Enduring Effects of Pre-K Mathematic Experiences on Executive Function and Mathematic Skills through Grade 1

Kimberly T. Nesbitt & Dale C. Farran
Vanderbilt University

Introduction

With calls for "universal pre-k" and arguments that pre-k experiences are essential for children from low-income families[1], it is critical to identify specific, and potentially malleable, aspects of pre-k classrooms that are associated with greater immediate and sustained gains for at-risk children.

Research has consistently found relations between children's executive function (EF) and mathematics skill across the transition to formal schooling.[2]

While recent focus has been on improving children's EF skills in hopes of indirectly improving mathematics skills[3], bidirectional associations[4] also indicate targeting mathematics skills could impact the development of EF skills.

Current Study

- Examine the enduring effects of teacher-directed and child-directed mathematic experiences in pre-k on the development of children's EF and mathematic skills through the end of Grade 1.
- Explore if effects of mathematic experiences are unique compare to other instructional content.

Participants

- 849 children. 40% Caucasian, 26% African American, and 24% Hispanic. 46% female, 29% ELL, and 87% FRPL. Average age at pretest 54.4 months (*SD* = 3.7).
- 60 pre-k classrooms taught by teachers with an average of 12.0 years (*SD* = 8.2) teaching experience. All licensed teachers.

Analytic Approach

Multilevel structural equation modeling (MSEM) in Mplus[5] to estimate direct and indirect relations between pre-k experiences and EF and math gains through Grade 1 (Figure 1).

- Separate models for EF and math skills controlling for initial skill.
- Separate models for math and non-math pre-k experiences.
- Bayesian estimations utilized.

Measures

Child Outcomes: Direct assessments of children's skills at fall (F-PK) and spring of pre-k (S-PK) and the spring of kindergarten (S-K) and Grade 1 (S-G1).

- **EF Skills:** Composite of 1) Peg Tapping, 2) Dimensional Change Card Sort, 3) Head-Toes-Knees-Shoulders, 4) Corsi Blocks Backwards Span, and 5) Copy Design Task.
- **Math Skills:** WJ-III Applied Problems and Quantitative Concepts

Pre-K Experiences: Three pre-k observations using a snapshot system for capturing teacher's and children's behaviors in the classroom across a day-long visit[6].

- **Teacher-Directed Instruction:** Proportion of snapshots teachers were observed in instruction.
  - Math Instruction: *M* = 4.4%, *SD* = 2.9%
  - Non-Math Instruction (Language Arts, Science, Social Studies, Drama, and Other Content): *M* = 25.2%, SD = 6.9%
- **Child-Directed Focus:** Proportion of snapshots children were observed in an academic focus.
  - Math Focus: *M* = 6.1%, *SD* = 4.0%
  - Non-Math Focus: *M* = 57.3%, *SD* = 9.8%

Results

Effect of Pre-K Math Experiences

Model Fit. Predictive accuracy of the models (i.e., data generated by the model and observed data) were adequate, posterior predictive p-value for EF model = 0.460 and 0.451 for Math model.

Direct Effects

- Independent of teachers' math instruction, child-directed math focus was positively associated with larger pre-k gains in both EF and math skills (Figure 1).
- Conversely, teachers' math instruction was not found to be related to gains for children in either EF or math skills.

Indirect Effects

- While pre-k child-directed math did not have a direct effect on children's skills in K and G1, they were indirectly related via greater gains in skills across pre-k.
- 95% posterior probability interval (PPI) for the indirect effect of child-directed pre-k math on K and G1 skills via pre-k gains:

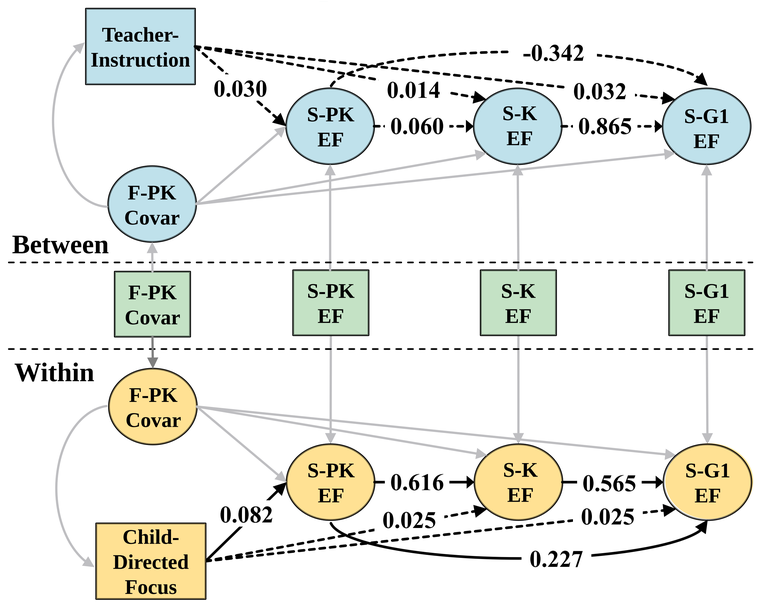
Indirect Effect on EF	Indirect Effect on Math Skills
S-PK → S-K = [0.013, 0.087]	S-PK → S-K = [0.006, 0.073]
S-PK → S-G1 = [0.005, 0.035]	S-PK → S-G1 = [0.003, 0.040]

Effects of Pre-K Non-Math Experiences

Neither teacher-directed nor child-directed non-math experiences were associated with pre-k, kindergarten, or Grade 1 gains in EF or math skills.

Results

Direct Effect of Math Experiences on Children's EF Skills



Direct Effect of Math Experiences on Children's Math Skills

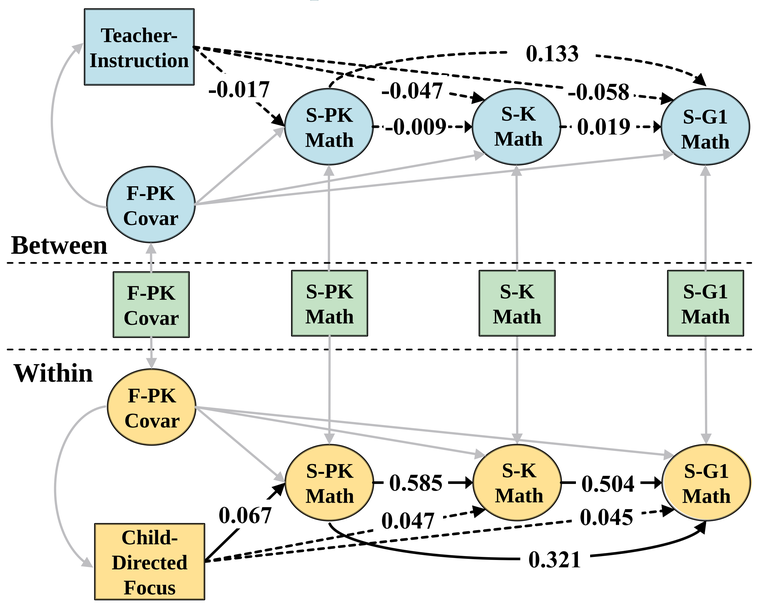


Figure 1. Effects of pre-k teacher-direct and children-directed experiences on children's spring pre-k (S-PK), kindergarten (S-K), and Grade 1 (S-G1) executive function (EF, top panel) and math skills (bottom panel) controlling for fall pre-k (F-PK) covariates (entering skills, age, gender, ell status). For parsimony estimate for model covariates have been omitted. Solid black lines indicate significant relations.

Discussion

While relatively little mathematics was occurring in these pre-k classrooms, children who engaged in more mathematics compared to their peers made larger gains in EF and math skills; effects that had a lasting indirect effect on through the end of Grade 1.

Effects on children's EF and math skills were not seen for greater teacher-directed instruction or for children's non-mathematic academic learning focus.

Policy and Practice Implications

If the benefits of pre-k for at risk children are to be realized, it is essential that we not only provide pre-k, but ensure that pre-k is high-quality and effective at optimizing children's outcomes and success.

Results of the study suggest that one avenue for lasting positive effects is to ensure that pre-k classrooms provide children access to rich, developmentally appropriate mathematic materials that enable them to learn math concepts without direct-teacher instruction.

Future work needs to:

- Identify how to design classrooms to provide children opportunities to effectively engage in math content.
- Experiment with what conditions best facilitate children's engagement in math in classrooms to achieve growth.

References

[1] Heckman, J. J., (2006). Skill formation and the economics of investing in disadvantaged children. *Science, 312*, 1900-1902.; Heckman, J. J., & Kautz, T. (2012). Hard evidence on soft skills. *Labour Economics*, *19*, 451-464.

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Acknowledgements

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Contact

For more information, please visit:
https://my.vanderbilt.edu/toolsofthemindevaluation/
or email Kimberly Nesbitt at:
kimberly.nesbitt@vanderbilt.edu

Enduring Effects of Pre-K Mathematic Experiences on Executive Function and Mathematics Skills through Grade 1: Results Supplement

Kimberly Turner Nesbitt, Vanderbilt University, kimberly.nesbitt@vanderbilt.edu
Dale C. Farran, Vanderbilt University, dale.farran@vanderbilt.edu
Website: https://my.vanderbilt.edu/toolsofthemindevaluation

Analytic Approach

Multilevel structural equation modeling with Bayesian estimations (Mplus 7.2; Muthén, & Muthén, 2014) was used to examine the direct and indirect relations between pre-k mathematic and non-mathematic experiences and children's EF and mathematics gains through Grade 1 (Figure 1). Separate models were conducted EF and mathematics skills controlling for entering skill level. Focal parameters at the between and within-level are indicated in the figure (e.g., $B_{B1,}$ B_{W1}).

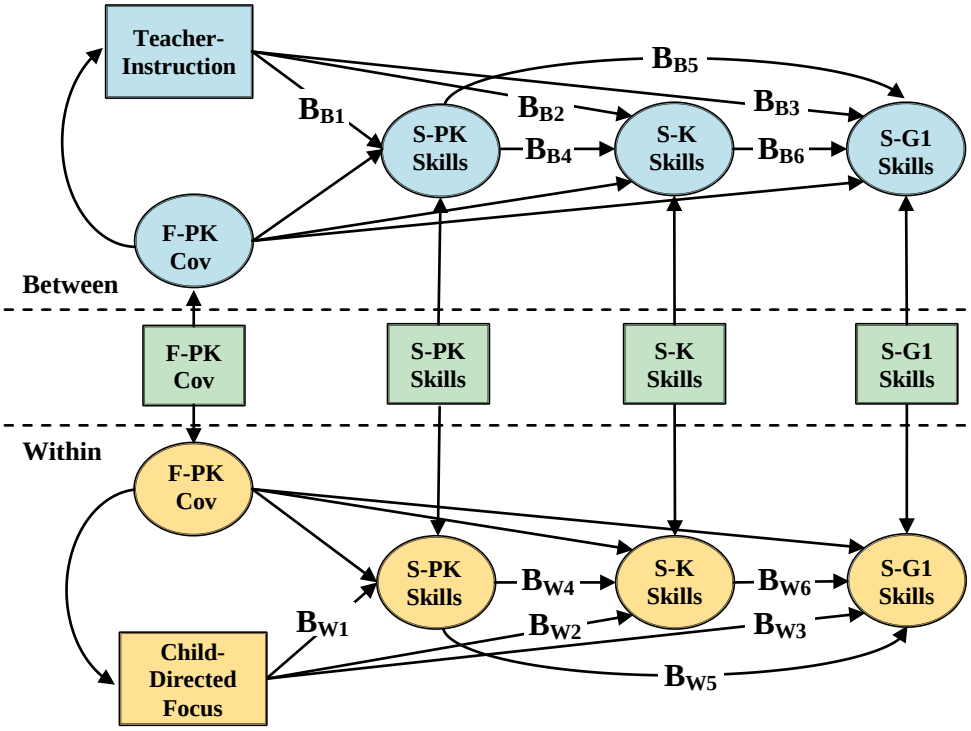

Figure 1. MSEM to estimate effects of pre-k teacher-direct and children-directed experiences on spring of pre-k (S-PK), kindergarten (S-K), and Grade 1 (S-G1) EF and math skills controlling for fall pre-k (F-PK) covariates (entering skills, age, gender, ell status).

Results

Effect of Mathematic Experiences

Model Fit. Predictive accuracy of the models (i.e., data generated by the model and observed data) were adequate, posterior predictive p-value for EF model = 0.460 and 0.451 for Math model.

Direct Effects. Independent of teachers' math instruction, child-directed math focus was positively associated with larger pre-k gains in both EF and math skills (Table 1 & 2). Conversely, teachers' math instruction was not found to be related to gains for children in either EF or math skills.

Indirect Effects: While pre-k child-directed math did not have a direct effect on children's EF and mathematics skills in K and G1, they were indirectly related via greater gains in skills across pre-k. The 95% posterior probability intervals of the indirect effects were: $EF_{S\text{-}PK \rightarrow S\text{-}K}$ = [0.013, 0.087], $EF_{S\text{-}PK \rightarrow S\text{-}G1}$ = [0.005, 0.035], $Math_{S\text{-}PK \rightarrow S\text{-}K}$ = [0.006, 0.073], and $Math_{S\text{-}PK \rightarrow S\text{-}G1}$ = [0.003, 0.040].

Table 1. *Direct Effects of Pre-K Math Experiences on Children's Executive Function Gains Through Grade 1.*

Parameters	Estimate (SD)	95% PPI
Teacher Direct Effects		
B_{B1}	0.030 (0.034)	-0.037, 0.098
B_{B2}	0.014 (0.032)	-0.044, 0.080
B_{B3}	0.032 (0.054)	-0.083, 0.142
B_{B4}	0.060 (0.269)	-0.501, 0.594
B_{B5}	-0.342 (0.345)	-1.212, 0.182
B_{B6}	0.865 (1.487)	-2.080, 3.697
Child Direct Effects		
B_{W1}	0.082 (0.030)*	0.023, 0.139
B_{W2}	0.025 (0.028)	-0.028, 0.081
B_{W3}	0.025 (0.028)	-0.029, 0.080
B_{W4}	0.616 (0.036)*	0.543, 0.689
B_{W5}	0.227 (0.041)*	0.143, 0.307
B_{W6}	0.565 (0.037)*	0.491, 0.636

Note. See Figure 1 for the interpretation of parameters. PPI= posterior probability interval. For parsimony estimates for model covariates have been omitted. *p<.05

Table 2. *Direct Effects of Pre-K Math Experiences on Children's Executive Function Gains Through Grade 1.*

Parameters	Estimate (SD)	95% PPI
Teacher Direct Effects		
B_{B1}	-0.017 (0.032)	-0.085, 0.042
B_{B2}	-0.047 (0.034)	-0.112, 0.019
B_{B3}	-0.058 (0.061)	-0.176, 0.066
B_{B4}	-0.009 (1.365)	-5.077, 0.689
B_{B5}	0.133 (2.583)	-1.273, 6.364
B_{B6}	0.019 (0.747)	-1.430, 1.594
Child Direct Effects		
B_{W1}	0.067 (0.028)*	0.011, 0.122
B_{W2}	0.047 (0.028)	-0.008, 0.100
B_{W3}	0.045 (0.028)	-0.008, 0.101
B_{W4}	0.585 (0.036)*	0.512, 0.653
B_{W5}	0.321 (0.042)*	0.239, 0.400
B_{W6}	0.504 (0.037)*	0.432, 0.577

Note. See Figure 1 for the interpretation of parameters. PPI= posterior probability interval. For parsimony estimates for model covariates have been omitted. *p<.05

Effect of Non-Mathematic Experiences

Model Fit. Predictive accuracy of the models (i.e., data generated by the model and observed data) were adequate, posterior predictive p-value for EF model = 0.484 and 0.439 for Math model.

Direct Effects. Neither teacher-directed nor child-directed non-math experiences were associated with pre-k, kindergarten, or Grade 1 gains in EF or math skills (Table 3 & 4).

Table 3. *Direct Effects of Pre-K Non-Math Experiences on Children's Executive Function Gains Through Grade 1.*

Parameters	Estimate (SD)	95% PPI
Teacher Direct Effects		
B_{B1}	0.045 (0.034)	-0.029, 0.107
B_{B2}	-0.015 (0.032)	-0.083, 0.079
B_{B3}	-0.029 (0.054)	-0.128, 0.038
Child Direct Effects		
B_{W1}	0.018 (0.030)	- 0.041, 0.079
B_{W2}	0.042 (0.027)	-0.012, 0.092
B_{W3}	0.055 (0.027)	-0.001, 0.105

Note. See Figure 1 for the interpretation of parameters. PPI= posterior probability interval. For parsimony estimates for model covariates and associations among early and later skills have been omitted. *p < .05

Table 4. *Direct Effects of Pre-K Non-Math Experiences on Children's Executive Function Gains Through Grade 1.*

Parameters	Estimate (SD)	95% PPI
Teacher Direct Effects		
B_{B1}	0.016 (0.033)	-0.048, 0.080
B_{B2}	-0.058 (0.038)	-0.117, 0.020
B_{B3}	0.004 (0.086)	-0.261, 0.109
Child Direct Effects		
B_{W1}	0.042 (0.029)	-0.016, 0.099
B_{W2}	0.060 (0.030)	-0.002, 0.116
B_{W3}	-0.055 (0.026)	-0.106, 0.005

Note. See Figure 1 for the interpretation of parameters. PPI= posterior probability interval. For parsimony estimates for model covariates and associations among early and later skills have been omitted. *p < .05

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