Early Math Trajectories: From Prekindergarten to the Middle Grades

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ABSTRACT

An Early Math Trajectories model is proposed and evaluated within a longitudinal study of 519 low-income American children from age 4 to 11. In preschool, nonsymbolic quantity, counting and patterning knowledge predicted fifth-grade mathematics achievement on a variety of measures. By the end of first grade, symbolic mapping, calculation and sometimes patterning knowledge were the key predictors. Further, the first-grade predictors mediated the relation between preschool math knowledge and fifth-grade mathematics achievement.

Background

Mathematics knowledge begins to develop at a young age, and this early knowledge predicts later math and reading achievement (Duncan et al., 2007; Watts et al., 2014).

We propose an Early Math Trajectory Model that encompasses a set of six early math topics that evidence indicates should be of particular importance for supporting mathematics achievement in the middle grades (See Figure). The 6 topics are:

1. ***Nonsymbolic quantity***: Magnitude of sets, without need to use symbols (LeFevre et al., 2010; Libertus et al., 2013). E.g., "Which one has more?" 3 vs. 4 dots
2. ***Counting***: Counting objects, including cardinality (Aunola, et al., 2004). E.g., "Count 5 cans and tell how many."
3. ***Symbolic Mapping***: Mapping between symbolic numerals, number names and magnitudes Kolkman et al., 2013; Sasanguie et al., 2012). E.g., "Match numerals 1-5 to the number of grapes."
4. ***Calculation***: Calculating combination or separation of sets (Geary, 2011). E.g., "Here are 6 pennies. Three more are hidden under the cloth. How many are there in all?"
5. ***Patterning***: Finding a predictable sequence in repeating patterns (Papic et al., 2011). E.g., "Finish my pattern here" when shown ABABAB pattern.
6. ***Shape***: Identifying shapes and their properties (Clements & Sarama, 2009). Included based on theory rather than evidence. E.g., "Select all the triangles" from a collection of 24 shapes.

Current Study

The goal of the current study is to elucidate specific early math knowledge that is predictive of later mathematics achievement for children from low-income backgrounds. We evaluated the Early Math Trajectories model within a longitudinal study of over 500 children from age 4 to 11.

Method

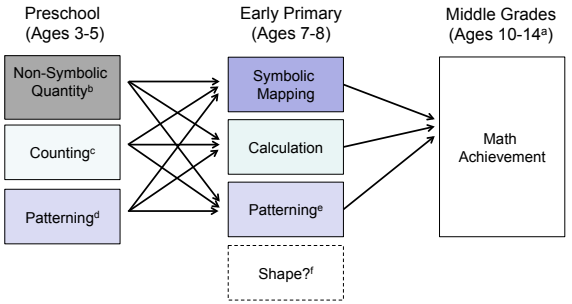
Participants:
•519 students from low-income homes, originally recruited from pre-k classrooms and participating in the Peabody Research Institute Middle School Follow Up Project (56% female; 79% Black, 9% Caucasian).
•Data collected at beginning and end of pre-k (*M* age = 4.4 and 5.0 yrs, respectively), end of first grade (*M* = 7.0 yrs) and end of fifth-grade (*M* = 11.0 yrs) though 14% had been retained in 4th grade.

Early Predictor Measures:
•Research-based Early Maths Assessment (REMA; Clements, Sarama & Liu, 2008). Numeracy items were broken into four subscales, in line with past research (Purpura & Lonigan, 2013). Patterning and shape items were treated as separate subscales.

•General cognitive and academic skills were assessed, including *narrative recall* skills (using the Renfrew Bus Story or Woodcock Johnson III Story recall, depending on time point), *reading* skill (using WJ Letter-Word Identification), and teacher ratings of *work-related skills* (Cooper-Farran) and *self-regulation* (from Instrumental Competence Scale for Young Children-Short Form).

Age 11 Mathematics Achievement Measures:
•Composite math achievement on norm-referenced measures: Sum z-scores on 3 KeyMath 3 Diagnostic Assessment subtests - Numeration, Algebra and Geometry - and WJ III Quantitative Concept subtest (individually administered)
•State test scores on the Tennessee Comprehensive Assessment Program (TCAP)

Early Math Trajectories Model



Note. [a]Current evidence is for ages 10-11 [b]Non-Symbolic was not a reliable predictor of state test scores at beginning of pre-k, but it was a unique predictor at the end of pre-k and first grade [c]Counting was a reliable predictor at beginning of pre-k, but not the end of pre-k. [d]Patterning not adequately assessed at beginning of pre-k to include in analyses [e]Patterning in first grade did not predict state test scores [f]Shape never a unique predictor.

Results

In preschool, individual differences in nonsymbolic quantity, counting and patterning knowledge predicted fifth-grade mathematics achievement over and above many other math and cognitive skills, with a few exceptions (see Table 1).

In first grade, individual differences in symbolic mapping, calculation and sometimes patterning knowledge were key predictors of later math achievement; shape knowledge was not (see Table 1). In addition, nonsymbolic knowledge was a predictor of state test scores.

Table 1: Regression Estimates Predicting 5th Grade Math Achievement from Early Knowledge

	Begin of Pre-K, *M* Age = 4.4		End of Pre-K, *M* Age = 5.0		End of First Grade. *M* Age = 7.0	
Measure	Norm-Referenced Tests	State Test	Norm-Referenced Tests	State Test	Norm-Referenced Tests	State Test
Math Predictors						
Nonsymbolic	.13**	.06	.19***	.10*	.03	.11*
Counting	.13*	.16**	-.02	.02	-.01	.05
Symbolic Mapping	.06	.05	.11	.12	.26***	.19***
Shape	.05	.06	.03	.00	.03	-.01
Patterning	--	--	.18***	.19***	.08*	.02
Calculation	--	--	--	--	.24***	.18***
Narrative Recall	.11*	.02	.17***	.09*	.09**	-.03
Reading	.04	.00	.10*	.06	.11**	.10*
Work-related Skills	.10	.14	.08	.04	.18**	.26***
Self-Regulation	.05	.07	.01	.10	.01	-.03

Note: All variables were standardized and standardized regression coefficients are reported. Control variables included gender, ethnicity, SES composite with maternal education and level of income, ELL status, PreK school type, age at time of testing at both time points & grade level at Age 11,nested within schools at Age 11. *p < .05. **p < .01. ***p < .001.

Table 2: Sample Mediation Model for Norm-Referenced Tests

End of Pre-K Predictors	Without Mediators	With Mediators
Nonsymbolic	.25***	.13***
Patterning	.23***	.07
Reading	.15***	.06
Narrative Rec.	.19***	.11**
End of first-grade mediators		
Symbolic Map	--	.30***
Patterning	--	.08*
Calculation	--	.26***

First-grade knowledge partially mediated the relation between preschool math knowledge and fifth-grade mathematics achievement in all models. See Table 2 for sample mediation results.

Conclusion

Strong support for Early Math Trajectories model for low-income children.

Early patterning knowledge merits increased attention in theories of math development and should be included in early standards (contrary to Common Core State Standards, 2010).

Nonsymbolic quantity knowledge in preschool may have an indirect effect on later achievement (see DeSmedt et al., 2013). It may support several primary-grade math topics, including symbolic mapping, calculation and patterning knowledge.

We will follow children through age 14 and evaluate whether these relations are consistent at later grade levels.