in columns (5), (10), and (12), p<.05.

[f]Coeffient for subscale 3 significantly different from coefficient for reading test in columns (10), and (12), p<.05.

Table 4. Regression Coefficients and Standard Errors from Models Predicting Eighth Grade Teacher Reported Outcomes with Fall Kindergarten Achievement

	Teacher Reported Reading					Teacher Reported Math					Grade Retention			
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	O.R.	(12)	O.R.
Fall Kindergarten														
Math Test Score														
Subscale 1[a]	.41***	.16***			.09***	.36***	.18***			.09***	-.83***	.43	-.24***	.79
	(.02)	(.02)			(.02)	(.02)	(.02)			(.02)	(.04)		(.05)	
Subscale 2[b]	.46***		.25***		.15***	.44***		.32***		.20***	-1.33***	.27	-.53***	.59
	(.01)		(.02)		(.02)	(.02)		(.02)		(.03)	(.06)		(.11)	
Subscale 3[c]	.37***			.16***	.09***	.35***			.23***	.13***	-2.22***	.11	-.32*	.73
	(.01)			(.01)	(.02)	(.01)			(.01)	(.02)	(.29)		(.15)	
Reading Test Score		.19***	.12***	.13***	.10***		.16***	.07***	.06***	.03			-.48***	.62
		(.01)	(.01)	(.01)	(.01)		(.02)	(.02)	(.01)	(.02)			(.14)	
Genral Knowledge		X	X	X	X		X	X	X	X			X	
Control Variables		X	X	X	X		X	X	X	X			X	
Observations	7305	7305	7305	7305	7305	3642	3642	3642	3642	3642	7645		7645	
R squared		.31	.33	.31	.33		.21	.24	.23	.25			.29	

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001.

First column for each dependent variable (columns 1, 6, & 11) shows coefficients from bivariate regressions.
Controls include gender, age, birth weight, race/ethnicity, geographic controls, home environment, parental education, family income, preschool child care arrangement, neighborhood characteristics, parent expectations. Missing dummies included for control variables. Complete list of control variables in Table 1 or Appendix A.

All variables are standardized by full, weighted sample standard deviations.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (5), (10), and (12), p<.05.

[b] Coeffient for subscale 2 significantly different from coefficient for reading test score in columns (5), (10), p<.05.

[c] Coeffient for subscale 3 significantly different from coefficient for reading test score in columns (10), p<.05.

Table 5. Regression Coefficients and Standard Errors from Models Predicting Eighth Grade Achievement with Fall Kindergarten Achievement for Low Math Achievers at Fall Kindergarten

	Reading				Math				Science	
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Fall Kindergarten										
Math Test Score										
Subscale 1[ab]	.32***	.14***		.12***	.35***	.22***		.16***	.34***	.13***
	(.02)	(.02)		(.02)	(.02)	(.02)		(.02)	(.02)	(.02)
Subscale 2[c]	.64***		.25***	.13**	.75***		.48***	.31***	.69***	.17**
	(.04)		(.04)	(.05)	(.04)		(.04)	(.05)	(.04)	(.04)
Reading Test Score		.13***	.11*	.08		.14***	.06	.02		.03
		(.04)	(.04)	(.04)		(.04)	(.05)	(.05)		(.04)
Genral Knowledge		X	X	X		X	X	X		X
Control Variables		X	X	X		X	X	X		X
Observations	2548	2548	2548	2548	2548	2548	2548	2548	2547	2547
R squared		.37	.36	.37		.34	.33	.37		.41

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001

First column for each dependent variable (columns 1, 5, & 9) shows coefficients from bivariate regressions.
Controls include gender, age, birth weight, child's ethnicity, geographic controls, home environment, parental educations, family income, preschool child care arrangement, neighborhood characteristics, parent expectations of child. Missing dummies are included for the control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (8), p<.05.

[b] Coeffient for subscale 1 significantly different from coefficient for reading test score in columns (8),(10), p<.05.

[c] Coeffient for subscale 2 significantly different from coefficient for reading test score in columns (8),(10), p<.05.

Table 6. Regression Coefficients and Standard Errors from Models Predicting Eighth Grade Teacher Reports of Achievement with Fall Kindergarten Achievement for Low Math Achievers at Fall Kindergarten

	Reading from Teachers' Report				Math from Teachers' Report				Retention			
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	odds ratio	(10)	odds ratio
Fall Kindergarten												
Math Test Score												
Subscale 1[a]	.22***	.13***		.09***	.20***	.12***		.06*	-.54***	.59***	-.21***	.81***
	(.02)	(.02)		(.02)	(.02)	(.02)		(.03)	(.04)		(.06)	
Subscale 2[b]	.46***		.28***	.18***	.46***		.36***	.29***	-1.66***	.19***	-.65***	.52***
	(.04)		(.04)	(.05)	(.05)		(.06)	(.07)	(.16)		(.19)	
Reading Test Score		.15***	.10*	.08		.09	-.02	-.03			-.50*	.61*
		(.04)	(.05)	(.05)		(.07)	(.07)	(.07)			(.20)	
Genral Knowledge		X	X	X		X	X	X			X	
Control Variable		X	X	X		X	X	X			X	
Observations	2398	2398	2398	2398	1220	1220	1220	1220	2548		2548	
R squared		.23	.23	.24		.18	.19	.19			.23	

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001

First column for each dependent variable (columns 1, 5, & 9) shows coefficients from bivariate regressions.

Controls include gender, age, birth weight, child's ethnicity, geographic controls, home environment, parental educations, family income, preschool child care arrangement, neighborhood characteristics, parent expectations of child. Missing dummies are included for the control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in column (8), p<.05.
[b] Coeffient for subscale 2 significantly different from coefficient for reading test score in column (8), p<.05.

Table 7. Coefficients and Standard Errors from Regressions Predicting Achievement Test Scores Across Elementary School with Fall Kindergarten Achievement

	Reading Acheivement Test					Math Acheivement Test					Science		
	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Grade 3	Grade 5	Grade 8
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Fall Kindergarten													
Math Test Score													
Subscale 1[ad]	.07***	.12***	.11***	.14***	.13***	.14***	.14***	.13***	.16***	.18***	.06***	.10***	.15***
	(.01)	(.01)	(.02)	(.02)	(.02)	(.01)	(.01)	(.01)	(.02)	(.02)	(.01)	(.01)	(.02)
Subscale 2[ce]	.02	.12***	.20***	.19***	.17***	.14***	.17***	.27***	.29***	.26***	.09***	.12***	.16***
	(.01)	(.02)	(.02)	(.02)	(.02)	(.01)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)
Subscale 3[bf]	.09***	.15***	.09***	.07***	.04***	.41***	.32***	.22***	.14***	.11***	.09***	.07***	.07***
	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
Reading Test Score	.75***	.42***	.13***	.09***	.05***	.16***	.07***	.04***	.03**	.03**	.06***	.03***	.03***
	(.02)	(.01)	(.01)	(.01)	(.01)	(.02)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
General Knowledge	X	X	X	X	X	X	X	X	X	X	X	X	X
Control Variable	X	X	X	X	X	X	X	X	X	X	X	X	X
Observations	7645	7470	7347	7330	7645	7645	7470	7382	7335	7645	7379	7335	7644
R squared	.70	.55	.54	.52	.47	.66	.55	.56	.54	.48	.59	.57	.50

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001.

Controls include gender, age, birth weight, race/ethnicity, geographic controls, home environment, parental education, family income, preschool child care arrangement, neighborhood characteristics, parental expectations. Missing dummies included for control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (1), (3), (8), (9), (10), p<.05.

[b] Coeffient for subscale 1 significantly different from coefficient for subscale 3 in columns (2), (4),(5), (6), (7), (8), (10), (12), (13), p<.05.

[c] Coeffient for subscale 2 significantly different from coefficient for subscale 3 in columns (1), (3), (4), (5), (6), (7), (8), (9), (10), (13), p<.05.

[d] Coeffient for subscale 1 significantly different from coefficient for reading test score in columns (1),(2), (4),(5), (7), (8), (9),(10),(12), (13), p<.05.

[e] Coeffient for subscale 2 significantly different from coefficient for reading test score in columns (1), (2), (3), (4), (5), (7), (8), (9), (10), (11), (12), (13), p<.05.

[f] Coeffient for subscale 3 significantly different from coefficient for reading test score in columns (1),(2),(3),(6),(7),(8),(9),(10),(12),(13), p<.05.

Table 8. Regression Coefficients and Standard Errors from Models Predicting Teacher Reports of Achievement Across Elementary School with Fall Kindergarten Achievement

	Reading from Teachers' Report					Math from Teachers' Report					Retention							
	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Grade 1	O.R.	Grade 3	O.R.	Grade 5	O.R.	Grade 8	O.R.
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		(12)		(13)		(14)	
Fall Kindergarten																		
Math Test Score																		
Subscale 1[ad]	.15***	.19***	.14***	.10***	.09***	.17***	.20***	.13***	.15***	.09***	-.29***	.75	-.29***	.75	-.20***	.82	-.24***	.79
	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.03)	(.02)	(.07)		(.06)		(.06)		(.05)	
Subscale 2[ce]	.22***	.27***	.21***	.20***	.15***	.24***	.24***	17***	.20***	.20***	-.56***	.57	-.56***	.57	-.60***	.55	-.53***	.59
	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.03)	(.03)	(.17)		(.15)		(.14)		(.11)	
Subscale 3[bf]	.05***	.08***	.09***	.09***	.09***	.03	.11***	.12***	.17***	.13***	.01	1.01	-.33	.72	-.34	.71	-.32*	.73
	(.02)	(.01)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.03)	(.02)	(.18)		(.22)		(.21)		(.15)	
Reading Test Score	.29***	.22***	.14***	.10***	.10***	.17***	.12***	.10***	.06**	.03	-.34	.71	-.76***	.47	-.66***	.52	-.48***	.62
	(.02)	(.01)	(.02)	(.01)	(.01)	(.01)	(.01)	(.02)	(.02)	(.02)	(.22)		(.17)		(.16)		(.14)	
General Knowledge	X	X	X	X	X	X	X	X	X	X	X		X		X		X	
Control Variable	X	X	X	X	X	X	X	X	X	X	X		X		X		X	
Observations	7356	6805	6278	6995	7305	7289	6723	6163	3466	3642	7593		7645		7645		7645	
R squared	.44	.41	.33	.30	.33	.35	.34	.25	.32	.25	.19		.30		.30		.29	

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001.

Controls include gender, age, birth weight, race/ethnicity, geographic controls, home environment, parental education, family income, preschool child care arrangement, neighborhood characteristics, parental expectations. Missing dummies included for the control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (1), (2),(4),(5),(6), (10), (13),(14), p<.05.

[b] Coeffient for subscale 1 significantly different from coefficient for subscale 3 in columns (1),(2),(3),(6),(7) p<.05.

[c] Coeffient for subscale 2 significantly different from coefficient for subscale 3 in columns (1),(2),(3),(4),(6),(7), (10) p<.05.

[d] Coeffient for subscale 1 significantly different from coefficient for reading test score in columns (1),(7),(9),(12),(13), p<.05.

[e] Coeffient for subscale 2 significantly different from coefficient for reading test score in columns (1),(2),(3),(4),(5),(6),(7),(8),(9),(10), p<.05.

[f] Coeffient for subscale 3 significantly different from coefficient for reading test score in columns (1),(2),(6),(9),(10), p<.05.

Table 9. Regression Coefficients and Standard Errors from Models Predicting Achievement Test Scores Across Elementary School with Kindergarten Achievement for Low Math Achievers at Fall Kindergarten

	Reading Acheivement Test					Math Acheivement Test					Science		
	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Grade 3	Grade 5	Grade 8
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Fall Kindergarten													
Math Test Score													
Subscale 1[ab]	.07***	.11***	.10***	.12***	.12***	.08***	.10***	.10***	.14***	.16***	.06***	.10***	.13***
	(.01)	(.01)	(.02)	(.02)	(.02)	(.01)	(.01)	(.01)	(.02)	(.02)	(.01)	(.02)	(.02)
Subscale 2[c]	.12***	.14***	.17***	.15***	.13**	.40***	.32***	.39***	.37***	.31***	.11**	.10**	.17**
	(.02)	(.03)	(.04)	(.04)	(.05)	(.03)	(.04)	(.04)	(.04)	(.05)	(.04)	(.04)	(.04)
Reading Test Score	.56***	.46***	.24***	.15***	.08	.15***	.06	.01	-.01	.02	.05	.01	.03
	(.03)	(.04)	(.04)	(.04)	(.04)	(.03)	(.04)	(.04)	(.04)	(.05)	(.04)	(.04)	(.04)
General Knowledge	X	X	X	X	X	X	X	X	X	X	X	X	X
Control Variable	X	X	X	X	X	X	X	X	X	X	X	X	X
Observations	2548	2467	2392	2406	2548	2548	2467	2424	2408	2548	2422	2408	2547
R squared	.46	.35	.39	.39	.37	.47	.36	.39	.39	.35	.51	.49	.41

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001.
Controls include gender, age, birth weight, child's ethnicity, geographic controls, home environment, parental educations, family income, preschool child care arrangement, neighborhood characteristics, parent expectations of child. Missing dummies are included for the control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (6),(7),(8), (9),(10), p<.05.

[b] Coeffient for subscale 1 significantly different from coefficient for reading test score in columns (1),(2),(3),(6),(8),(9),(10),(13), p<.05.

[c] Coeffient for subscale 2 significantly different from coefficient forreading test score in columns (1),(2),(6),(7),(8),(9),(10),(13), p<.05.

Table 10. Regression Coefficients and Standard Errors from Models Predicting Teacher Reports across Elementary School with Achievement for Low Math Achievers at Fall Kindergarten

	Reading from Teachers' Report					Math from Teachers' Report					Retention							
	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Spring K	Grade 1	Grade 3	Grade 5	Grade 8	Grade 1	O.R.	Grade 3	O.R.	Grade 5	O.R.	Grade 8	O.R.
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)		(12)		(13)		(14)	
Fall Kindergarten																		
Math Test Score																		
Subscale 1[ab]	.13***	.18***	.12***	.09***	.09***	.15***	.20***	.11***	.10***	.06*	-.18*	.84	-.21***	.81	-.15*	.86	-.21***	.81
	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.03)	(.03)	(.09)		(.07)		(.06)		(.06)	
Subscale 2[c]	.19***	.20***	.24***	.27***	.18***	.28***	.25***	.22***	.26***	.29***	-.94*	.39	-1.13***	.32	-1.08***	.34	-.65***	.52
	(.04)	(.04)	(.05)	(.05)	(.05)	(.04)	(.05)	(.05)	(.08)	(.07)	(.47)		(.34)		(.30)		(.19)	
Reading Test Score	.48***	.37***	.19***	.11*	.08	.26***	.18***	.12*	.20*	-.03	-.89*	.41	-.71***	.49	-.57**	.57	-.50*	.61
	(.04)	(.05)	(.05)	(.05)	(.05)	(.05)	(.05)	(.06)	(.08)	(.07)	(.38)		(.22)		(.20)		(.20)	
General Knowledge	X	X	X	X	X	X	X	X	X	X	X		X		X		X	
Control Variable	X	X	X	X	X	X	X	X	X	X	X		X		X		X	
Observations	2445	2160	2000	2279	2398	2430	2140	1955	1139	1220	2536		2548		2548		2548	
R squared	.33	.28	.23	.22	.24	.27	.25	.19	.26	.19	.21		.22		.21		.23	

Notes: Standard errors in parentheses, clustered by fall of kindergarten classroom. * p<.05, ** p<.01, *** p<.001.

Controls include gender, age, birth weight, child's ethnicity, geographic controls, home environment, parental educations, family income, preschool child care arrangement, neighborhood characteristics, parent expectations of child. Missing dummies are included for the control variables. Complete list of control variables in Table 1 and Appendix A.

[a] Coeffient for subscale 1 significantly different from coefficient for subscale 2 in columns (4),(6),(10),(12), p<.05.

[b] Coeffient for subscale 1 significantly different from coefficient for reading test score in columns (1),(2),(6),(12) , p<.05.

[c] Coeffient for subscale 2 significantly different from coefficient for reading test score in columns(1),(2), (10), p<.05.

Appendix A. Descriptive Statistics for Control Variables for Three Samples

	Full Sample n=21,409 (1)		Analytic Sample n=7655 (2)		Low Math Skills Anal. Sample n=2551 (3)		Mean Diff. Col. 1 & 2 (4)	Mean Diff. Col. 2 & 3 (5)
	Mean	S.D	Mean	S.D	Mean	S.D		
Age (in months at Fall Assessment, squared)	4698.57	598.63	4717.99	583.64	4563.94	569.37	***	***
Age (cubed x 1000)	3.24E+08	6.21E+07	3.26E+08	#######	3.10E+08	5.87E+07	***	***
Birth weight (in pounds)	6.92	1.34	6.99	1.32	6.86	1.38	***	***
Missing birth weight	0.18	0.38	0.06	0.23	0.09	0.28	***	***
Premature (child over 2 weeks early)	0.17	0.38	0.06	0.24	0.08	0.27	***	***
Parent report of overall child health (1=excellent, 5=poor)	2.17	0.95	2.08	0.90	2.25	0.96	***	***
Geographic controls								
West	0.23	0.42	0.19	0.40	0.20	0.40	***	
Midwest	0.25	0.43	0.30	0.46	0.26	0.44	***	***
Northeast	0.18	0.39	0.21	0.40	0.20	0.40	***	
South	0.33	0.47	0.30	0.46	0.34	0.48	***	***
Home Environment								
Number of siblings (squared)	3.53	6.53	3.23	5.59	3.85	6.55	***	***
Number of siblings (cubed)	11.96	46.03	10.00	36.66	13.13	40.61	***	***
Child part of multiple birth	0.02	0.14	0.02	0.15	0.03	0.17		*
Four or more moves pre-school	0.26	0.44	0.12	0.33	0.15	0.36	***	***
Parent reads to child (days/week)	5.01	2.11	5.23	1.97	4.87	2.15	***	***
Missing read to child	0.16	0.36	0.04	0.20	0.06	0.24	***	***
Parent tells stories to child (days/ week)	3.72	2.41	3.76	2.37	3.62	2.43	*	***
Missing parent tells stories to child (days/ week)	0.16	0.36	0.04	0.20	0.06	0.24	***	***
Number of children's books at home	72.80	59.52	85.23	60.25	67.44	57.27	***	***
Missing number of books	0.16	0.37	0.05	0.22	0.07	0.25	***	***
Watched Sesame Street pre-school	0.62	0.48	0.58	0.49	0.64	0.48	***	***
Parental Characteristics								
Mother's age at child's birth	27.53	6.57	28.70	6.24	27.60	6.91	***	***
Missing mother's age at child'd birth	0.20	0.40	0.06	0.23	0.08	0.27	***	***
Mother's ag at first birth	23.79	5.45	25.03	5.40	23.07	5.17	***	***
Missing mother's age at first birth	0.22	0.41	0.10	0.29	0.13	0.34	***	***
Mother's education (in years)	13.36	3.01	14.00	2.60	13.02	2.68	***	***
Missing mother's education	0.07	0.26	0.03	0.18	0.04	0.20	***	***
Father's education (in years)	13.55	3.22	14.09	2.97	12.96	2.95	***	***
Missing father's education	0.25	0.43	0.17	0.38	0.25	0.43	***	***
Mother worked between birth and kindergarden	0.73	0.44	0.77	0.42	0.75	0.43	***	*
Missing whether mother worked between birth and kindergarden	0.10	0.30	0.05	0.22	0.07	0.26	***	***
Income	52039.89	56398.95	60180.39	56687.67	43550.79	39192.79	***	***
Missing income	0.06	0.24	0.02	0.13	0.03	0.16	***	***
Mother's occupation(prestige score)	43.43	11.16	44.60	11.63	41.42	10.10	***	***
Mother's occupation (squared)	9.95E+07	8.49E+07	1.08E+08	#######	8.52E+07	7.49E+07	***	***
Mother'occupation(cubed x 1000)	2010.63	1100.51	2124.56	1158.06	1817.69	983.85	***	***
Missing mother's occupation	0.38	0.49	0.31	0.46	0.34	0.47	***	**
Father's occupation(prestige score)	43.17	10.98	44.19	11.48	41.19	9.80	***	***
Father's occupation (squared)	1984.25	1104.17	2085.01	1167.38	1793.05	973.00	***	***
Father's occupation(cubed x 1000)	9.77E+07	8.80E+07	1.05E+08	#######	8.33E+07	7.66E+07	***	***
Missing Father's occupation	0.31	0.46	0.22	0.41	0.31	0.46	***	***
WIC	0.40	0.49	0.30	0.46	0.47	0.50	***	***
Missing WIC	0.18	0.39	0.06	0.24	0.09	0.28	***	***
Food stamp	0.19	0.39	0.12	0.32	0.21	0.41	***	***
Missing food stamp	0.16	0.37	0.04	0.20	0.06	0.24	***	***

(Appendix A Continued)								
AFDC	0.11	0.32	0.07	0.25	0.12	0.33	***	***
Missing AFDC	0.16	0.37	0.04	0.20	0.06	0.24	***	***
Child care Arrangement								
Relative pre-school care	0.18	0.39	0.18	0.39	0.23	0.42		***
Center--Based pre-school care	0.17	0.38	0.18	0.38	0.13	0.34	*	***
Non-Relative pre-school care	0.10	0.30	0.12	0.32	0.11	0.31	***	
Head Start	0.16	0.37	0.13	0.33	0.22	0.41	***	***
Varied pre-school care	0.01	0.09	0.01	0.08	0.01	0.07		
Child ever in center-based pre-school care	0.76	0.42	0.80	0.40	0.73	0.44	***	***
Neighborhood characteristics (1="Big Problem", 3="No Problem")								
Neighborhood safety	2.66	0.55	2.74	0.49	2.66	0.53	***	***
Neighborhood litter	2.86	0.41	2.89	0.34	2.85	0.40	***	***
Neighborhood drug use	2.54	0.65	2.60	0.60	2.47	0.68	***	***
Neighborhood burglary	2.86	0.39	2.88	0.35	2.86	0.38	***	**
Neighborhood violence	2.95	0.25	2.97	0.18	2.97	0.22	***	**
Neighborhood vacancies	2.94	0.29	2.95	0.24	2.93	0.29	***	***
Parental expectations at baseline								
Years of education parent expects child to complete	16.64	2.38	16.65	2.14	16.34	2.46		***
Missing education expectation	0.16	0.37	0.04	0.20	0.06	0.24	***	***
How important is it that your child does the following by kindergarten? (1="Essential", 5="Not Important")								
Count	2.32	0.89	2.39	0.90	2.45	0.89	***	***
Missing count	0.16	0.36	0.04	0.20	0.06	0.23	***	***
Share	1.74	0.57	1.71	0.58	1.78	0.55	***	***
Missing share	0.16	0.36	0.04	0.20	0.06	0.23	***	***
Draw	2.08	0.76	2.08	0.78	2.13	0.76		**
Missing draw	0.16	0.36	0.04	0.20	0.06	0.24	***	***
Calm	1.95	0.68	1.95	0.69	1.96	0.65		
Missing calm	0.16	0.36	0.04	0.20	0.06	0.23	***	***
Knows letters	2.18	0.83	2.25	0.85	2.28	0.82	***	*
Missing knows letters	0.16	0.36	0.04	0.20	0.06	0.23	***	***
Communicates well	1.72	0.59	1.69	0.60	1.75	0.57	***	***
Missing communicates well	0.16	0.36	0.04	0.20	0.06	0.23	***	***

Sampel sizes for each variable change due to missing data.
* p<.05; ** p<.01; *** p<.001 for T test.