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Effects of MyTeachingPartner–Math/Science on Teacher–Child Interactions in Prekindergarten Classrooms

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ABSTRACT

Research Findings: This study examined the impact of MyTeachingPartner–Math/Science, a system of math and science curricula and professional development, on the quality of teachers' interactions with children in their classrooms. Schools were randomly assigned to 1 of 2 intervention conditions (Basic: curricula providing within-activity, embedded teacher supports; Plus: curricula plus implementation support via online resources and in-person workshops) or to a Business-as-Usual (BaU) control condition. Results showed that teachers in the Basic and Plus conditions showed higher levels of Instructional Support and Facilitation of Mathematical and Scientific Thinking. Teachers in the Basic condition also showed higher levels of Emotional Support compared with teachers in the BaU condition. We did not find any significant differences between teachers' interactions in the Basic and Plus conditions. *Practice or Policy*: Children are entering kindergarten unprepared in the areas of mathematics and science, largely as a result of inadequate exposure to early experiences and high-quality interactions in these domains. The results of this study suggest that providing teachers with math and science curricula that include embedded teacher supports can have an impact on the quality of their math and science instruction.

Children who develop strong mathematics and science skills in preschool are much more likely to succeed in school and in life (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; National Mathematics Advisory Panel, 2008). Current research suggests that these early skills are foundational and are strong predictors of later academic success (Grissmer et al., 2010; Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Pagani, Fitzpatrick, Archambault, & Janosz, 2010).

Given the emerging research supporting the importance of these skills, educators and policymakers, now more than ever, are recognizing the need to foster and promote early mathematics and science knowledge and skills in young children. This is evidenced in the Common Core State Standards, including standards in math for Grades K–12 (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). In addition, the newly developed Next Generation Science Standards for Grades K–12 provide target science benchmarks (National Research Council [NRC], 2012). Within the domain of early childhood, the Head Start Child Development and Early Learning Framework (Office of Head Start, 2011) and almost all state early learning standards (Daily, Burkhauser, & Halle, 2010) identify mathematics and science knowledge and skills as critical areas of learning and development for children ages 3 through 5.

Despite increased attention to the importance of mathematics and science, children continue to enter kindergarten without the foundational skills needed to succeed in these areas, and this is

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especially true for children from low-income families (National Center for Education Statistics, 2009). However, high-quality mathematics and science curricula can support teachers in providing the interactions and learning environments needed for children to develop mathematics and science skills (e.g., Clements & Sarama, 2008; French, 2004; Kinzie et al., 2014). Furthermore, the benefits curricula can provide for improvement of teachers' instructional practice may be greatest when teachers also receive professional development (PD) support on how to engage in interactions that promote children's skill development (e.g., Pianta, Mashburn, Downer, Hamre, & Justice, 2008; Wasik, Bond, & Hindman, 2006). In this study, we examine the impacts of the early childhood mathematics and science curricula MyTeachingPartner–Math/Science (MTP-M/S) on the quality of teachers' interactions. We further consider whether providing teachers with supplemental PD in support of high-quality, high-fidelity curricular implementation leads to greater gains in the quality of teachers' interactions with students compared to offering the curricula alone.

To begin, we provide an overview of children's mathematics and science learning and the current state of early childhood mathematics and science instruction and related PD. Then we describe our methods, present our findings, and discuss implications for the design and implementation of mathematics and science curricula and PD.

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Children are entering kindergarten unprepared in the areas of mathematics and science

Current research suggests that children's early mathematics skills are the strongest predictor of later academic success and that preschool mathematics ability predicts mathematics achievement through age 15, even after early cognitive skills and family characteristics are accounted for (Hooper et al., 2010; Pagani et al., 2010; Watts, Duncan, Siegler, & Davis-Kean, 2014). In fact, children's mathematical knowledge at school entry is a more significant predictor of later academic success than are early reading skills (Duncan et al., 2007). Children's early science skills are also important predictors of later academic functioning; in a recent analysis of six longitudinal data sets, researchers found that children's thinking and reasoning skills, including their ability to formulate questions about the natural world, gather evidence, and communicate answers, were the strongest early predictor of their later science and reading skills and a strong predictor of later mathematics skills (Grissmer et al., 2010).

Despite recognition of the importance of early development in mathematics and science, children continue to exhibit significant deficits in these skills. Children in the United States lag behind their peers in other countries on tests of mathematics and science achievement (National Center for Education Statistics, 2011). Children from families with lower levels of parental education and income are at even greater risk for displaying gaps in key mathematical and science skills at school entry. Results from analyses using the Early Childhood Longitudinal Study–Birth Cohort suggest that only 45% of 4-year-olds from very poor families are proficient in numbers and shapes compared to 72% of their peers from families at or above the poverty level (National Center for Education Statistics, 2009). Children from low-income families enter kindergarten with even lower relative performance in science compared with other domains (e.g., language and literacy, mathematics). Research suggests that these science skill deficits are due to lower ability levels on prekindergarten (pre-K) entry and fewer gains than in other domains across the pre-K school-year (Greenfield et al., 2009). Clearly, there is work to be done in improving young children's mathematics and science skills, particularly for those children who are at highest risk—those who have been exposed to the negative effects of poverty and are entering school without the knowledge and skills necessary for school success.

Early childhood mathematics and science instruction is of generally poor quality

Given the influence of children's early mathematics and science skills on their later academic development (Grissmer et al., 2010; Hooper et al., 2010; Pagani et al., 2010), there is no doubt that to be effective, today's early childhood teachers need to know how to interact with children in ways that foster these critical skills. Unfortunately, few current teachers possess the necessary content knowledge and pedagogical skills in these domains (Copley, 2004; Garbett, 2003; National Mathematics Advisory Panel, 2008).

Beyond displaying this lack of teacher expertise, early childhood teachers typically do not place a high importance on teaching mathematics, feel anxious about teaching the subject, and do not feel competent in their ability to effectively teach it (Blevins-Knabe, Austin, Musun, Eddy, & Jones, 2000; Hart, 2002; Yesil-Dagli, Lake, & Jones, 2010). This is evident in teachers' classroom practice, in which their mathematics instruction tends to be rote (Ginsburg, 2009) and focused primarily on the more basic concepts within number sense rather than more advanced skills of which young children are capable (e.g., operations, geometry, measurement; Rudd, Lambert, Satterwhite, & Zaier, 2008). In addition, little instructional time is spent on mathematics. For example, results from the National Center for Early Development and Learning's national studies (Early et al., 2010) showed that children were exposed to mathematics activities during only 8% of classroom time.

Science is another area in which early childhood teachers struggle (Klahr, Zimmerman, & Jirout, 2011). Teachers' content knowledge in science is low, and they often are unaware of their lack of knowledge and of how their lack of content knowledge influences their ability to provide science experiences for young children (Garbett, 2003). Early childhood teachers lack confidence in their knowledge of science and science education pedagogy (Fensham, 1991; Garbett, 2003). When teachers do engage in science activities, the focus is often on displays of science materials or art projects involving them, with teachers rarely encouraging related inquiry (NRC, 2005). As with mathematics, little time in the classroom day is spent on science (11%; Early et al., 2010), and during center time the science center has been found to be the least likely to be visited by teachers (Nayfeld, Brenneman, & Gelman, 2012).

High-quality curricula as a support for children's mathematics and science development

There is emerging research demonstrating that high-quality math and science curricula can support children's learning (e.g., Clements & Sarama, 2008; French, 2004; Starkey, Klein, & Wakeley, 2004). Implementations of pre-K math and science curricula have resulted in positive effects on children's language, approaches to learning, math, and literacy (e.g., Clements & Sarama, 2007; French, 2004; Greenfield et al., 2009; Presser, Clements, Ginsburg, & Ertle, 2015).

Effective curricula typically embed teacher supports that assist in the development of teachers' content and pedagogical knowledge (e.g., Clements & Sarama, 2007; Gelman & Brenneman, 2004; Greenfield et al., 2009). These supports can include learning explicitly tied to children's developmental trajectories, assessment tools that help teachers recognize where children are in their development, and suggestions for how to differentiate instruction to best meet the needs of students.

However, even when implementing validated curricula, teachers sometimes struggle to engage in the high-quality instruction and interactions necessary to support children's skill development (e.g., Justice, Mashburn, Hamre, & Pianta, 2008; Pianta et al., 2005).

Curricula alone may not be sufficient; teachers need support to implement them via high-quality interactions

Standardized observations involving several thousand U.S. early education classrooms clearly demonstrate that on average the quality of child–teacher interactions is low and effective curricular implementation is inadequate (National Institute of Child Health and Human Development Early Child Care Research Network, 2002; Peisner-Feinberg & Burchinal, 1997; Pianta et al., 2005). Large-scale national studies suggest that, even when offered validated curricula, pre-K teachers do not deliver them with high degrees of quality of instruction that supports the development of children's skills (e.g., Justice et al., 2008). Teachers struggle to implement mathematics and science curricula

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and to facilitate children's mathematical and scientific thinking within the context of curricular activities (Copley, 2014; Garbett, 2003; NRC, 2009; Nayfeld et al., 2012).

There is evidence that high-quality teacher child interactions are the mechanism through which curricula benefit children's development (Copley, 2014; Hamre & Pianta, 2005). Teacher–child interactions serve two primary functions with regard to encouraging children's learning and skill development. First, in effective interactions, teachers support the development of children's basic task-related skills, such as attention, conceptual development, communication skills, and reasoning, as well as children's motivation and interest to approach tasks in an organized and confident manner (Bergin & Bergin, 2009; H. A. Davis, 2003; Hamre & Pianta, 2001). Second, teacher–child interactions perform an instructional function, in which intentional efforts by the teacher increasingly call children's explicit attention to relevant concepts and skills (e.g., Curby et al., 2009; Mashburn et al., 2008; Roorda, Kooman, Spilt, & Oort, 2011). However, national studies show that on average the quality of this instructional support is low (e.g., Hamre & Pianta, 2005; Pianta et al., 2005), suggesting that teachers are not providing the type of instructionally rich interactions that would produce gains in children's academic learning.

Providing pre-K teachers with PD in mathematics and science, with a focus on high-quality teacher–child interactions, is critical—as is examining how best to provide it (Ginsburg & Ertle, 2008; National Mathematics Advisory Panel, 2008; Zaslow, 2014). Experts suggest that in order to successfully implement mathematics and science curricula, teachers need support with regard to (a) mathematics and science concept knowledge, (b) an understanding of developmentally appropriate mathematics and science in early childhood education, and (c) an understanding of how to foster children's mathematical and scientific development with a research-based curriculum (NRC, 2006, 2009). PD in the area of mathematics and science should be sustained; focus on high-quality interactions; and provide an opportunity for active learning, including discussion of strategies with teachers (Garet, Porter, Desimone, Birman, & Yoon, 2001; NRC, 2006; Zaslow, 2014).

An ongoing concern is not only achieving effective teacher PD but also scaling these efforts to meet the needs of many teachers in an accessible and economically feasible way. For example, a popular pre-K mathematics curriculum, My Math (McGraw-Hill Education, 2013), offers custom webinars for less than half the cost of in-person training (U.S Department of Health and Human Services, 2014). The multimedia affordances of the Internet make possible easy inclusion of visual exemplars (videos or animations) of classroom practice, which are more effective than textual descriptions in encouraging teachers' ability to describe specific applications of targeted teaching skills (Moreno & Ortegano-Layne, 2008). It is important to note that delivery of teacher development activities via the Internet holds promise for accommodating teachers' busy schedules, minimizing their out-of-classroom time (and for teachers who are distant, removing travel requirements), and providing opportunities for teachers to select aspects of practice to focus their attention toward developing.

To address the need for high-quality mathematics and science curricula and associated, scalable PD, we developed the MTP-M/S curricula and online teacher implementation supports. In the next section, we describe the MTP-M/S curricula and PD supports.

Description of MTP-M/S curricula and PD supports

Curricula

The MTP-M/S curricula were designed in response to the need for high-quality pre-K mathematics and science curricula (see Kinzie, Vick Whittaker, McGuire, Lee, & Kilday, in press, for a detailed description of curricular development and design). The mathematics domains covered include number sense, operations, geometry, and measurement, and within each the big ideas—the most important concepts and skills—are addressed. For example, a small-group math activity with a focus on measurement, specifically comparing and describing the weight of objects, begins by having students predict whether a golf ball or a ping pong ball will be heavier; the teacher tallies students' predictions. Next, students are given a balance to compare the weight of the balls, after which they record their results. Finally, students compare their predictions to the results obtained from using the balance. Teachers are provided with suggestions for how to provide opportunities to students to compare the weight of objects throughout the day. The activities also embed suggestions for students requiring more support or challenge.

The MTP–Science curriculum addresses three domains of science—life science, earth science, and physical science—with inquiry-based activities to meet instructional objectives that are aligned with state and national standards. Activities were designed to provide opportunities to apply science process skills, including prediction, observation, and analysis and description of findings. For example, a whole-group physical science activity focuses on predicting, observing, and describing the effects of smooth/rough surfaces on the sliding and rolling of an object. The teacher begins by reading *The Snowy Day* by Ezra Jack Keats (1976). Then children are given the opportunity to experiment with the movement of objects across ice and across the carpet, describing similarities and differences. During the discussion section of the activity, the teacher encourages connections with the book and asks open-ended questions about the ways in which smooth and rough surfaces can affect motion.

The MTP-M/S curricula include two mathematics and two science activities (15 to 20 min long implemented in either whole- or small-group format) every week for 33 weeks across the school year. Additional weekly center time activities enable the teacher to revisit specific mathematics and science activities with small numbers students.

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PD supports

Our teaching supports were intended to promote high-quality teacher–child interactions within the context of delivery of the mathematics and science curricula. They included specific instructional strategies that teachers could use to support children's concept development in the respective domains. For example, teachers were provided with extensive supports on asking children open-ended questions develop students' cognitive skills, as they develop students' cognitive skills by encouraging students to express and elaborate on their thinking and challenge them to provide rationales for their thoughts (e.g., Ritz, 2007). Research suggests that teachers can effectively support their own learning through the use of such educative curricular materials (Forbes & Davis, 2010).

In response to the NRC's (2005) call for curricula to be comprehensive enough for teachers with a range of preparation and experience to implement, we developed a range of teaching supports that would be quick and easy for teachers to use. Some of these supports are within-activity supports provided to both MTP-M/S Basic (curricula only) and MTP-M/S Plus (curricula plus online and workshop supports) teachers. Online supports and a corresponding series of in-person workshops (a total of 23.5 hr) were provided to the MTP-M/S Plus teachers. Next we describe each set of supports in more detail.

Within-activity curricular supports. The within-activity supports, provided to teachers in both intervention groups (Basic and Plus), included several key forms of support for every activity, including (a) recommendations for language to model and elicit, (b) recommendations for teachers' questioning during the inquiry process, (c) suggestions for multiple extensions of the activity across the school day, and (d) adaptations teachers can make to enable differentiated instruction for students needing more support or more challenge. We scaffolded teachers' instruction using an explicit visual layout of the four-step inquiry model embodied in every activity (Engage, Investigate, Discuss, and Extend) and a greater emphasis on recommendations for teacher questioning, with more question options suggested and displayed in a prominent fashion (see Kinzie et al., in press, for a figure delineating this model).

Online supports and workshops. Online supports and corresponding in-person workshops were provided to Plus teachers only. We developed more than 130 2- to 3-min video demonstrations of high-fidelity curricular implementation that also embodied the qualities of high-quality teacher–child interactions; at least one demonstration was provided for each activity. Brief Teaching Tips were also provided, addressing best pedagogical practices, common ways students construct understandings (including misconceptions), or key mathematics or science concepts. Other online supports included weekly video-based 5-min Quality Teaching Challenges featuring one of the activities teachers would implement that week. Every month, we highlighted a different dimension of quality teacher–child interactions, including a 1- to 2-min video; a brief description of the dimension and why it is important; and links to a Quality Teaching Library offering 150 video examples across many instructional settings, formats, and content areas. As suggested by E. A. Davis and Krajcik (2005), the form and format of teacher-educative curriculum materials matter, with online modalities capable of offering teachers authentic depictions of practice, including high-quality enactments of curricular implementation, with the nature and amount of support accessed determined by each teacher's perception of need.

The online support components were complemented by a series of eight workshops (one full day and seven partial days [2.5 hr]) specifically designed to enhance teachers' use of these supports and to encourage self-reflection and peer discussion of their own teaching practice. Each workshop featured explorations of a dimension of high-quality teacher–child interactions. In addition, there was exploration of relevant mathematics and science concept knowledge, self- and peer-review of teaching, error analysis activities (in which common student behaviors were modeled and teachers practiced identifying and responding to errors in student thinking), and group discussion, based in part on the recommendations of the NRC (2006).

Previous findings and the present study

We have reported elsewhere on the effects of MTP-M/S on children's mathematics and science knowledge and skills (Kinzie et al., 2014). We compared students' mathematics and science knowledge and skills in classrooms assigned to one of three conditions: the district's existing mathematics and science curriculum (Business-as-Usual [BaU] condition), the MTP curricula (Basic condition), and the MTP curricula and PD supports (Plus condition). There were intervention effects on children's geometry and measurement skills and number sense and place value skills. Children in Plus classrooms made greater gains in geometry and measurement compared with those in BaU classrooms. Children in Plus classrooms also performed better on a number sense and place value assessment than did those in Basic or BaU classrooms. We did not find any significant treatment effects on children's science knowledge and skills.

In this article, we extend these findings to include the quality of pre-K teachers' interactions with students in their classrooms. We hypothesized that teachers who participated in the MTP-M/S Plus and Basic conditions would show higher quality teacher–student interactions compared with teachers in the BaU condition. Because of research suggesting the need for both high-quality curricula and support for high-quality curricular implementation, we hypothesized that teachers who participated in the MTP-M/S Plus condition would evidence the highest quality interactions compared to teachers who participated in the Basic and BaU conditions.

Method

Participants

Participants in the year-long trial included 42 pre-K teachers in state-funded classrooms from 24 schools in a single school district in a large mid-Atlantic city (11 BaU teachers, 17 MTP Basic teachers, and 14 MTP Plus teachers) during the 2009–2010 school-year. The experimental evaluation

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was carried out using stratified random assignment with schools being randomly assigned to one of the three conditions. We stratified schools by the number of participating teachers. Random assignment was conducted at the school level in an effort to prevent contamination of intervention effects across conditions.

All teachers in this study taught in classrooms that included students with one or more risk factors for later school failure (poverty, learning a second language, or health or developmental problems). The teachers were mostly female (98%) and ranged in age from 24 to 65 years old (M = 45, SD = 10.72). Teachers reported their race/ethnicity as Caucasian (54%), African American (44%), or other race (2%).

Over the course of the study, seven teachers dropped out: The district pulled four teachers (2 Basic teachers, 2 Plus teachers) to participate in another study, and three teachers dropped for other reasons (family tragedy: 1 Plus teacher; workload: 2 BaU teachers), for an attrition rate of 17%. To estimate attrition bias, we conducted analyses comparing teacher and classroom characteristics for the 35 teachers who participated fully and the seven teachers who withdrew from the study. There were no significant differences between the two groups of teachers with regard to highest level of education (t = –1.07, p = .31) or years of experience working with children in pre-K (t = 7.62, p = .86).

We included all teachers in the study who submitted any data prior to withdrawing (n = 41; 10 BaU teachers, 17 MTP Basic teachers, and 14 MTP Plus teachers). One BaU teacher was excluded because she did not submit any data. See Table 1 for teacher characteristics.

A total of 434 students participated in the study (an average of 10 randomly selected students per classroom; M age = 4.60 years, SD = .32). The sample was predominantly low income; the average income-to-needs ratio (computed by taking the family income, exclusive of federal aid, and dividing this by the federal poverty threshold for that family) was 1.32 (SD = 0.97). For the purpose of this study, student characteristics were aggregated to the classroom level and are presented in Table 1.

Materials

BaU group. The district used the HighScope curriculum (HighScope Educational Research Foundation, 2012), with an additional district-prepared pre-K curricular guide providing activity suggestions across topics in oral language, literacy, mathematics, science, history, and social science. The mathematics and science activities were explicitly informed by state pre-K learning

Table 1. Teacher, classroom, and video characteristics by condition.

	Control (Business as usual) (n = 10)			Curricula only (Basic) (n = 17)			Curricula plus supports (Plus) (n = 14)		
Characteristic	% or M (SD)	n	Missing	% or M (SD)	n	Missing	% or M (SD)	n	Missing
Classroom characteristics									
Average maternal education[a]	4.33 (0.44)	9	1	4.03 (0.60)	17	0	4.33 (0.42)	14	0
Average PPVT	68.23 (5.10)	10	0	66.47 (10.45)	17	0	68.04 (8.13)	14	0
Teacher characteristics									
Teacher education		10	0		15	2		13	1
Bachelor's	25%			21%			54%		
Bachelor's plus one	38%			7%			15%		
Master's	37%			72%			31%		
Teacher years of experience	15.05 (10.49)			18.00 (9.87)			22.50 (9.32)		
Video characteristics									
Total tapes submitted[b]	85.10 (48.00)	10	0	85.29 (45.94)	17	0	83.14 (38.07)	14	0
Math tapes	41.90 (19.30)	10	0	44.06 (22.75)	17	0	44.36 (19.76)	14	0
Science tapes	20.30 (18.30)	10	0	41.24 (23.39)	17	0	38.79 (18.66)	14	0

Note. PPVT = Peabody Picture Vocabulary Test.

[a]Maternal education was rated on a 9-point scale (1 = eighth grade or less, 2 = some high school but no diploma, 3 = high school diploma or equivalent, 4 = some college but no degree, 5 = technical training certificate, 6 = 2-year degree, 7 = bachelor's degree, 8 = master's degree, 9 = doctoral degree). [b]For Business-as-Usual teachers, total tapes submitted includes tapes submitted in domains other than mathematics or science.

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standards and by the HighScope curriculum as well as by assessments of early learning (including the HighScope Child Observation Record and related quarterly assessments in each subject area). The instructional strands addressed for mathematics and science included number and number sense; computation; measurement; geometry; data collection and statistics; patterns and relationships; scientific investigation, reasoning, and logic; matter (physical motion and forms of water); earth and space systems; earth patterns, cycles, and change; resources; and history/change over time.

Basic and plus treatment groups. The Basic group received the MTP curricula described previously and any teaching materials needed to implement the activities that might not otherwise have been present in the classroom (teddy bear counters, bean seeds, etc.). The Plus group received the MTP-M/S curricula, needed materials, and also access to the online and workshop-based PD supports. Both the Basic and Plus groups were encouraged to fully implement the MTP-M/S curricula as well as any other mathematics and science activities they liked.

Procedures

Recruitment. Teachers were recruited from a single district in a large mid-Atlantic city. Invitation letters were sent to all pre-K teachers in the district that described the mathematics and science curricula and the PD supports. Several informational meetings were held with interested teachers to describe the study in more detail. Follow-up phone calls and/or in-person meetings were held with interested teachers. Teachers who consented to participate attended an introductory workshop in September 2009 at which they were oriented to the purpose of the study, trained on the intervention to which they were assigned (for Basic and Plus teachers) or instructed to continue implementing their current curricular activities (for BaU teachers), and given information about data collection requirements. To help encourage their use of the online supports, teachers in the Plus group also participated in seven half-day workshops (2.5 instructional hours about once a month) specifically focused on the use of these online resources.

Information about the study and consent forms were sent to all children in participating teachers' classrooms. Parents were also asked to complete a short demographic survey. From among the students with parental consent, we randomly selected 10 students per classroom for participation in direct assessments. Students with limited English proficiency or with an individualized education plan in an area other than speech were excluded from the study, as we did not have psychometrically valid assessments for these populations.

Child assessment protocol. Data collectors completed two full days of didactic training on administration of the direct child assessments. For the analyses reported here, only the direct assessment data from the Peabody Picture Vocabulary Test (PPVT) were used (as a covariate at the classroom level); however, data were also collected on students' mathematics and science knowledge and skills, the analysis of which is reported elsewhere. Data collectors were blind to the experimental condition of the students. Students were brought to a quiet, private area and administered an assessment battery. After the completion of the assessments, students were given a book for their participation.

Coding of videotapes. As part of their participation in the study, we asked teachers to videotape themselves implementing mathematics and science activities. Teachers were asked to record one activity per videotape and to submit 15 videotapes per month by mail, for a total of 132 tapes across the year. We asked intervention teachers to record all implemented MTP-M/S mathematics and science activities. We asked teachers in the BaU condition to record all mathematics and science activities that they implemented. If they did not implement 15 mathematics and science activities in a month, we asked them to videotape curricular activities in other domains, in order to ensure that

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we were asking teachers in all conditions to submit the same number of videos per month (see Table 1 for descriptive information about submitted videos).

We selected videos for coding in an effort to obtain an adequate sample of teachers' practice across the year (September, October, November, February, March, April), across domains (mathematics and science; for these analyses we did not include any tapes that BaU teachers submitted in domains other than mathematics or science), and across activity settings (whole vs. small group). We selected two tapes per month for each teacher, for a possible total of 12 tapes. If for one month for a given teacher we selected videotapes for a whole-group mathematics activity and a small-group science activity, then for the next month for that same teacher we selected a small-group mathematics activity and a whole-group science activity. On average, 8.80 (*SD* = 3.92) tapes were coded per teacher (range = 1–12).

Videotape coding focused on documenting the quality of interactions during mathematics and science activities (described below). A total of 20% of tapes were double coded in order to calculate interrater reliability.

Measures

Teacher characteristics. Teachers reported on the number of students in their classrooms and completed a personal demographic survey after enrolling in the study. They reported on level of education (advanced degree = 1, bachelor's degree = 0), field of study (early childhood education, elementary education, or other), and years of experience teaching pre-K, among other variables.

Classroom characteristics. Parents or caregivers completed a survey that provided demographic information about their child and themselves, including highest level of maternal education.

Selected students completed the PPVT-4 (Dunn & Dunn, 2007). The PPVT-4 serves as an achievement test of receptive language ability. The PPVT-4 consists of four training items and 204 test items grouped into 17 sets with 12 items each. The item sets are arranged in order of increasing difficulty. Each item consists of four black-and-white pictures arranged on a page called a PicturePlate. The child is to select the picture that best represents the meaning of a stimulus word presented orally by the examiner. The PPVT-4 demonstrates excellent reliability, with high internal consistency for 3- to 5-year-old children (αs = .95–.97) and high test–retest reliability (*r*s = .91–.94; Dunn & Dunn, 2007). The PPVT-4 has been validated with other measures of children's verbal abilities (Dunn & Dunn, 2007).

Teachers' interactions with children. Two measures were used to assess the quality of teachers' interactions with children. The Classroom Assessment Scoring System (CLASS; Pianta, La Paro, & Hamre, 2008) is an observational measure of teacher–child interactions developed based on large-scale classroom observation studies, including the National Institute of Child Health and Human Development Study of Early Child Care (Pianta, La Paro, Payne, Cox, & Bradley, 2002) and the National Center for Early Development and Learning Multi-State Pre-K Study (Pianta et al., 2005). The CLASS is made up of 11 dimensions scored on 7-point scales that make up the three primary domains of Emotional Support, Classroom Organization, and Instructional Support. CLASS observation scores have been shown to be associated with greater gains in students' academic achievement and social skill development (Howes et al., 2008; Mashburn et al., 2008). Coder agreement within 1 on each dimension ranged from 70.1% to 98.9%. Internal consistency for Emotional Support was α = .94, Classroom Organization was α = .61, and Instructional Support was α = .88.

The other measure of interactions, the Facilitation of Mathematical and Scientific Thinking measure, was a three-item scale designed to assess teacher interactions that supported students' mathematics and science thinking and reasoning. The included items were a subset of our MTP-M/S fidelity measure (see Kinzie, Vick Whittaker, Kilday, & Williford, 2012) that were coded across all

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three conditions. The items were informed by a review of the theoretical foundations of high-quality interactions between teachers and children as children learn mathematics and science. The items included "Teacher elicits children's observations and explanations for the activity, during available opportunities," "Children share their own observations and explanations," and "Teacher extends/elaborates on students' comments or questions." Items were scored on a 4-point Likert-type scale from *none of the time* to *all of the time*. To determine interrater reliability we used intraclass correlation coefficients for the ordinal items. The interrater reliability across items ranged from .88 to .93, with an average of .91. Internal consistency for the measure was $\alpha = .67$. In this study, the Facilitation of Mathematical and Scientific Thinking measure was significantly correlated with the CLASS domains of Emotional Support ($r = .63$, $p < .05$) and Instructional Support ($r = .56$, $p < .05$) but not Classroom Organization ($r = .25$, $p > .05$).

Multilevel analysis

The structure of the data included two levels: activity and teacher. Therefore, we fit two-level hierarchical linear models that accounted for the nesting of activities within teachers. Data were analyzed using Mplus Version 6.1 (Muthen & Muthen, 1997–2010). Missing data for any one variable ranged from 0% to 15%. Analyses were run using full information maximum likelihood estimation so that data analyses used all available data when estimating parameters, increasing the precision and accuracy of the estimated parameters (Enders & Bandalos, 2001). Control variables included activity domain (mathematics or science), activity setting (whole group or small group), teacher years of experience, teacher level of education, classroom aggregates of maternal education and PPVT scores for children, and total amount of recorded video time received from the teacher.

We fit a series of two-level models that attempted to explain teachers' interactions. The Level 1 model included the date the activity was implemented, the domain (mathematics, science), and the activity setting (whole group, small group). The Level 2 model included the teacher's study condition, the classroom-level aggregates of maternal education and PPVT scores, the teacher's education level, the teacher's total years of teaching experience, and the total time of tape submitted across all activities. When entering the study condition, we created two dummy variables and entered them simultaneously so that BaU teachers were the reference group and the different indicators corresponded to those in the Basic group and those in the Plus group. We calculated effect sizes for the significant treatment effects by dividing the difference between adjusted means for the two groups by the standard deviation for the outcome after removing variability associated with model factors. This made our effect size estimates correspond to the difference between the estimated marginal means of the two groups being compared.

Results

Descriptive statistics

Descriptive statistics for classrooms, teachers, and tapes are presented in Table 1. Children's PPVT scores in this study ranged from 51.27 to 82.20 ($M = 67.43$, $SD = 8.36$). As for reported levels of maternal education, 35% reported a high school diploma or less, 27% indicated some college but no degree, 28% reported holding a 2-year degree or training certificate, and 10% indicated completing a bachelor's degree or higher. Teachers across all three conditions submitted an average of 84.51 tapes ($SD = 42.83$). For BaU teachers, this included tapes for domains other than math or science. In looking across treatment groups at the number of submitted videos by domain, we found no significant differences across groups in the number of mathematics videos submitted (M across groups = 43.63, $SD = 20.46$). However, there was a significant difference in the number of science tapes submitted, with Plus ($M = 38.79$, $SD = 18.66$) and Basic ($M = 41.24$, $SD = 23.39$) teachers submitting significantly more than BaU ($M = 20.30$, $SD = 18.30$) teachers, $F(2, 38) = 3.52$, $p < .05$.

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Are there differences, based on treatment condition, in teacher–child interactions across the pre-K year?

Coefficients for variables included in our models are provided in Table 2. The estimated marginal means for the different treatment groups (controlling for the covariates) are presented in Table 3. Comparisons for the homogenous subsets comparing the BaU group to the Basic and Plus groups were based on the tests of the dummy codes from the multilevel model discussed previously. The comparison of the Basic to the Plus group was taken from a dummy code in a second model that was identical to the model discussed previously except that the Basic group was the reference group instead of the BaU group.

There were significant effects of treatment, such that teachers in both the Plus and Basic groups were observed to be providing significantly higher quality Instructional Support (effect sizes = .58 and .60, respectively) and Facilitation of Mathematical and Scientific Thinking (effect sizes = .38 and .44, respectively) than BaU teachers. Basic teachers were also observed to be offering significantly higher levels of Emotional Support than BaU teachers (effect size = .27). There were no significant differences between the Plus and Basic groups on any of the teacher–child interaction outcomes.

There were some significant covariates in the models. With regard to classroom characteristics, teachers in classrooms in which students' PPVT scores were higher were observed to be providing higher levels of Emotional Support and Classroom Organization. Where teacher characteristics are concerned, teachers' education was negatively associated with teachers' observed Classroom Organization and Facilitation of Mathematical and Scientific Thinking. As for activity characteristics,

Table 2. Treatment effects on teacher–child interaction quality.

	Emotional support	Classroom organization	Instructional support	Facilitation of mathematical and scientific thinking
Covariates and predictors	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)	*β* (*SE*)
Level 1 covariates				
Date of activity	−0.041 (0.030)	−0.024 (0.039)	0.056 (0.038)	−0.004 (0.023)
Domain (math, science)	0.010 (0.066)	0.081 (0.073)	0.438 (0.083)***	0.011 (0.046)
Activity setting (whole group, small group)	−0.051 (0.055)	−0.075 (0.060)	0.120 (0.089)	0.090 (0.032)**
Level 2 covariates				
Total tape time	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.002 (0.001)†
Teacher experience	0.006 (0.005)	0.010 (0.008)	0.005 (0.006)	−0.002 (0.004)
Teacher education	−0.109 (0.063)†	−0.226 (0.112)*	−0.116 (0.080)	−0.115 (0.049)*
Average maternal education	−0.139 (0.073)†	−0.102 (0.126)	−0.027 (0.095)	0.041 (0.078)
Average PPVT	0.018 (0.006)*	0.019 (0.008)*	0.011 (0.007)	0.008 (0.004)†
Treatment effects				
(Plus − BaU) dummy	0.145 (0.136)	0.320 (0.227)	0.647 (0.159)***	0.352 (0.131)**
(Basic − BaU) dummy	0.263 (0.133)*	0.326 (0.168)†	0.507 (0.116)***	0.419 (0.131)**
(Basic − Plus) dummy[a]	0.118 (0.082)	0.006 (0.119)	−0.140 (0.140)	0.067 (0.085)

Note. PPVT = Peabody Picture Vocabulary Test; BaU = Business as Usual.
[a]The effect of the (Basic − Plus) dummy code was taken from a second model using Plus as the reference group for the treatment dummy codes.
†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 3. Estimated marginal means by condition.

Outcomes	Business as usual (Control)	Curricula only (Basic)	Curricula plus supports (Plus)
Emotional support	5.117_{a}	5.380_{bc}	5.262_{ac}
Classroom organization	5.054_{a}	5.380_{a}	5.374_{a}
Instructional support	2.199_{a}	2.706_{b}	2.846_{b}
Facilitation of mathematical and scientific thinking	2.936_{a}	3.355_{b}	3.288_{b}

Note. Means within a row that do not share any subscripts are significantly different ($p < .05$). Means control for all covariates.

the domain of the activity was significantly associated with the quality of teachers' Instructional Support, such that Instructional Support was higher in science activities than in Mathematical activities. In addition, teachers' Facilitation of Mathematical and Scientific Thinking was higher in whole-group settings than in small-group settings.

Discussion

The growing demand to reduce the achievement gap in mathematics and science and prepare children to excel in science, technology, engineering, and mathematics fields requires evidence-based, accessible training for teachers that is shown to be linked to improvements in the quality of teachers' instruction. The early childhood field has started to respond to this demand by developing an increasing number of mathematics and science curricula and associated PD aimed at improving the effectiveness of mathematics and science instruction (e.g., Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Greenes, Ginsburg, & Balfanz, 2004; Greenfield et al., 2009; Kinzie et al., 2012; Starkey et al., 2004). However, evaluations of these curricula and PD are rare (NRC, 2009). When they do exist (e.g., Clements et al., 2011; Klein, Starkey, Clements, Sarama, & Iyer, 2008 ; Starkey et al., 2004), they evaluate effects of curricula and PD together, making it impossible to disaggregate the effects of the curricula from the PD.

In this study, we used planned variation to examine the impact of the MTP-M/S curricula alone versus the MTP-M/S curricula combined with PD delivered via online and workshop supports. Outcome measures reflected different aspects of the quality of teachers' classroom interactions. Our results suggested that providing the MTP-M/S curricula alone (the Basic intervention) had positive impacts on teachers' interactions with students. Compared with those in the BaU group, teachers in the Basic group (curricula only) demonstrated higher levels of Emotional Support, Instructional Support, and Facilitation of Mathematical and Scientific Thinking in their classroom interactions. The MTP-M/S curricula were designed so that some of the PD supports were embedded throughout the written curricula (considered to be within-activity supports, these included recommendations for language for teachers to model and elicit, suggested open questioning to spur students' inquiry and application of knowledge and skills, adaptations for differentiated instruction, and suggested extensions across the day). The MTP-M/S curricula were also developed through a rigorous research on curriculum development model (see Kinzie et al., in press, for a detailed description). As a part of this process, we engaged in iterative development and evaluation of the curricula in pre-K classrooms, which enabled refinement of the curricular design based on feedback from our target users. Taken together, these results suggest that purposefully designed curricula that include embedded supports for teachers can effectively support teachers in their practice.

Our hypothesis was that teachers in the Plus group (curricula plus online and workshop PD supports) would show higher quality interactions than teachers in the BaU group. Our results partially supported this hypothesis in the areas of Instructional Support and Facilitation of Mathematical and Scientific Thinking.

In addition, we hypothesized that teachers in the Plus group would outperform teachers in the Basic group, given research suggesting that PD can provide the necessary scaffolds to implement curricula with high degrees of quality (Copley, 2014; Zaslow, Tout, Halle, Vick Whittaker, & Lavelle, 2010). This hypothesis was not supported by our results; there were no significant differences on any of our outcomes for teachers in the Plus versus Basic groups. Teachers may not have availed themselves of a sufficient dosage of the online supports to improve their practice. As we have reported elsewhere (Kinzie et al., 2012), the majority of teachers attended all of the PD workshops. However, there was a wide range in teachers' access of the online supports. The number of logins to the MTP-M/S website for the teachers in the Plus group ranged from 4 to 122 (M = 45.36, SD = 37.72) across the year. Similarly, total minutes spent on the website ranged from 70.22 to 1,263.27 min (M = 631.52, SD = 408.29). In future research with larger sample sizes, teacher characteristics that may lead to more or less engagement with Web-based supports should

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be examined in order to better understand this variability in teachers' engagement. In addition, recent studies have suggested that there may be a minimum dosage of PD required to create improvements in teacher–child interactions (e.g., Pianta et al., 2014). The sample size of teachers in this study was too small to determine whether teachers' dosage of PD was related to the quality of their teacher–child interactions. We are now conducting an efficacy trial of MTP-M/S with a larger sample of teachers and are beginning to explore how the use of specific implementation supports relates to the quality of teacher–child interactions (Vick Whittaker, Kinzie, Williford, & DeCoster, 2015) and whether there is a minimum dosage of PD required to change teacher practice. This study did not include coaching as part of the teachers' PD. In a review of 44 studies focusing on coaching in early childhood classrooms, Isner et al. (2011) found substantial benefit for PD coaching, with 27 out of 31 (87%) studies showing improvements in observed teaching quality as a result of coaching. Research suggests that coaching may lead to improvements in teacher practice beyond those that can be achieved with curricula and training alone (Chen & McCray, 2012; Clements & Sarama, 2007). We may have found differences between the Basic and Plus groups had coaching been offered as part of the Plus PD supports. Coaches could have provided more individualized supports to teachers based on their practice. In addition, coaches could have encouraged greater use of the Web-based supports, albeit with greater expense to implementation.

It is worth noting that, in a related inquiry during this same research trial (Kinzie et al., 2014), we found that students in Plus teachers' classrooms outperformed students in BaU classrooms in geometry and measurement skills and performed better than students in both BaU and Basic classrooms on an assessment of number sense and place value skills. Although we did not find Plus–Basic differences in our measures of the quality of teacher–child interactions in the analyses reported here, Plus teachers may have been providing additional support to students that was not assessed by our observational measures (e.g., using mathematical tools to represent concepts) but that did support students' skill development. In our current efficacy trial of MTP-M/S, we are using measures specifically designed to assess additional mathematics supports that teachers might be providing to children that were not sufficiently captured in the measures used in this study (e.g., Classroom Observation of Early Mathematics Environment and Teaching; Sarama & Clements, 2007).

There were several significant covariates in the models worth noting. Consistent with previous research suggesting that lower risk classrooms have higher quality teacher–child interactions (e.g., LoCasale-Crouch et al., 2007), classrooms with children with higher PPVT scores were served by teachers observed to be providing higher quality Emotional Support and Classroom Organization. With regard to teacher characteristics, teachers' level of education was negatively related to Classroom Organization and teachers' Facilitation of Mathematical and Scientific Thinking. This is consistent with large-scale studies that have found either no relationship or a null relationship between teacher education and classroom quality (e.g., Early et al., 2007). Given that teacher education and training programs spend very little time preparing early educators in math and science instruction (Ginsburg et al., 2006; Hyson, Horm, & Winton, 2012; Lobman, Ryan, & McLaughlin, 2005), it is not surprising that teachers' education is not supporting their classroom practice during math and science activities.

With regard to characteristics of the activities, domain was a significant covariate in the model predicting Instructional Support, with related interactions observed to be of higher quality in science versus math activities. This finding is consistent with a recent study suggesting that teachers display the highest quality instructional support during science activities compared with activities in other domains (Cabell, DeCoster, LoCasale-Crouch, Hamre, & Pianta, 2013; Fuccillo, 2011). Teachers in the Plus and Basic groups, compared to teachers in the BaU group, were engaging in more science activities, as suggested by the number of science tapes they submitted, which could have led to the significant differences in the quality of Instructional Support for activities within this domain. Teachers' Facilitation of Mathematical and Scientific Thinking was higher in whole-group compared with small-group settings. This finding is also consistent with recent research by Cabell et al. (2013), who found that the quality of instructional interactions was highest in large-group settings. However, in Cabell and colleagues' study, effects of small-group settings were not examined, as not enough time was spent in this type of setting (36.9% of time in whole group vs. 3.5% in small group) to examine differences in quality. In a large-scale examination of how pre-K children spent their time in school, only 6% of the day was found to be spent in small-group activities compared with 28% of the day in whole-group activities. It could be that teachers feel less comfortable facilitating instruction in small-group settings.

Limitations

There are several limitations of this study that are worth noting. First, randomization occurred at the school level; however, we conducted our analyses and made inferences at the teacher level. We randomly assigned treatment conditions at the school level in order to limit treatment contamination between classrooms, but this decision limited our ability to draw causal conclusions from our findings. Second, the study had a small sample size (n = 41 teachers) and teacher attrition (seven teachers dropped over the course of the study), which limited our power to detect significant differences between groups. This is particularly true when examining differences between teachers in the intervention conditions where the differences were expected to be much smaller (compared to larger expected differences when comparing teachers in either one of the treatment conditions to teachers in the control condition). Finally, our sample included teachers in state-funded pre-K classrooms, all with a bachelor's degree or higher. This level of educational preparation is not characteristic of the early childhood teacher workforce as a whole, and therefore results are not generalizable to a larger, more diverse population of early childhood educators.

In sum, the results of this study have important implications given that the purchase and adoption of evidence-based curricula including embedded teaching supports may be a less expensive alternative to providing external PD supports (one estimate suggests that urban districts spend \$8,000–\$9,000 on PD a year per teacher; Sawchuck, 2010). Although online PD is often a more affordable alternative than in-person PD (e.g., My Math offers custom webinars for \$1,000 and in-person training for \$2,500/day; McGraw-Hill Education, 2013), there are still costs associated with development, maintenance, and personalization. In contrast, well-designed activities with embedded supports have a one-time cost associated with their development, and research suggests that these can be educationally effective in supporting high-quality interactions and children's outcomes (Clements, 2007 ; Forbes & Davis, 2010; Kinzie et al., in press).

Many early childhood programs either are not using mathematics and science curricula or are using curricula that have no evidence of improving teacher practice or child outcomes (U.S. Department of Health and Human Services, 2014; Office of Head Start, 2014). These data suggest that implementing high-quality domain-specific mathematics and science curricula with embedded supports may be an effective way to improve the quality of teacher–child interactions in the classroom.

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