Abstract Title Page
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Title: What specific preschool math skills predict later math achievement?

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Abstract Body

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Background / Context:

The widespread concern about mathematics achievement has drawn extensive research attention to what skills predict later academic achievement. There is clear and consistent evidence that math achievement at school entry is the strongest predictor of later school success and educational attainment (Duncan et al., 2007; Entwisle et al. 2005; Murnane, Willett, & Levy, 1995). Early childhood math achievement can thus have far-reaching effects on students' schooling.

The level of math skills and input children receive prior to school entry are particularly important for those from low-income and disadvantaged backgrounds. Preschool children from low socioeconomic status (SES) families begin school with less mathematical knowledge than their peers from higher SES families (e.g., Jordan, Huttenlocher, & Levine, l994; Starkey, Klein, & Wakeley, 2004). As a result, children from lower SES families often enter school at different levels of readiness to learn a standards-based mathematics curriculum (Clements, Sarama, & DiBiase, 2004; Starkey, 2007).

The accumulated research on childhood math skills indicates the importance of particular mathematical competencies to later achievement and encourages the investigation of the nature of early math learning and achievement. Thus, examining the importance of specific math skills prior to school entry may be especially important for low-income children, who stand to benefit the most from early exposure to math. We do this in the present study.

Purpose / Objective / Research Question / Focus of Study:

Using longitudinal data from a low-income sample of preschoolers, we identify specific preschool mathematical competencies and relate them to later math achievement for students of low-income and minority backgrounds.

Setting & Intervention:

This study is a secondary data analysis of data collected from the Technology-enhanced, Research-based, Instruction, Assessment, and professional Development (TRIAD) intervention evaluation study (Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Clements, Sarama, Wolfe, & Spitler, 2012), which assessed the impact of an early mathematics intervention in low-resource schools.

The intervention included the *Building Blocks* mathematics curriculum and professional development for teachers who utilized it. Schools were randomly assigned to three conditions: (1) pre-kindergarten only treatment; (2) pre-kindergarten to first grade treatment; (3) control condition. In pre-kindergarten, the two treatment groups received identical interventions, but in the pre-kindergarten to first grade treatment condition, teachers had knowledge of the pre-kindergarten intervention and were provided with strategies to build upon that knowledge.

Population / Participants / Subjects:

The full sample consisted of 1375 students in the fall of the preschool year. Our analysis employs a sub-sample of children (n=781) who had valid mathematics achievement score data in pre-kindergarten and fifth grade. The data are not nationally representative, as this is a predominantly low-income sample. 83% qualified for free or reduced price lunch. Additionally, 53% of the children are African-American and 18% are Hispanic. Descriptive statistics for this sample are presented in Table 1.

Research Design:

We conducted analyses on previously collected data. This data set was chosen because of the unique sample and it takes into account the broad array of mathematical skills that are taught in early childhood settings. It contains detailed assessments of children's early mathematical skills and achievement. We do not exploit the randomization of classrooms to treatment conditions. Instead, we investigate the non-experimental association between the preschool mathematical competencies to later achievement.

Data Collection and Analysis:

The current study utilizes data collected during preschool, kindergarten, 1st, 4th, and 5th grade. We use multivariate regression analyses to relate end of pre-k math skills to math achievement to later grades in elementary school.

Our key independent variable is fifth grade mathematics achievement. These scores come from the Tools for Early Assessment in Math (TEAM). In the TRIAD dataset, fourth and fifth grade math achievement test scores were measured with the TEAM. The test is comprised of two sections that contain detailed assessments of mathematical competencies across a variety of sub-topics: (1) spatial and geometric concepts and (2) numeracy concepts. This analysis used an aggregated score from both sections of the exam.

Our independent variables of interest included math achievement test scores measured in the fall and spring of pre-kindergarten. These were measured with the Research-based Early Mathematics Assessment (REMA). The exam is well validated and specifically designed for early mathematics (Clements, Sarama, & Liu, 2008). The exam contains two sections – children's numeracy and geometry skills – that evaluates counting and cardinality, recognizing shapes, patterning, measurement, and addition and subtraction. The child's baseline level of achievement as measured by the REMA in the fall was also included in the models.

We coded the preschool REMA test items into four mathematical skill categories based on the Massachusetts state-defined preschool math standards: (1) measurement and data; (2) geometry; (3) operations and algebraic thinking; (4) counting and cardinality (Massachusetts Department of Elementary and Secondary Education, 2011). We chose to code the skill measures in this way since Massachusetts is most commonly regarded as one of the highest achieving states in math. In order to minimize the potential for omitted variable bias and to adjust for the randomization of this intervention, child and parent level controls were included in the analyses. Child covariates

included: ethnicity (with children identified as white, non-Hispanic serving as the reference group), gender (1=male; 0=female), age at first assessment measured in years, birthweight measured in pounds, whether special education, whether the child was designated as limited English proficiency, and whether the child received free and reduced price lunch. All continuous variables (age at first assessment and birthweight) were standardized. Parent covariates included the mother's level of education. We created dummy coded variables indicating the highest level of formal schooling (with the mother attaining a college degree or higher as the reference group).

Since we did not examine the experimental variation in this study, we included controls for the characteristics of the intervention: the geographic location (whether at the first or second site) and treatment group (whether in the preschool only treatment, the preschool to first grade treatment, or the control condition). We also included a vector of preschool teacher fixed effects due to the clustering of the sample. By adding these fixed effects into our model, we are accounting for any differences in math achievement between classrooms.

To ensure that missing data did not bias our final results, we handled variables that were missing using dummy variable adjustments. Variables were created for the covariates indicating if the value was missing (1=missing; 0=not missing). We also used the Full Information Maximum Likelihood (FIML) procedure in Stata 13.0 as a robustness check. While this procedure increased the sample size, the results were not substantively different.

Findings / Results:

Table 2 displays the series of regression models of the relationship between the specific pre-k math skills and math achievement in 1st, 4th, and 5th grade. All variables have been standardized to have a mean of zero and standard deviation of one so that coefficients are comparable with one another. Coefficients presented were estimated from models that included a control for the baseline fall math composite and preschool teacher fixed effects.

Counting and cardinality are by far the strongest predictors of later math achievement, followed by operations and algebraic thinking. Geometry skills were also predictive, but less so. Measurement and data skills were not predictive after 1st grade. Our study is consistent with other investigations suggesting the powerful associations between early math skills and later achievement. Our results suggest strong support of mathematics in preschool.

Conclusions:

The present study expands our understanding of children's math achievement in their earliest years of schooling. We sought to relate specific mathematical competencies in the spring of pre-kindergarten to later math achievement in elementary school. The results reported in this study, along with a growing body of research with converging data (Claessens, Duncan, & Engel, 2009; Clements, et al., 2012; Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009), lend support to strengthening the link between promoting math skills in early childhood education and elementary school mathematics for later success. Even though measurement and data skills were not predictive after 1st grade, this does not necessarily mean that these skills are not important.

Indeed they are, but perhaps it is the case that children need to develop their early numeracy skills before moving on to more advanced skills.

Understanding the nature of early math learning and achievement is important since national education policy is increasingly moving towards investing in high-quality early childhood education programs. The TRIAD intervention is unique in that it was developed for schools serving low-resource communities, though the curriculum is designed to enable *all* children to develop a strong mathematical foundation (Clements et al., 2011; Sarama, Clements, Wolfe, & Spitler, 2012). Our results might suggest that providing students with more learning opportunities and supports for mathematical development can help level the playing field when they enter formal schooling, but future work is needed to empirically affirm this. Furthermore, our findings also lend support to developing effective math curricula that focus on precursory skills that empirical research has found to be most important for later math achievement.

Limitations to our study include: we examined the non-experimental association between early math skills and later math achievement, so our data are subject to omitted variable bias; though diverse, our sample is not a nationally representative dataset, which might limit our ability to draw firm, policy relevant conclusions.

Appendices

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Appendix A. References

References are to be in APA version 6 format.

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Appendix B. Tables and Figures
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Table 1. Participant characteristics.

	M/ Proportion of sample	SD
Child characteristics		
African American	0.53	0.50
Hispanic	0.18	0.38
White	0.22	0.41
Other	0.07	0.26
Female	0.55	0.50
Age at first test (in years)	4.33	0.35
Special education	0.16	0.37
Free or reduced price lunch	0.83	0.46
Birthweight (in pounds)	7.20	1.08
Limited English proficiency	0.15	0.36
Mother's education		
No high school	0.11	0.31
High school	0.26	0.44
Some college	0.24	0.43
College and beyond	0.13	0.33
Site		
Site 1	0.80	0.50
Site 2	0.20	0.50
Treatment		
Pre-k treatment	0.32	0.47
Follow through treatment	0.36	0.48
Control	0.31	0.46
Observations	781	

Table 2. Regression coefficients and standard errors for the association between end of preschool mathematical competencies and later math achievement

	Model 1	Model 2	Model 3	Model 4	Model 5
	Spring of kindergarten	Spring of 1st grade	Fall of 4th grade	Spring of 4th grade	Spring of 5th grade
Measurement and data	0.09***	0.07***	0.01	0.01	0.05
	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Geometry	0.14***	0.12***	0.09*	0.14***	0.10***
	(0.02)	(0.03)	(0.04)	(0.03)	(0.03)
Operations and algebraic thinking	0.22***	0.18***	0.17***	0.16***	0.16***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.05)
Counting and cardinality	0.37***	0.40***	0.41***	0.40***	0.39***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)
Classroom fixed effects	Inc.	Inc.	Inc.	Inc.	Inc.
Child and family characteristics	Inc.	Inc.	Inc.	Inc.	Inc.
Missing dummy variables	Inc.	Inc.	Inc.	Inc.	Inc.
R^2	0.63	0.58	0.48	0.5	0.46
Observations	781	781	781	781	781

Note. Standard errors in parentheses. All robust standard errors were adjusted to account for classroom-level clustering. All models control for the composite score of math achievement at the fall of pre-k. Control variables include baseline math skills (measured in the fall of pre-k), ethnicity, gender, age, special education status, birthweight, and missing dummy variables. All continuous variables were standardized. All models control for treatment and geographical location. Inc. indicates included.

* p <0.05; ** p < 0.01; *** p < 0.001