An Evaluation of the Incremental Impact of Math Intervention on Early Literacy Performance

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Abstract

This study examined spring literacy scores among at-risk pre-kindergarten students exposed to supplemental support solely in literacy or a combination of literacy and math. Propensity scores were used to match students receiving combined support (n = 39) with an equivalent number of students receiving only literacy tutoring. Students were matched using fall math scores and fall literacy scores. After confirming baseline equivalence, we used a multi-level model to evaluate the association between support type and spring literacy scores, controlling for fall literacy scores, fall numeracy scores, and the total number of intervention sessions completed. In addition to a significant and positive association between fall and spring scores, students who received support in both literacy and math scored significantly better on the spring literacy assessment. More specifically, participating in both literacy and math support was associated with a 23.81 increase in spring literacy scores relative to participating in literacy support alone, explaining 5% of student-level variance.

Keywords: literacy, math, intervention, early education

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By the time children reach kindergarten, there are vast differences in their academic skills and those differences have a clear influence on short- and long-term academic development (Fuchs et al., 2010; McLoyd, 1998). One hypothesis regarding the underlying reason for predictable differences across student groups concerns disparities in the educational experiences of students at home and in formal schooling environments (Piasta et al., 2014). That is, at home and at school, some children may experience fewer opportunities to access high quality early learning experiences, which likely influences long-term academic development (Hamre & Pianta, 2007).

It is important to draw attention to disparities in the early educational experiences of children because those disparities matter a great deal. In an academic domain like mathematics, when students fail to grasp how numbers work at a young age, they are at a significant disadvantage for years to come (Jordan et al., 2009; Siegler et al., 2012). Students' early math skills significantly predict math skills in late elementary grades (Watts et al., 2018), and in some longer-term studies have been observed to predict achievement at age 15 (Watts et al., 2014). The predictive value of early academic skills is particularly important to note because it stands in contrast to the proportion of time spent developing core academic skills in the Pre-Kindergarten (PreK) environment. This is especially true for math, in which studies have observed that children enrolled in PreK environments spend very little of their time during the day on math activities (Early et al., 2010; Thornton et al., 2009).

Given the value of early academic skills, it follows that early intervention to support the development of those skills is likely to yield positive changes (Burchinal et al., 2010; Vandell et al., 2010). The current study took place in the context of a PreK literacy support program to which instructional math content was added. Of particular interest for this study is the body of research highlighting cross-domain relationships in preschool math and literacy skills (e.g., Purpura et al., 2011). Yet, a majority of that work has explored these relationships at single points in time or across time, and the degree to which ongoing instruction or intervention exerts influence on cross-domain learning has been less studied. In the current study, we examined end-of-year literacy outcomes among PreK students, some of whom were exposed to targeted literacy support and others who were exposed to both literacy and math support.

Development of Early Academic Skills

There is substantial research to support the value of early math and literacy skills on future learning outcomes. In math, for example, skills that reflect understanding of early numerical principles and operations have been consistently and empirically supported as predictive of future success in longitudinal analyses (e.g., Mazzocco & Thompson, 2005; Purpura et al., 2013). Accordingly, the competencies that make up these skills—such as identifying, sequencing, and comparing quantities (Clements et al., 2013)—are often recognized as a primary goal for early math instruction (Frye et al., 2013). Researchers have developed a variety of promising and highly structured instructional approaches to improve these competencies, including both curricula (Clements & Sarama, 2007) and targeted intervention strategies (Klein et al., 2008).

With respect to early literacy, alphabet knowledge, phonological awareness, and oral language skills appear most strongly associated with later reading competence (National Early Literacy Panel, 2008). Although the strength of the contribution to overall reading proficiency may attenuate over time, those skills remain significant predictors of later reading outcomes (Bus & Van Izjendoorn, 1999; Catts et al., 2015; Suggate, 2016). Accordingly, robust bodies of research have been summarized in meta-analytic analyses of interventions designed to improve these early literacy skills. For example, systematic phonics instruction of increasingly complex phonetic relationships can be used to increase students' alphabet knowledge (Ehri et al., 2001). Phonological awareness training that uses explicit modeling, practice, and corrective feedback improves a variety of phonological awareness skills (Bus & Van Ijzendoorn, 1999). Similarly, approaches that involve repeated shared book reading with explicit vocabulary instruction have demonstrated large effects on vocabulary learning (Marulis & Neuman, 2013).

Reciprocal Benefits of Early Academic Skills

An expanding body of research from diverse disciplines of study suggests that reading and math skills develop not in isolation but rather in a mutually beneficial manner (Purpura et al., 2019). Further, executing both skills involves similar cognitive functions, such as working memory, information processing, and attention regulation, and deficits in these functions are risk factors for learning difficulties (Moll et al., 2016). More concretely, both math and reading involve written symbols that, whether isolated or combined, represent ideas and concepts (Collins & Laski, 2018). For young students in particular, these similarities offer explanations for why empirical evidence is accumulating that performance in one domain influences performance in the other.

Indeed, empirical evidence suggests cross-domain relationships might exist. Of particular interest for the current study are findings that early math skills predict literacy performance. For example, one prominent study found that among a series of academic, attentional, or social-emotional predictors of later school achievement—as late as age 13 or 14—early math skills had the greatest predictive value (Duncan et al., 2007). This finding was generally supported in subsequent research examining national longitudinal datasets (Claessens & Engel, 2013; Hooper et al., 2010). Hypotheses regarding the mechanisms by which early math skills predict later achievement are mixed. There is some evidence that the effects may be mediated via mathematical language (Purpura et al., 2017); however, evidence also supports the notion that non-linguistic early math skills such as pattern recognition uniquely predict reading skills (Burgoyne et al., 2019). Nevertheless, the overall body of research suggests that at least some aspects of early math are related to and may facilitate children's literacy skills.

Purpose

Despite evidence demonstrating an association between math and literacy skills, less is known regarding the impact of targeted intervention in one domain on the performance in another domain. In the present study we evaluated differences in end-of-year literacy performance across two relevant subgroups of students—those exposed solely to literacy intervention and those exposed to targeted intervention in literacy and math. The primary research question guiding the study was the extent to which similar PreK students at risk for reading and math problems demonstrated different spring literacy scores depending on whether they experienced targeted literacy intervention alone or a combined experience of literacy and math intervention. Based on evidence highlighting the covariance between math and reading skills, we hypothesized that students in the combined group would demonstrate higher literacy scores.

Method

Data for the current study were obtained from a pilot within a broader early literacy support program—Reading Corps. The pilot included an expansion of the existing Reading Corps program to include an explicit focus on math skills. The participants, measures, and program features are described in more detail below, followed by a description of the methodological and analytic procedures we adopted to examine the primary research question.

Participants

As noted, data for the current study were obtained from a broader database that included students (*N* = 213) enrolled in 13 classrooms implementing a pilot evaluation of a literacy and math support program. The experience of students within partner classrooms differed as a function of students' academic needs and the capacity of the tutor. Some students within the classroom received targeted literacy intervention, targeted math intervention, or both forms of support. To be included in the present study, students were required to have received literacy intervention (*n* = 92). Among those students, 39 students also received targeted math intervention and 53 students received only targeted literacy intervention. We used propensity score matching (described below) to create an appropriate counterfactual (i.e., 39 of the 53 students receiving only literacy intervention were matched to the 39 students receiving both interventions). The resulting analytic sample included 78 students across 13 classrooms. Each classroom was served by an interventionist trained by the intervention program. Demographic information for students split by group is displayed in Table 1. Across both groups, a majority (90%) of students were either four or five years old. Approximately half of participating students were male and the largest proportion of students served were Black or African American (31-33%).

Measures

Preschool Early Literacy Indicators (PELI). The primary measure of interest in the present study included scores on the Preschool Early Literacy Indicators (PELI). The PELI is administered individually in storybook format and takes about 15 minutes per student. The measure assesses alphabet knowledge, vocabulary and oral language, phonological, and comprehension skills. Alternate form reliability on the PELI ranges from .85 to .92 and concurrent criterion-related validity coefficients with other measures of early literacy range from .66 to .74 (Kaminski et al., 2014). The publisher recommended benchmarks for the PELI Composite score were used to identify students as at-risk. All tutors received training on the PENS prior to the academic year. In addition, the fidelity of assessment implementation was evaluated during the academic year. The average fidelity of implementation for the PELI was 94%.

Preschool Early Numeracy Screener (PENS). The PENS is an early math screening tool for use with PreK children (Purpura et al., 2015). The test includes 24 items spanning across basic number skills including numbering, numerical relations, and arithmetic operations. During administration, students are read a prompt by the administrator and respond either verbally or by pointing to their answer on a test administration booklet. Test administration finishes when a student either (1) provides an incorrect answer for three consecutive items or (2) completes all 24 items. Total administration time for the PENS is approximately 5 min. Previous research with the PENS provides support for its reliability contextualized within classical test theory and item response theory frameworks (Purpura et al., 2015). In addition, the test has demonstrated relatively high correlations (r = .73) with broader tests of early math skills such as the third edition of the Test of Early Mathematics. As with the PELI, all tutors were trained to administer the PENS prior to academic year and observed during the year to evaluate assessment fidelity. The average fidelity rating for tutors included in the present analysis was equal to 99%.

Standard Literacy Intervention Procedures

Literacy Intervention. All participating students were supported by the Reading Corps program. Reading Corps is a literacy support program implemented by full-time AmeriCorps members placed in PreK classrooms. As the largest AmeriCorps state program in the country, the program has garnered previous empirical evidence via rigorous evaluation methods (see Markovitz et al., 2014; 2018 for a detailed overview of program procedures and impact). In preschool settings, AmeriCorps members augment teacher-led instruction by engaging in language-rich interactions with students, leading small-group repeated read aloud activities, and supporting classroom management with techniques such as transition songs that build phonological awareness. In addition, and of particular importance to this study, AmeriCorps members also identify at-risk students performing below a seasonal benchmark on the PELI Composite Score and then use a series of scripted interventions to provide supplemental support consistent with the Big Five Early Literacy Predictors outlined by the National Reading Panel (2000). Students receiving supplemental support typically work with tutors in small groups 3-4 times each week for 5-10 min. Scripted protocols for Reading Corps are available upon request. All tutors were observed approximately 15 times during the year by program staff using a checklist aligned with the interventions. The average level of intervention fidelity across tutors in the present study was equal to 94%.

Math Intervention. In addition to literacy assessment and intervention activities, AmeriCorps members also identified and supported a subset of students in each preschool classroom on key early math skills. Specifically, all students were screened in the fall with the PENS which provides scores that range between 0 and 24. Students scoring below the PENS benchmark were eligible to receive targeted math intervention. Math interventions consisted of short scripted activities that explicitly focused on early number understanding (e.g., counting, numeral identification, quantity comparison, composition, decomposition). Similar to the literacy interventions, all math interventions lasted between 5 and 10 min. Average math intervention fidelity across tutors in the present study was equal to 97%. The presence of the AmeriCorps member in PreK classrooms had the practical effect of offering at-risk students supplemental support in math and/or literacy. That is, within all 13 classrooms from which these data were collected, some students received literacy support, some received math support, and some received both. That variance in implementation serves as the primary focus of the current study.

Propensity Score Matching

To be included in the present study, students were required to have received literacy intervention (n = 92). Among those students, 39 students also received targeted math intervention. In the present study we used the MatchIt package in R to create a matched sample (Ho et al., 2011) among the students who did not receive math intervention. Logistic regression was used to calculate each students' propensity for receiving targeted math intervention. To facilitate the matching process, we included students' fall PELI score and fall PENS score. The resulting logistic regression model produced a value representing the propensity of a given student receiving math interventions during the academic year.

The second analytic step involved matching cases according to their propensity scores, where students receiving math intervention were matched with students who had a similar propensity for receiving math support but did not receive support. In the present analysis we used nearest neighbor matching without replacement to pair cases based on their likelihood of receiving math intervention (Rubin, 1973). Unmatched comparison cases were excluded from further analysis. Thus, as previously noted, the final analytic sample consisted of 79 students. In addition to the demographic distribution across groups in Table 1, descriptive data for the analytic sample separated by group are shown in Table 2. A series of chi-squared and *t*-tests indicated that there were no statistically significant differences between groups in regard to age, gender, race, initial literacy score or initial math score.

Analysis

Information on all students' math and literacy performance was available for the analytic model. In addition, information on students' intervention experiences (i.e., type of intervention and overall dosage) was also available. The primary predictor of interest was whether students received math intervention in addition to literacy intervention during the academic year. Because students were nested within tutors, we estimated a series of multi-level models to evaluate the impact of math intervention on students' end-of-year literacy scores. Those models included a baseline model with no predictors, a covariate model that included fall PELI scores, fall PENS scores, and total intervention sessions, and a full model that included all covariates and a dichotomous indicator of whether students were provided math intervention in addition to literacy support. Throughout the model fitting process, we evaluated the incremental value of each model by examining improvements to model deviance, statistical significance of fixed effects, and the amount of variance explained relative to previous models. All analyses were conducted using the lme4 package (Bates et al., 2015) within the R computer program (R Core Team, 2016).

Results

Descriptive data for fall and spring PELI scores along with fall PENS scores and literacy intervention sessions are displayed in Table 2. Both groups demonstrated a marked increase in PELI scores between data collection windows, with students exposed to only literacy intervention recording an average spring PELI score of 162.26 and those exposed to both literacy and math interventions recording a spring PELI score of 196.67. Students across groups tended to record similar fall PENS scores, and on average tended to receive a similar number of literacy intervention sessions (35.69 among literacy-only students and 31.59 among students receiving math and literacy intervention). However, by nature of the pilot, students exposed to both literacy and math interventions experienced a greater total number of intervention sessions (M = 68.18). Thus, the total number of intervention sessions was included as a control in the inferential analyses.

Inferential Analysis

Results for each analytic model are displayed in Table 3. Results from the null model indicate that the proportion of variance in students' spring literacy scores attributable to tutors was non-negligible (1,064/3,362 = 32%), supporting the need to model the clustering inherent in the data. Model A in Table 3 includes results for the three fixed effect covariates. The addition of those covariates resulted in a statistically significant improvement in model fit (χ^2_3=41.10, p <.001) accounting for 26% of tutor-level variance and 42% of student-level variance. A statistically significant and positive effect was observed for fall PELI scores with each one unit increase above the grand mean associated with about a half-point predicted increase (B = 0.49) in the spring PELI score. A similar effect was observed for each unit increase above the average fall PENS score (B = 3.38). No effect was observed for the total number of intervention sessions. That is, the number of intervention sessions alone was not a significant predictor of spring literacy scores.

The final model (B in Table 3) included all covariates and a dichotomous variable indicating exposure to both math and literacy intervention. Adding that variable resulted in a statistically significant improvement in model fit (χ^2_1=46.30, p <.001), explaining an additional 5% of the variance in spring PELI scores attributable to students. The significance and magnitude of effects observed in Model A were replicated in the final model, with both fall PELI and PENS scores demonstrating a positive and statistically significant association with spring

PELI scores. In addition, a statistically significant and positive association was observed between receiving combined support and spring PELI scores. More specifically, receiving both math and reading intervention was associated with a 23.81 predicted point increase in spring literacy scores ($p < .05$), controlling for fall literacy achievement, fall math achievement, and the total number of intervention sessions provided to students.

Discussion

Within the body of research that has identified relations between early literacy and math skills (e.g., Burgoyne et al., 2019; Hooper et al., 2010; Purpura et al., 2011), relatively little research has examined the value of instructional support targeted to one domain on outcomes in the other. The present study examined this question and found preliminary support for the notion that the provision of math support produces some benefit on students' literacy scores. At-risk preschool students who received supplemental literacy and math support had an almost 24 point advantage on the current literacy measure compared to students who received only literacy support. Below, we describe the observed results in more detail and outline areas in need of ongoing research.

Incremental Impact of Math Intervention on Literacy Performance

Given existing research on the role of math on literacy performance, there are several potential instructional factors that may be relevant when interpreting the current findings. First, all supplemental math instruction was language-based. For example, for quantity comparison instruction, students were shown sets of two different quantities of objects and provided multiple opportunities to practice identifying which had 'more' or 'less'. These are essential concepts that students need to master before they learn more complex math concepts, but they are language-based (Gelman & Butterworth, 2005). Additional practice with these and similar concepts (e.g., number after) could, over the course of the preschool year, support overall language development within young students. Second, supplemental math support afforded students new and diverse opportunities to practice symbolic decoding. In the current study, numeral identification activities supported students in readily recognizing alphanumeric symbols that corresponded with a given quantity (e.g., '3' next to three blocks). As such, it is possible that practice identifying numerals could have facilitated improved letter recognition performance on the literacy measure, and the essential requirement to read symbolic code is shared between literacy and math (Collins & Laski, 2018).

Lastly, phonological processing skills may also have been strengthened by the supplemental math support students were provided. An empirical link between phonological processing and the more advanced early numeracy skills (e.g., simple addition) has been identified in previous research (Fuchs et al., 2010). Less is known about mechanisms that connect these two skills, but given the specific subskills that are involved it is possible that composition and decomposition practice might have indirectly supported improved phonological awareness skills. Given that phonological awareness is essentially the ability to isolate and recognize discrete sound units in spoken language, this skill might have been facilitated by the related practice of composing and decomposing numerical quantities into their discrete parts. Regardless of the underlying mechanisms, the results observed in the present study are generally consistent with previous research examining the relationship between literacy and math at various stages of students' academic development. That is, it seems likely that support provided in one domain may translate somewhat readily to the other. In practice, this insight into the nature of intervention implementation may prove to be useful for those concerned that math intervention may detract from literacy practice. Currently, far less time is devoted to math support in the PreK setting (Early et al., 2010; Thornton et al., 2009). The relatively low proportion of time dedicated to early math skills is relevant to highlight given (1) existing research highlighting the covariance between early literacy and math skills (e.g., Purpura et al., 2019) and (2) the current finding that the provision of targeted math intervention may produce gains in early literacy skills. More widespread adoption of math support for young children may offer teachers the opportunity to support a wider range of content in confidence that said support may in fact result in a net academic benefit to students while also offering a more equitable instructional experience.

Limitations and Directions for Future Research

Although there is considerable extant research in which to situate the current findings, several limitations suggest the findings be considered preliminary and also offer directions for future research. First, although tutors demonstrated strong evidence for fidelity during independent observations, future research may consider the inclusion of intervention quality ratings. Adherence ratings, such as those used in the present study, are commonly used in intervention research (e.g., Codding et al., 2009; Swanson et al., 2013) and offer clear benefit for ensuring implementation matches design. However, implementation fidelity is a multi-faceted construct and assessments of quality may offer useful information for evaluating any observed effects (Nelson et al., 2020; O'Donnell, 2008). Second, the assessments used for the study only measured select aspects of literacy and numeracy, and also did not provide subscale data to permit direct analyses of subskills (e.g., phonological awareness and numeral identification). Future research would benefit from more robust measures of literacy and math skills as well as additional characteristics that may have domain-specific and cross-domain effects (Cragg &

Gilmore, 2014; Geary, 2011). Such research would offer the benefit of a more nuanced view of the co-variance between literacy and math development.

In the current study experimental control was not applied to how tutors selected students and how many students for whom they could provide the various combinations of instructional support. As a result, an extraneous variable might have influenced the findings, such as an unmeasured student trait that was related to math such as social emotional or executive functioning skills (Geary, 2011; Hooper et al. 2010). For example, executive functioning (EF), which includes skills such as inhibitory control and working memory, has been observed to demonstrate a clear relationship with academic skills, particularly early math (Fuhs et al., 2014). Yet, while that relationship appears directional in kindergarten and beyond—in that EF skills predict math and not vice versa—the relationship appears bidirectional in preschool (Schmitt et al., 2017). The potential implication is that it may be worthwhile to construct studies to examine the relative benefits of math versus EF training programs, particularly in light of their reciprocal benefits on each other and literacy. It may also be worthwhile to consider related neuroimaging work in which researchers have examined developmental changes associated with executive functioning and literacy or math performance. For example, previous research has provided some evidence that differences in the sophistication by which young children approach skill-based tasks are associated with different profiles of neurological activity (Cho et al., 2011).

It follows that future research could expand the current knowledge base by adopting additional baseline measures and using random assignment among similar students to examine the potential for effects similar to those observed in the present study. Given that random assignment is often overly burdensome for practicing teachers, that work may opt to include a more expansive approach to data collection coupled with a larger sample of classrooms and students, which would facilitate a stronger matching and reporting infrastructure.

Finally, it is important to note that students who received math and reading support generally received more supplemental support overall. This issue was addressed statistically by including intervention time as a covariate, and notably, intervention time alone was not a statistically significant predictor in any model. Nevertheless, future research could compare literacy outcomes across groups of students who received comparable amounts of support that differed only in the mix of literacy and math support.

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Table 1.

Distribution of Demographic Information across Groups

Demographics	Literacy Intervention (n =39)	Literacy and Math Intervention (n = 39)
Age 3	10%	10%
Age 4-5	90%	90%
Male	51%	49%
White	13%	5%
Black/African American	31%	33%
Latino	15%	15%
Asian	28%	16%
Multi-Race	5%	10%
Other	8%	21%

Table 2.

Descriptive Data across Groups

	Literacy Intervention (*n* =39)		Literacy and Math Intervention (*n* = 39)	
Outcome	*M*	*SD*	*M*	*SD*
Fall PELI Score	91.54	57.43	108.51	45.70
Spring PELI Score	162.26	62.87	196.67	44.76
Fall PENS Score	4.74	3.91	5.36	3.63
Literacy Intervention Sessions	35.69	17.32	31.59	14.74
Math Intervention Sessions	0.00	0.00	36.59	15.78

Table 3.

Results of Multi-Level Analyses Predicting Year-End Literacy Scores

Fixed Effect	Null			A			B		
	B	se	t	B	se	t	B	se	t
Spring PELI Score (γ_{00})	185.16**	10.94	16.65	181.41**	13.67	13.26	111.01**	23.94	4.64
Fall PELI Score (γ_{10})				0.49**	0.12	3.93	0.44**	0.12	3.53
Fall PENS Score (γ_{20})				3.38*	1.60	2.11	3.45*	1.56	2.20
Total Intervention Sessions (γ_{30})				0.23	0.20	1.16	-0.12	0.26	0.46
Math Treatment (γ_{40})							23.81*	11.95	1.99
Random Effect	Variance			Variance			Variance		
M Post-Intervention Score μ_{0j}	1064			789.3			838.5		
Level 1 effect (r_{ij})	2298			1342			1274		
Model Fit	Deviance	χ^2_{df}		Deviance	χ^2_{df}		Deviance	χ^2_{df}	
	833.60	--		792.50	41.10_3**		746.2	46.30_1**	

* *p* < .05, ***p* <.001
Note. PELI = Preschool Early Literacy Indicators; PENS = Preschool Early Numeracy Screener; Fall PELI and PENS Scores grand mean centered.