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Professional Development for Early Childhood Educators: Efforts to Improve Math and Science Learning Opportunities in Early Childhood Classrooms

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Abstract

Because recent initiatives highlight the need to better support preschool-aged children's math and science learning, the present study investigated the impact of professional development in these domains for early childhood educators. Sixty-five educators were randomly assigned to experience 10.5 days (64 hours) of training on math and science or on an alternative topic. Educators' provision of math and science learning opportunities were documented, as were the fall-to-spring math and science learning gains of children (*n* = 385) enrolled in their classrooms. Professional development significantly impacted provision of science, but not math, learning opportunities. Professional development did not directly impact children's math or science learning, although science learning was indirectly affected via the increase in science learning opportunities. Both math and science learning opportunities were positively associated with children's learning.

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Results suggest that substantive efforts are necessary to ensure that children have opportunities to learn math and science from a young age.

Keywords

professional development; efficacy study; mathematics instruction; science instruction; preschool; early childhood education

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The most recent National Assessment for Educational Progress report indicates that a considerable percentage of children in the U.S. perform below basic levels in math and science, and only a minority of children achieves proficiency in these critical academic domains (National Center for Education Statistics, 2011a; National Center for Education Statistics, 2011b). Specifically, 18% of fourth graders and 27% of eighth graders fell below basic levels of performance in math, with only 40% of fourth graders and 35% of eighth graders demonstrating proficiency. Similarly, for science, 35% of eighth graders fell below basic levels of performance in science, and only 32% of children demonstrated proficiency. American students also rank consistently rank lower than other developed countries on international assessments of math and science achievement, including the Trends in International Mathematics and Science Study (Mullis et al., 2007). Consequently, panels and organizations at both state and national levels have called for greater attention to the provision of high-quality math and science instruction throughout children's educational careers (Kuenzi, 2008). Specific recommendations include providing high-quality teacher training and professional development in math and science, as well as developing, evaluating, and implementing evidence-based math and science curricula and learning standards.

Calls for greater attention to math and science include recommendations to attend to these domains for young children prior to formal school entry. Children's experiences during early childhood impact their understanding and knowledge of a host of cognitive skills, including math and science concepts (e.g., Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001; Huttenlocher, Jordan, & Levine, 1994; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006). For example, Klibanoff and colleagues (2006) investigated relations between the amount of "math talk" and the growth of preschool-aged children's math knowledge over the course of an academic year. Results revealed that children's math knowledge significantly increased with the amount of exposure to "math talk." In other words, young children who had more math learning opportunities demonstrated significant growth in math knowledge. This finding adds to a growing body of literature linking young children's early learning experiences and their learning gains in various domains, including math (Bodovski & Farkas, 2007; Wang, 2010) and literacy (e.g., Connor, Morrison, & Slominski, 2006). Although much less research has examined associations between science learning opportunities in classrooms and children's gains in this domain, extant literature leads to the hypothesis that children who have increased opportunities to learn about science will demonstrate greater knowledge and skills related to this academic content domain (French, 2004; Leung, 2008; Peterson & French, 2008).

Missed Opportunities to Learn Math and Science in Early Childhood Classrooms

Despite strong endorsements by national and state standards and policy (e.g., Brenneman, Stevenson-Boyd, & Frede, 2009; National Association for the Education of Young Children & National Council of Teachers of Mathematics, 2010; Ohio Department of Education, 2007), research suggests that not all preschool-aged children are afforded adequate learning opportunities in math and science. For example, Connor and colleagues (2006) completed videotaped observations of 34 preschool classrooms, which were coded for the amount of time (minutes:seconds) spent in academic activities, including literacy, math, and science, and non-academic areas. Although the study mainly focused on literacy, results revealed that average preschoolers only spent approximately eight minutes of their day in math- and science-related activities.

Additional studies have focused exclusively on math and science learning opportunities in early childhood classrooms. For example, a recent study by Piasta, Yeager Pelatti, and Miller (2014) examined the amount and types of math and science learning opportunities afforded to children in 65 diverse early childhood classrooms. Results revealed that although most educators provided at least some opportunities to learn about math and science, considerable variability existed such that time devoted to math learning opportunities ranged from 0 to 120 minutes, and time dedicated to science learning opportunities ranged from 0 to 102 minutes, resulting in positively skewed distributions for learning opportunities in these two domains. More specific to math instructional practices, Thornton, Crim, and Hawkins (2009) found that early childhood teachers reported engaging their preschool-aged students in math-related activities infrequently. Additionally, Tu (2006) and Nayfeld, Brenneman, and Gelman (2011) revealed scant science learning opportunities provided by participating early childhood educators.

There may be several reasons for the lack of instructional time devoted to math and science learning opportunities. First, this may reflect a historical belief that young children are unprepared to learn math and science, based on two now-discredited assumptions: (a) cognitive processing necessary for math and science reasoning was entirely learned (e.g., Staats & Staats, 1963), and (b) children in the preoperational stage of development were not cognitively capable of learning math and science (e.g., Piaget, 1965). It may be the case that these erroneous assumptions still pervade instruction, despite more recent research indicating that very young children possess cognitive capacities for math and science reasoning. Current research supports that even infants display a rudimentary sense of numbers (Izard, Sann, Spelke, & Streri, 2009; McCrink & Wynn, 2007; Xu, Spelke, & Goddard, 2005), and preschool-aged children demonstrate impressive levels of informal math knowledge (e.g., Gelman & Gallistel, 1978; see Ginsburg, Klein, & Starkey, 1998; Feigenson, Dehaene, & Spelke, 2004 for reviews), geometric and spatial reasoning (e.g., Newcombe & Huttenlocher, 2000), and problem solving skills (see Berg & Strough, 2010). Indeed, these skills develop rapidly during the years immediately preceding formal school entry. Young children also demonstrate ample science-related knowledge prior to entering formal schooling, including probabilistic reasoning (Denison, Reed, & Xu, 2013) as well as understandings of cause and effect (e.g., Duschl, Schweingruber, & Shouse, 2006) and animate and inanimate objects (e.g., Gelman & Opfer, 2002). Such science knowledge continues to develop during the preschool years, as children acquire more abstract, sophisticated skills related to causal reasoning (e.g., Gottfried & Gelman, 2004; Harris, German, & Mills, 1996) and hypothesis testing (e.g., Ruffman, Perner, Olson, & Doerty, 1993).

Additionally, opportunities to learn math and science in early childhood may also be limited by educators' knowledge and preparation in these areas. Research suggests that early childhood educators frequently lack specific math and science content knowledge (Isenberg, 2000). For example, in a review of New Jersey colleges providing preschool educator training, only 21% of programs offered an entire course focused on academic content, including math, whereas many of the teacher training programs did not offer any such courses (Lobman, McLaughlin, & Ryan, 2005). Additionally, early childhood educators frequently report not feeling prepared or comfortable teaching math (e.g., Copley, 2004) or science (e.g., Greenfield et al., 2009). Finally, educators of young children may feel increased pressure or place greater emphasis on providing opportunities to learn about other developmental domains, including language and literacy (e.g., Copley, 2004; Greenfield et al., 2009). This finding is consistent with the previously described reports that more instructional time was dedicated to language and literacy than math and science (e.g., Connor et al., 2006; Early et al., 2010; La Paro et al., 2009). Taken together, these studies provide several explanations as to why math and science may not be a focus in early childhood classrooms and highlight the need for additional studies to investigate how provision of learning opportunities in these domains may be encouraged.

Improving Early Math and Science Education through Professional Development

Math and science professional development in early childhood education may provide one means by which the previously-described inconsistencies in early math and science learning opportunities may be addressed (Ginsburg, Lee, & Stevenson Boyd, 2008). Extant literature generally supports that provision of high-quality professional development can positively impact classroom practices (e.g., Desimone, Porter, Garet, Yoon, & Birman, 2002), which in turn, may impact child outcomes (e.g., Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). Research evidence on the impacts of professional development is particularly abundant in the domains of language and literacy (e.g., Neuman & Cunningham, 2009; Piasta et al., 2012; Wasik, Bond, & Hindman, 2006). For example, Landry and colleagues (Landry, Swank, Smith, Assel, & Gunnewig, 2006) conducted a large professional development intervention with 500 early childhood educators to determine impacts on preschoolers' skills and teachers' approaches. Overall, results revealed that the preschool-aged children in the intervention classrooms made more substantial gains across a host of skills, including receptive and expressive language, than the children in the control group. In addition, educators in the treatment group reported positive impacts on their teaching perspectives as a result of the professional development activities, specifically positive awareness, morale, and confidence (Landry et al., 2006). Similarly, Hamre and colleagues (2012) conducted a randomized controlled trial to determine the impact of professional development on educators' knowledge, beliefs, and instructional practices. Specifically, 440 early childhood educators were randomly assigned to a treatment condition, which was a 14-week course, or the "business-as-usual" control condition. Results revealed that teachers who participated in the professional development demonstrated changes in their beliefs and knowledge about language and literacy learning as well as several aspects of instructional interactions as measured by the Classroom Assessment Scoring System.

Despite the mounting research dedicated to the language and literacy professional development of early childhood educators, evidence specific to understanding the impacts of math and science professional development within this population is more limited. Of the studies examining math and science professional development in early childhood, two major approaches have emerged: (1) descriptive studies that detail the rationale behind and efforts to provide math and science professional development but do not rigorously evaluate its impact (e.g., Akerson, 2004; Brenneman et al., 2009; Katz, Sadler, & Craig, 2005), and (2) empirical studies that investigate the impacts of professional development as implemented with a specific math or science curriculum (e.g., Arnold, Fisher, Doctoroff, & Dobbs, 2002; Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Greenfield et al., 2009; Peterson, 2009).

Descriptive studies of professional development

Thornton et al. (2009) provide one example of a descriptive study of math professional development. These researchers discussed the C^3 (collaborative, collegial, and cooperative) approach, which included an initial training and ongoing individual and small-group sessions for early educators. This study described pre- and post-test questionnaire data for early educators' reported emphasis of, time spent in, and instructional practices related to math. The authors reported significant changes in several specific areas, with impacts varying across math topics. In a second example of this type of work, Katz et al. (2005) utilized professor-teacher candidate dyads as a means of providing mentorship related to a standards-based science unit on inquiry and documented the mentor-mentee interactions and resultant science lessons. They found evidence that mentors provided guidance during lesson development despite great variability in the extent to which such guidance resulted in higher-quality science instruction. In a third example, Akerson (2004) approached professional development for early childhood educators by creating a science methods course designed to provide increase overall comfort and instructional skills through reflection and hands-on experience. Although this article provides a theoretical background for providing this type of professional development, no data were collected. Altogether, these efforts describe the compelling rationale behind and potential of math and science professional development for early childhood educators; however, the lack of control groups and limited data collection prevent such studies from making causal claims about the effectiveness of professional development for impacting educator skills and practices or child outcomes.

Empirical studies of professional development and specific math and science curricula

Several additional studies have examined the impacts of math and/or science professional development, as coupled with a specific math or science curriculum. Such studies do not allow disentanglement of effects of professional development alone. Nonetheless, they provide important evidence concerning the potential of math and science professional development for impacting educator practices and child outcomes.

Clements et al. (2011) investigated the impact of the curriculum, *Building Blocks*, together with its corresponding professional development, on educators' classroom practices and children's math outcomes. Educators participated in 13 days of professional development over the course of two years. Specifically, these activities included training related to math knowledge, skills, and instructional practices and followed the *Building Blocks* curriculum. Results showed that the children in the *Building Blocks* classrooms made greater math gains than the children in comparison classrooms, a finding consistent with earlier studies on this curriculum (e.g., Clements, 2007; Clements & Sarama, 2007). Notably, these positive impacts were detected despite variability in educators' classroom math practices. Although the authors reported that educators in the *Building Blocks* condition demonstrated significantly higher implementation of math practices, educators ranged in both fidelity to the curriculum and in the amount and quality of math learning opportunities provided. The latter partially mediated impacts of the curriculum on children's learning gains.

Similarly, Arnold and colleagues (2002) investigated the impact of a six-week experimental math curriculum on preschoolers' math achievement and interest. Educators participated in a two-hour professional development session prior to the intervention as well as ongoing, weekly discussions surrounding specific math activities. The authors found significant, positive impacts on children's math learning, but also noted considerable variability in response to the intervention. Positive impacts were found for some measures of children's math interest, with gains in interest associated with the extent to which their classroom educators implemented math curriculum activities.

With regard to science curricula, Greenfield and colleagues (2009) reported exploratory data on the program, *Early Childhood Hands-On Science (ECHOS)*. The two-day teacher professional development session and monthly follow-up meetings were designed to encourage early childhood educators to target all domains of school readiness during science lessons. Data were collected using Galileo, an assessment of children's skills across the eight domains of school readiness denoted by Head Start. Results indicated significant impacts on four of eight school readiness domains, including math, with a trend signifying potential impacts on science. In another study of an early childhood science curriculum, Peterson (2009) provided *ScienceStart!* and associated professional development to 19 educators, with additional educators serving in a comparison condition. Analysis of classroom observations was used to determine the impact of the *ScienceStart!* curriculum on educators' provision of explanations during science. The author reported that the curriculum significantly and positively affected educators' use of explanations; however, variability existed such that seven educators in the *ScienceStart!* condition did not provide any explanations, seven provided between one and four explanations, and five provided at least five explanations. Although the author suggested that this finding may be related to teachers' prior science beliefs, no data on this matter were collected.

Aims of the Present Study

In sum, recent research and educational initiatives have called for greater attention to math and science learning opportunities during early childhood, including recommendations to provide high-quality math and science professional development for educators. The existing research on this topic is either descriptive in nature or intertwined professional development with curriculum implementation. Although both avenues provide preliminary evidence regarding potential effects, more research is required to better understand the extent to which professional development may increase math and science learning opportunities and impact child outcomes.

The present study was designed to address this gap in the literature and examine the logic model positing that math and science professional development would impact educators' provision of math and science learning opportunities and affect young children's math and science learning. We hypothesized that participation in math and science professional development, our independent variable of interest, would positively impact the amount of math and science learning opportunities provided by early childhood educators. We also hypothesized that math and science professional development would positively impact children's math and science learning gains, either directly or indirectly through the increased learning opportunities provided by educators. Finally, we hypothesized that we would replicate extant findings demonstrating positive associations between math learning opportunities and children's math learning gains and also extend previous work by finding similar associations between science learning opportunities and science learning gains.

Method

Participants

Study participants were recruited through a two-step procedure. In Step One, lead or co-lead educators from 34 early childhood centers in a mid-sized city in Ohio were invited to participate in the study. Educators from a broad array of centers were invited to participate, to represent the diversity typical in early childhood education (e.g., public, private, and religiously-affiliated centers; half-day and full-day centers; centers with inclusion classrooms; Rhodes & Huston, 2012). Educators were required to be employed in classrooms serving preschool-aged children, with the restriction that only one educator per classroom could participate. Those who volunteered for the study provided written informed consent and agreed to facilitate child enrollment. In Step Two, participating educators provided recruitment materials to the caregivers of children in their classrooms who met three eligibility criteria: (1) preschool-aged (i.e., age range of 3 to 5 years), (2) proficiency in English, and (3) no profound disabilities that would prevent participation in study-related assessments. Children who met these criteria and whose caregivers provided written consent were enrolled in the study, with a goal of enrolling approximately seven children per classroom as per a priori power analyses. Actual classroom enrollments ranged from two to nine children, with an average of about 6 children per classroom.

Using these procedures, 65 early childhood educators were initially enrolled in the project and randomly assigned to math and science professional development ($n = 31$) or comparison ($n = 34$) conditions. Blocked randomization was used to ensure that the 15 centers with multiple participants were represented across both conditions. These educator and classroom characteristics are described in Table 1. Of these original 65 participating early childhood educators, 22 withdrew from the study at various points: 13 left the project due to position changes (i.e., accepted a new job or position, resigned, or were terminated), 3 had extended personal leaves that prevented their continued participation, and 6 left when their director withdrew the entire center from the project. This rate of turnover (34%) is not unexpected in the early childhood field (Rhodes & Huston, 2012). Importantly, educator attrition was not differential across conditions, χ^2 $(1, N = 65) = 1.711$, $p = .191$, nor were the reasons for attrition differential across conditions, χ^2 $(3, N = 22) = 0.702$, $p = .873$. Thus, attrition was not confounded with condition, and impact estimates can be considered unbiased despite limitations in generalizability (Shadish, Cook, & Campbell, 2002). With respect to the latter, educators who left the study were disproportionately non-White, χ^2 $(1, N = 65) = 6.414$, $p = .011$, employed in non-inclusion classrooms, χ^2 $(1, N = 57) = 3.930$, $p = .047$, and not using commercially-available curricula, χ^2 $(1, N = 65) = 4.325$, $p = .038$. Such educators were also disproportionately from private early childhood centers whereas those who remained in the study were disproportionately from religiously-affiliated centers, χ^2 $(2, N = 65) = 5.54$, $p = .063$. There were no additional differences between those educators who did or did not complete the study on any of the characteristics listed in Table 1 (*p*-values > .125).

At the time of child enrollment, educators in 60 classrooms were participating in the study, and 385 children from these classrooms were enrolled in the study; data from these participants constitutes the sample included in the present analyses. Characteristics of the 385 children are reported in Table 2. To the extent possible (i.e., with center and caregiver permission), these children completed study assessments regardless of whether their classroom educators subsequently withdrew from the study, to preserve the intent-to-treat design (Flay et al., 2005). Eighty-four children did not complete posttest assessments, however: 44 withdrew along with their classroom educators, 35 moved to non-participating classrooms or centers, and 5 could not be located and/or did not provide a reason for leaving the study. Neither the extent of attrition nor reasons for attrition were differential across conditions, χ^2 $(1, N = 385) = 0.170$, $p = .680$ and χ^2 $(2, N = 84) = 1.504$, $p = .471$, and children who remained in the study did not differ on any demographic characteristics from those who withdrew (*p*-values > .210).

General Procedure

Educators participated in two phases of study activities, for a total of 18-months. In the Professional Development phase (March 2010 – August 2010), educators completed pretest questionnaires and an initial classroom observation, followed by twice-monthly professional development sessions. In the Implementation phase (September 2010 – May 2011), educators were expected to integrate professional development content into their classroom instruction, maintain weekly teaching logs, participate in a second classroom observation and a refresher workshop, and complete end-of-project questionnaires. Children enrolled in participating educators' classrooms joined the study for the Implementation phase and were pretested in the fall of 2010 and posttested in the spring of 2011.

Professional development—All educators received equivalent amounts of professional development, for a total of 10 and a half days, or 64 hours. Educators attended two consecutive days of professional development each month from April – August 2010. Each day included 6 content hours plus additional time for lunch and breaks. Educators also attended a half-day refresher workshop in January 2011, consisting of 4 content hours. All professional development activities were approved by the state Department of Education and could count toward required licensing/continuing education hours. Educators who were absent from one or more professional development sessions were asked to view video of the missed session and complete an activity on the session's content; 16 teachers made up one or more sessions in this manner. For the 65 educators initially enrolled in the study, the majority ($n = 55$) experienced all professional development; 10 experienced 6-9 sessions, and 4 experienced three or fewer sessions. For the 60 educators who participated in the Implementation phase, six did not experience all sessions: three educators assigned to math and science professional development completed two, six, or eight sessions; two educators assigned to the comparison condition experienced eight sessions, and one educator assigned to the comparison condition experienced nine sessions. There were no significant differences in the number of sessions based on the condition to which educators were assigned when either the original sample or those included in current analyses were considered (p-values > .326). All educators also completed a brief 6-item survey at the end of the Professional Development phase to gauge satisfaction and perceived value of the professional development that they attended. Educators indicated similar levels of satisfaction regardless of condition (p-values > .674), with an average rating of 3.54 on a scale of 0 to 4.

Math and science condition: The math and science professional development was adapted from the math and science portions of the Core Knowledge Preschool Sequence (Core Knowledge Foundation, 2000), Teacher Handbook (Hirsch & Wiggins, 2009), and accompanying professional development materials. The Core Knowledge approach organizes learning content and goals into a systematic scope and sequence to assist with instructional planning (see http://www.coreknowledge.org/the-preschool-sequence). For each of the domains targeted in early childhood (movement and coordination, social and emotional development, language and literacy, visual arts, music, mathematics, history and geography, and science), the approach provides a developmental progression of what 3- to 5- year old children should know and be able to do based on early childhood research and theory. For example, within mathematical reasoning, the broad goal of learning about patterns is broken out into five increasingly complex skills: learning to (a) identify similarities and differences, (b) classify and sort using one characteristic (e.g., size), (c) classify and sort using more than one characteristic (e.g., size and color), (d) pattern using only one alternating characteristic (e.g., big-little-big pattern), and (e) identify and create complex patterns involving at least two characteristics. Content and learning goals align with the Head Start Performance Outcomes and many state early learning standards, including Ohio's (Core Knowledge Foundation, n.d.). The Core Knowledge Preschool Sequence is coupled with a Teacher Handbook and other resources to assist educators in locating individual children's progression within the sequence and using that information to best meet individual learning needs. These resources also provide suggestions for instruction and activities that are directly aligned to the Core Knowledge scope and sequence and based on developmentally-appropriate best practices in early childhood education, such as those espoused by the National Association for the Education of Young Children (NAEYC, 2009). It is important to note, however, that the Core Knowledge Preschool Sequence does not provide lesson plans or otherwise mandate particular instruction or activities.

Educators randomly assigned to the math and science professional development condition participated in professional development led by a certified Core Knowledge consultant. The consultant had a background in teacher education, early childhood, and educational psychology, with over 7 years of experience in providing professional development to educators. The professional development content was adapted from existing professional development offerings for the Core Knowledge Preschool Sequence. Professional development topics included (a) a general introduction to the Core Knowledge approach to math and science, (b) assessing and meeting individual children's math and science instructional needs, (c) mathematical reasoning and number sense learning objectives and activities, (d) scientific reasoning learning objectives and activities, and (e)"fine tuning" math and science such that it is integrated with the full curriculum (e.g., expanding math and science into shared reading and dramatic play). Each topic was addressed for two full days, with sessions including whole group lecture and discussion, demonstrations using video clips and instructional materials, small group hands-on activities, and self-reflection. Educators received copies of the Core Knowledge Preschool Sequence, the Teacher Handbook, Core Knowledge math and science assessment probes, professional development notes, and approximately $500-worth of classroom materials (e.g., books, Unifix cubes, magnifying glasses). These materials were supplied to facilitate translation into classroom instruction, as educators were asked to implement knowledge from their professional development experiences to emphasize math and science in their classrooms during the upcoming year (i.e., Implementation phase). In January of the Implementation phase, educators reconvened for one half-day session led by study staff during which they shared classroom experiences, challenges, and reflections on math and science instruction in their classrooms.

Comparison condition: Educators randomly assigned to the comparison condition followed the same professional development schedule and received equivalent amounts of training. Instead of math and science, however, their professional development focused on art and creativity in early childhood. Professional development sessions were led by a local artist who has also served as a teacher educator for over 25 years, in conjunction with study staff. Educators learned about how art can be integrated into early childhood curricula and used to enhance various aspects of young children's development (e.g., movement, social and emotional development, cultural sensitivity). Professional development sessions utilized a text on the arts in early childhood and included whole-group lecture and discussion, demonstrations, small-group and individual hands-on activities, and self-reflection. Educators in this condition also received professional development notes and approximately $500-worth of classroom materials (e.g., books, art supplies, musical instruments).

Classroom observations and math and science learning opportunities— Videotaped classroom observations were conducted prior to the start of the Professional Development phase (March-April 2010) and again during the Implementation phase (i.e., post-professional development; March-April 2011). Classroom observation procedures were similar to those used by Connor et al. (2009). Study staff visited the classroom on a day mutually-agreed upon with the participating educator. Educators were told that we wished to observe the entirety of "instructional time," any time during which they engaged children in instruction or provided learning opportunities. Instructional time could encompass any of the wide variety of activities typical of early childhood classrooms, including whole group activities, small group activities, free choice and center time, circle time, and even meals/snacks for those educators who indicated that they utilized mealtimes as "teachable moments." Observations thus ranged in duration, lasting from 45 minutes to 3 hours and 23 minutes, with an average of 1 hour and 45 minutes. All observations were videotaped using two video cameras, one on a tripod with a wide-angle lens to capture the majority of classroom activities, and one handheld camera to record activity details not otherwise captured on the first camera. At the same time, study staff wrote descriptive notes to provide documentation of classroom activities taking place.

Videotaped classroom observations were coded for math and science learning opportunities using the Early Learning Math and Science (ELMS; Piasta & Miller, 2010) coding scheme. ELMS was specifically designed for this project. It was created by reviewing early learning standards, guidance documents, and research (e.g., National Association for the Education of Young Children & National Council of Teachers of Mathematics, 2002; Ohio Department of Education, 2007; Sackes, Trundle, & Flevares, 2009) to identify an exhaustive list of early childhood math and science topics and learning goals. This information was organized into 18 non-overlapping categories: Numbers and Number Sense, Computation, Geometry, Spatial Awareness, Measurement, Sequencing and Time, and Money for Math; Critical Thinking and Tools, Humans, Animals, Plants, Water, Air, Light, Recycling and the Environment, Magnets, and Seasons and Weather for Science. Using the Noldus Observer Pro 10.1software package, each videotaped observation was coded with respect to the amount of time, in minutes:seconds, that children were involved in learning opportunities in any of these categories. Any formal (e.g., a planned science lesson in which children plant and grow grass seeds) or informal math or science learning opportunity (e.g., an impromptu discussion of how rainbows are formed; a child choosing to work with pattern cards and accompanying blocks during center time) lasting at least 10 seconds was coded; an adult did not need to be present for learning opportunities to be coded. ELMS also captured multiple learning opportunities occurring simultaneously, as might be common in early childhood classrooms (e.g., a small group of children listening to *The Very Hungry Caterpillar* [Carle, 2005] and counting the fruit that the caterpillar eats while other children experiment with objects that float versus sink at the water table). Further details regarding the ELMS coding scheme are provided in Piasta et al. (2014). For purposes of this study, the amount of time spent in math learning opportunities was summed to create a single math composite; the same was done for science learning opportunities.

ELMS coders were systematically trained to ensure high reliability. Coders reviewed the coding manual, received individual instruction on coding content and processes, and achieved at least 85% accuracy on a written test regarding this information. Coders also practiced coding and were required to score 85% exact agreement with a gold standard, master-coded video. Finally, 10% of videos were randomly selected for double-coding as a means of gauging interrater reliability. Reliability was high, as assessed for durations by intraclass correlation (.99 across all categories) and kappa (.99, averaged across categories).

Child assessments—Child assessments were conducted at the beginning (fall) and end (spring) of the Implementation phase, corresponding to academic year 2010-2011. All assessments were conducted by trained research staff. Children were assessed individually at quiet locations at their early childhood centers. The math and science child measures pertinent to the current study are described below.

Applied Problems: The Applied Problems subtest of the Woodcock-Johnson Tests of Achievement III (Woodcock, McGrew, & Mather, 2001) was used to assess children's mathematical problem solving. For young children, the subtest requires basic reasoning and mathematical analysis to solve orally-presented problems that gradually increase in difficulty. Test-retest reliabilities for young children on this measure range from .88 to .94 as reported in the manual; Cronbach's α = .89 for the present sample. Raw scores were used in analyses.

Tools for Early Assessment in Math: The Tools for Early Assessment in Math (TEAM; Clements, Sarama, & Wolfe, 2011) was used to assess children's emerging mathematical understanding. The TEAM is the published form of the Research-Based Early Maths Assessment (Clements, Sarama, & Liu, 2008), an earlier version of which was used in the Preschool Curriculum Evaluation Research program (Preschool Curriculum Evaluation Research Consortium, 2008) and other studies (e.g., Clements et al., 2011; Sarama, Clements, Starkey, Klein, & Wakeley, 2008). It employs manipulatives and an interview format to assess children's growing understandings of mathematical concepts, requiring them to respond to oral prompts or scenarios that tap a number of domains of early mathematical abilities (e.g., number and subitizing, counting, number comparison, number sequencing, number composition and decomposition, adding and subtracting, shape recognition, shape composition and decomposition, congruence). Number sense and mathematical operations are assessed in Part A of the TEAM and geometry is assessed in Part B. Following instructions in the TEAM manual, scores for both parts were combined and converted to the Rasch-based T-scores used in analyses. Item and person reliability for this measure is strong, .99 and .92 respectively, as reported in Sarama, Clements, and Wolfe (n.d.); Cronbach's α = .87 for the present sample.

Core Knowledge Preschool Assessment Tool – Science items: Given the lack of standardized science measures appropriate for young children at the time this project was begun (Greenfield et al., 2009), an adaptation of the Core Knowledge Preschool Assessment Tool (CKPAT; Core Knowledge Foundation, 2004) was used as one measure of children's knowledge of science concepts. The CK-PAT, in its original format, includes assessment activities or probes linked to each of the targeted domains in the Core Knowledge Preschool Sequence and was designed to be used by teachers in their classrooms. For the current study, research staff selected a subset of probes that targeted children's science knowledge and could be adapted for administration in a standardized fashion. Five science probes from the original CK-PAT, each of which included multiple items, were adapted for inclusion. To provide greater coverage of science content, these were supplemented with additional probes designed specifically for this study. The final CK-PAT science assessment consisted of 114 items and targeted children's knowledge of the living world (senses and sensory attributes, body parts, animals and habitats, plants), the physical world (water, air, light, seasons and weather, tools), and causal reasoning, most of which are reflected in Ohio's Early Learning Content Standards (Ohio Department of Education, 2007). Reliability statistics for this measure included an internal consistency of Cronbach's $\alpha = .93$ and test-retest reliability of .84. Moreover, a 1-factor confirmatory factor analysis fit the data well (RMSEA = 0.032, CFI = 0.908, TLI = 0.945), suggesting that all 114 items assessed an underlying construct. Item scores (correct versus incorrect) were thus summed to create a single CK-PAT Science composite for analyses.

Scientific reasoning: An experimental measure of scientific reasoning (Bao & Raplinger, 2010) appropriate for young children was also developed for this study. The measure was created by collaborators with expertise in scientific reasoning who were unaffiliated with the project. The measure presented children with a scenario affording demonstration of probabilistic reasoning (4 items) and hypothesis testing (3 items); sample items are presented in the Appendix. Both the scenario and children's response options were supported with pictures. Initial pilot testing confirmed that the language, length, and response options were appropriate for this age group. Children's item responses were scored as correct or incorrect, and subsequent analysis confirmed that, by the end of the academic year, children provided correct responses at higher-than-chance levels for all but one of the more difficult hypothesis testing items. Cronbach's α for this measure was .21, and it is unclear whether such low internal consistency was due to the small number of items, representation of multiple constructs (probabilistic reasoning and hypothesis testing), or other factors. The total number of correct responses was used in analyses.

RESULTS

Descriptive and Preliminary Analyses

Descriptive information for all variables included in analyses is provided in Tables 1 and 2. Correlations among variables, at both the child and classroom levels, are provided in Table 3.

We first conducted preliminary analyses to examine initial equivalence across conditions. For educators, these analyses were conducted both for the original sample ($n = 65$) as well as for the subsample who continued to participate during the Implementation phase and are thus included in the present analyses ($n = 60$); statistics for the latter are reported as findings were the same for both sets of analyses. Educators did not significantly differ on any variable reported in Table 1 (p-values > .317) with two exceptions. Educators in the math and science condition tended to be employed in inclusion classrooms to a greater extent than comparison educators (*p* = .058). Educators in the comparison condition tended to present more science learning opportunities at the start of the study, prior to any professional development (*p* = .039). It is important to note that this difference arose simply by chance and does not represent selection bias (Shadish et al., 2002); given this finding, amount of pre-professional development learning opportunities was included as a covariate in the analyses described below. Further preliminary analyses confirmed that children did not differ by condition on any variables reported in Table 2.

Impact Analyses

All analyses were conducted using Mplus v6.0 and restricted maximum likelihood estimation. To test our hypothesis that participation in math and science professional development would positively impact the amount of learning opportunities provided by early childhood educators, we regressed math and science learning opportunities on a dummy-coded variable representing condition (1 = math and science professional development, 0 = comparison condition); as noted above, we controlled for amount of learning opportunities provided by educators prior to participation in the professional development. Learning opportunities were modeled as count data, given that these variables followed non-normal distributions. Results indicated a significant impact of professional development on educators' provision of science learning opportunities (coefficient = 1.128, *p* = .005, *d* = 0.62, with *d* computed using the methods for calculating effect sizes with logit-based coefficients described in Chinn, 2000) but not math learning opportunities (coefficient = −0.136, *p* = 0.418, *d* = −0.08).

To test the hypothesis that math and science professional development would positively impact children's math and science learning, we conducted a series of multilevel analyses, one for each of the four child outcomes. Children were nested within classrooms as moderate to large proportions of the variance in posttest scores were attributable to between-educator differences, with intraclass correlations (ICCs) from fully unconditional models ranging from .35 (TEAM) to .56 (CK-PAT). Children's pretest scores on the outcome of interest were grand-mean centered and included as a fixed covariate at level-1, with the dummy-coded condition variable included at level-2; ICCs from these conditional models ranged from .16 (TEAM) to .41(CKPAT). Results indicated no significant impacts of professional development on children's residualized gains on Applied Problems (coefficient = −0.036, *p* = .976, *d* = −0.01), TEAM (coefficient = −0.439, *p* = .795, *d* = −0.08), CK-PAT (coefficient = 4.320, *p* = .626, *d* = 0.13), or Scientific Reasoning (coefficient = 0.092, *p* = .791, *d* = 0.08).

Mediation Analyses

Our full logic model posited that math and science professional development would impact educators' provision of math and science learning opportunities, which, in turn, would impact children's math and science learning gains. We therefore conducted multilevel path mediation analyses, with separate models for each child outcome. Path models included the dummy-coded condition variable, learning opportunities modeled as count data, and children's pretest and posttest math and science scores which were entered as fixed effects and grand-mean centered. A graphical representation of the path model is presented in Figure 1; note that although not depicted, all models also included the correlation between condition and amount of learning opportunities provided prior to professional development. Direct paths are labeled a-e, and the loadings (and significance tests) for each path for each outcome are presented in the corresponding table. Indirect effects of the professional development on children's learning gains, also indicated in the Figure 1 table, were estimated using the method provided by Preacher, Zyphur, and Zhang (2010). Confidence intervals for indirect effects were also estimated using Selig and Preacher's (2008) Monte Carlo method in R to confirm results.

ICCs from the mediation path models (accounting for covariates and condition) ranged from .21 (TEAM) to .43 (Applied Problems and CK-PAT). Model results showed no impact of professional development on educators' provision of math learning opportunities (path a); this path replicates the impact analysis for math learning opportunities described above. Correspondingly, professional development did not demonstrate direct (path c) or indirect effects on children's math learning gains. However, consistent with the previous literature, math learning opportunities were positively associated with children's math learning gains (path b). Children gained approximately 1 point with an additional 15 minutes of math learning opportunities.

Turning to science, path analysis results demonstrated the statistically-significant impact of professional development on provision of science opportunities (path a; again, this path replicates the impact analysis for science learning opportunities). Moreover, although no direct effects on science outcomes were found (path c), professional development showed a significant indirect effect on children's gains in scientific reasoning and similar trend for CK-PAT. In addition, and analogous to the math findings, science learning opportunities were positively associated with children's science learning gains (path b). For the CK-PAT, children gained approximately one point for every additional 3 minutes of science learning opportunities. For scientific reasoning, over an hour of science learning opportunities were required for a corresponding 1-point gain.

In summary, the mediation analyses confirmed the results of the impact analyses, showing no direct impact of professional development on provision of math learning opportunities or children's math or science outcomes, but a significant impact on provision of science learning opportunities. The mediation analyses also extended impact findings by showing (a) an indirect effect of professional development on children's science outcomes, supporting our hypothesis that professional development would lead to greater provision of science learning opportunities and thereby affect children's science learning, and (b) associations between opportunities to learn and child outcomes for both math and science.

Discussion

Building on recent calls highlighting the importance of math and science in early childhood education, as well as the promise of professional development for creating more positive early learning experiences, the present study examined the efficacy of math and science professional development for increasing young children's math and science learning opportunities. Study results indicated that extended amounts of math and science professional development may have an impact on the science, but not math, learning opportunities afforded by early childhood educators. Furthermore, the professional development did not result in large benefits for children's math and science learning, despite associations between learning opportunities and child learning gains. The latter represents one noteworthy finding from this study, which we discuss prior to the effects of professional development.

Math and Science Learning Opportunities and Child Learning Gains

Our results showed consistent, positive associations between math and science learning opportunities and children's math and science learning gains. Although such associations were statistically significant for all child outcomes, we observed substantially weaker associations for the scientific reasoning outcome. The restricted range and limited reliability for this measure provide possible explanations for this finding. Moreover, we note that scientific reasoning may be more complex than the math and science content knowledge assessed via our other measures, in that it requires knowledge integration and use of domain-general strategies (Zimmerman, 2000). As such, more extended or particular types of learning opportunities (e.g., those involving high-level thinking skills) may be necessary to see gains on this measure.

Albeit purely correlational in nature, these associations add to the growing literature indicating links between early childhood learning experiences and child outcomes (e.g., Connor et al., 2006; Howes et al., 2008; Klibanoffet al., 2006; Mashburn et al., 2008) and, to our knowledge, represent the first instance linking science learning opportunities to child outcomes. As a whole, this literature complements causally-interpretable work showing that preschool experiences matter (Campbell, Ramey, Pungello, Sparling, & Miller-Johnson, 2002; Wong, Cook, Barnett, & Jung, 2008) by unpacking how attention to particular aspects of the curriculum relates to children's learning.

Effects of Math and Science Professional Development

The professional development offered in the present study was expected to influence the math and science learning opportunities provided by early childhood educators, as well as the math and science learning of children enrolled in these classrooms. We anticipated positive impacts based on preliminary evidence suggesting benefits of math and science professional development (e.g., Clements et al., 2011; Greenfield et al., 2009; Thornton et al., 2009) and the success of professional development efforts in changing educator practices and child outcomes in other domains (e.g., Hamre et al., 2012; Landry, Swank, Anthony, & Assel, 2011; Landry, Anthony, Swank, & Monseque-Bailey, 2009; Landry et al., 2006; Sarama & diBiase, 2004). We also anticipated positive effects given the high-quality nature of the professional development provided, which was grounded in best practices for both professional development and early childhood education. Consistent with research and professional recommendations (e.g., Garet, Porter, Desimone, Birman, & Yoon, 2001; Guskey, 2003; Kennedy, 1998; National Association for the Education of Young Children, 1993; Wayne, Yoon, Zhu, Cronen, & Garet, 2008; Yoon et al., 2007), the math and science professional development: (a) targeted topics of relevance and importance to the participating educators, (b) focused on building specific content knowledge, including how children learn such content, and linked this to pedagogical applications, (c) stressed active participation and collaboration of all educators, (d) provided opportunities for hands-on practice and self-reflection, and (e) was of sufficient dose (i.e., > 14 hours; Yoon et al., 2007) over a sustained period of time (i.e., 10 days over 6 months, with an additional refresher training the following year). The content of the professional development was also evidence-based, aligned to state and federal early learning standards, and developmentally appropriate for early childhood education.

Nonetheless, our results provide only some evidence that professional development influenced educators' provision of learning opportunities. Specifically, our findings suggest that professional development increased science learning opportunities but that this change led to only a limited corresponding impact on children's science learning. The professional development resulted in no changes in math learning opportunities or children's math learning. Moreover, there was a great deal of variability in the extent to which math and science learning opportunities were provided by educators who experienced professional development, as evidenced by the large standard deviations. Such variability was apparent not only for math learning opportunities, for which we found no significant impact, but also for science learning opportunities. These results suggest that, despite the effect on science learning opportunities, the high-quality math and science professional development provided was insufficient for (a) enacting substantial change in both math and science across all educators and (b) achieving the desired impacts on children's learning.

The lack of change in provision of math learning opportunities, or consistent change in provision of science learning opportunities, may have various explanations, of which we highlight two. First, provision of high-quality professional development does not ensure that content becomes integrated into classroom practices. In the current study, although educators were provided with hands-on opportunities to try new math and science activities during professional development and encouraged to attempt these in their own classrooms in-between sessions, there was no systematic means of ensuring that educators had regular opportunities to apply new content to their classrooms during the professional development phase; the latter is generally recommended when expecting professional development to result in classroom change (Garet et al., 2001). Second, changes in early childhood educators' math and science practices may be difficult to achieve. The emphasis on math and science in early childhood education, including math and science early learning standards, is relatively new, and may require greater amounts of or more intensive professional development than for more established domains given lack of pre-service preparation in these areas (Isenberg, 2000; Lobman et al., 2005), lack of confidence or feelings of inefficacy in providing math and science learning opportunities (Copley, 2004; Greenfield et al., 2009), long-standing mistaken assumptions and misconceptions surrounding math and science education for young children (Ginsburg & Golbeck, 2004; Lee & Ginsburg, 2009), and lower priority often assigned to these domains of the early childhood curriculum (Copley, 2004; Greenfield et al., 2009). As to why, in this particular study, the professional development resulted in significant change for science, but not math, learning opportunities, we can only speculate. Both domains received approximately equal attention in the professional development. Notably, the descriptive statistics suggest that, while only educators who received the math and science professional development increased their provision of science learning opportunities, educators in both conditions increased their provision of math learning opportunities from one year to the next. It may have been the case that math learning opportunities, in particular, were being emphasized in the broader context of early childhood education across the state.

As for the minimal impact on child math and science outcomes, we must acknowledge the possibility that math and science professional development alone does not lead to intended child impacts. Indeed, evidence as to the extent to which professional development translates to child learning gains is mixed (e.g., see Fukkink & Lont, 2007, Yoon et al., 2007). Not only does provision of professional development not necessarily lead to change in classroom practice (e.g., lack of impact on math learning opportunities), but such changes may not be implemented in a high-quality way. In the current study, for example, although educators, on average, implemented more science learning opportunities following professional development, the content or quality of such opportunities may not have been sufficient to impact children's science learning. In addition, the studies offering the strongest evidence of change in educator practices resulting in change in child outcomes paired professional development with a particular curriculum (Arnold et al., 2002; Clements et al., 2011; Greenfield et al., 2009; Peterson & French, 2008). Such work suggests that the presence of a specific scope and sequence, or predetermined series of math or science activities, may provide important supports for educators engaged in changing math and science classroom practices. Although the latter remains an empirical question, continued development and evaluation of math and science curricula are desirable.

Limitations and Conclusion

Five limitations of the present work deserve attention. First, despite best efforts to recruit and retain participating early childhood educators, the current study experienced considerable educator attrition with 22 of 65 educators (34%) withdrawing prior to study completion. The rate of child attrition was somewhat more acceptable, at 22%. Despite evidence that attrition was not differential across conditions and unrelated to the study itself (i.e., largely due to factors associated with general educator turnover in early childhood education; Rhodes & Huston, 2012), along with use of maximum likelihood estimation to maintain maximum sample size, results should still be interpreted cautiously, particularly with respect to external validity. Second, despite random assignment, some evidence indicated group non-equivalence (i.e., educators' employment in inclusion classrooms and pre-professional development provision of science learning opportunities). The initial difference in provision of science learning opportunities, in particular, necessitates replication with an equivalent sample. Third, the two child science assessments were experimental in nature, given the lack of available science assessments at the time that this study was begun (Ginsburg & Golbeck, 2004; Greenfield et al., 2009; Mantzicopoulo, Patrick, & Samarapungavan, 2008), and our scientific reasoning measure, in particular, exhibited low reliability. Future work ought to incorporate standardized science assessments newly-created for preschool, such as those under development by Greenfield and colleagues at the University of Miami. Fourth, the present study was concerned with the extent to which professional development would increase the amount of math and science learning opportunities, as amount of math and science experiences have been emphasized in the literature (e.g., Early et al., 2010; Nayfeld et al., 2011; Thornton et al., 2009) and linked with child outcomes (e.g., Klibanoff et al., 2006). Much less is known about the quality of math and science in early childhood classrooms. Although the limited impact on child outcomes suggests that our professional development did not affect the quality of math or science opportunities provided by educators, future studies might attend to both aspects of quantity and quality. Fifth, the present study does not speak to factors that may have facilitated or inhibited educators' responses to the professional development offered. For instance, educators may have been more interested in learning new ways to incorporate science learning opportunities into their classroom instruction, or educators may have been particularly responsive to a particular professional development leader. With respect to the latter, we are unable to disentangle effects specific to professional development leader in the current study, given that one leader was assigned to each condition. Understanding factors related to change in educators' practices as a result of professional development is a promising and important avenue for future research.

Despite such limitations, the current study is important in responding to calls for increased professional development on math and science for early childhood educators. Our empirical findings yield only partial support for claims that greater attention to these domains will help improve math and science achievement. Although greater attention to math and science was associated with increased math and science learning, our results indicate that the professional development offered in the present study was insufficient to substantially boost children's early learning in these domains. Further research and more substantive efforts are necessary to ensure that children have opportunities to learn math and science from a young age.

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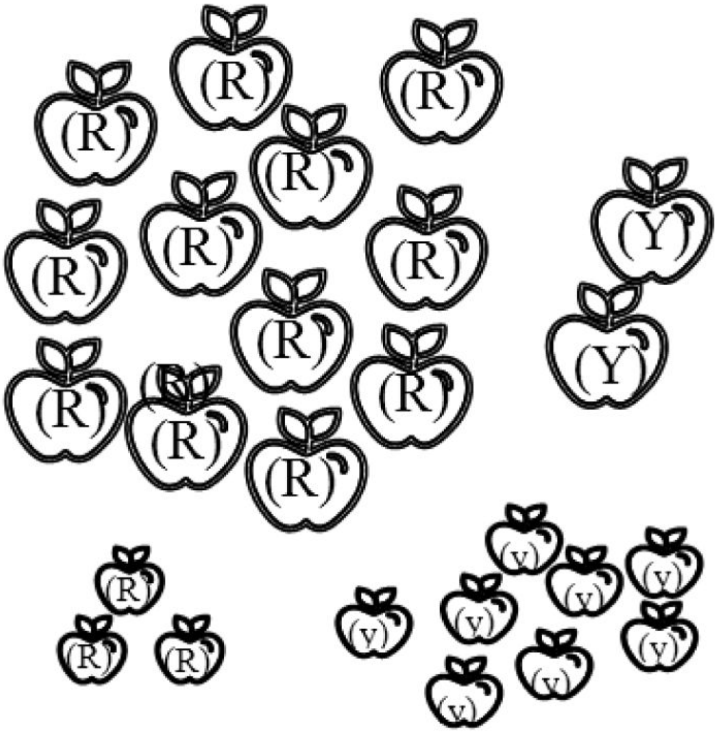
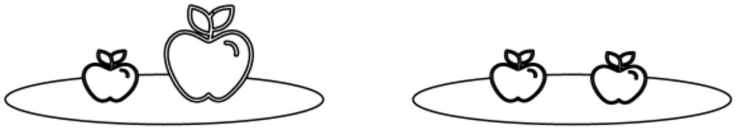
Appendix: Sample Items from the Scientific Reasoning Measure

The assessor says, "We went to the store and bought some apples! Look at this picture. This picture shows the apples that we bought. Imagine that all of the apples were put into a bag." The assessor then shows the child a color graphic, a version of which appears below, depicting apple that vary in terms of size (big and small) and color (red [R in the graphic]and yellow [Y in the graphic). The graphic clearly illustrates that the vast majority of big apples are red. The graphic remains visible for all associated items.



Sample item one: The assessor says, "I close my eyes and reach into the bag to pull out an apple. It feels like a really big apple. Look at the picture of apples that I bought. Now, what color apple do you think I pulled out of the bag? Yellow or red?" The child is able to respond verbally or nonverbally; in the latter case, he or she is prompted to point to a red box or a yellow box.

Sample item two: The assessor says, "Some of the apples are really yummy, but some of them are not. Apples might be yummy because of their <u>color</u> or because of their <u>size</u>…Let's see if <u>big</u> apples or <u>small</u> apples are yummiest. Pretend that you can only taste one plate of apples. This one or this one. Which would you taste to figure out what <u>size</u> apple is yummiest?" The child is shown the graphic below and asked to respond verbally or nonverbally via pointing.



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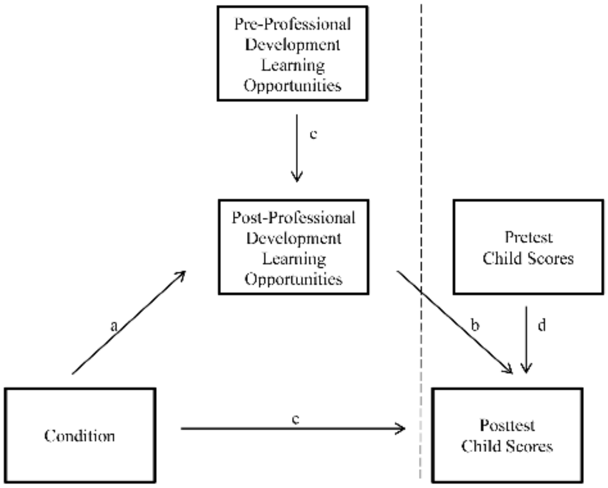

	Math				Science			
	Applied Problems		TEAM		CK-PAT		Scientific Reasoning	
path	Coeff	*p*	Coeff	*p*	Coeff	*p*	Coeff	*p*
a	-0.136[a]	.418	-0.136[a]	.418	1.128[a]	.005	1.128[a]	.005
b	0.067	.004	0.073	.022	0.346	.012	0.015	.009
c	-0.247	.830	-0.766	.638	-2.000	.820	-0.189	.577
d	0.439	<.001	0.582	<.001	0.464	<.001	0.236	.001
e	0.003[a]	.174	0.003[a]	.174	0.015[a]	.001	0.015[a]	.001
Indirect effect	-0.009	.414	-0.010	.426	0.391	.060	0.017	.036

Figure 1.

Graphical representation of the multilevel mediation path model. Dotted line represents the division of between (left of the line) and within (right of the line) educator variance. Correlation between condition and pre-professional development learning opportunities included although not depicted. Condition coded as 1 = math and science professional development, 0 = comparison condition. Coeff = coefficient.

aParameter estimates for path a and path e vary between Math and Science models but do not vary between the two specific child outcomes within Math or Science domains.

Table 1

Educator and classroom characteristics

	Math and Science PD (*n* = 31)		Comparison (*n* = 34)	
	n	**percentage**	***n***	**percentage**
Female	30	97%	32	94%
Race/ethnicity				
White/Caucasian	24	77%	24	71%
Black/African-American	5	16%	7	21%
Other/Multiracial	2	6%	3	9%
Highest degree earned				
High school diploma	5	16%	6	17%
Associate degree	5	15%	8	24%
Bachelor degree	17	55%	16	47%
Master degree	4	13%	4	12%
Held Child Development Associate	3	10%	2	6%
Held state certification	14	45%	12	35%
Taught at center accredited by NAEYC	17	55%	21	62%
Taught at center accredited by state	19	61%	25	74%
Program type				
Head Start	7	23%	6	18%
Public, state-funded	3	10%	2	6%
Religiously-affiliated	6	19%	9	27%
Private	15	48%	17	50%
Length of day				
Half-day program	5	16%	3	9%
Full-day program	15	48%	22	65%
Mixed	7	23%	6	19%
Length of program				
4-5 days per week	14	45%	14	41%
2-3 days per week	2	7%	1	2.9%
Mixed	15	48%	19	56%
Classroom population				
Non-inclusion	9	29%	18	53%
Inclusion	17	55%	13	38%
Primary curriculum				
Creative Curriculum	15	48%	21	62%
Innovations	5	16%	4	12%
Kid Sparkz	2	7%	2	6%
Creating Child-Centered Classrooms:				
Step by Step	0	0%	2	6%
Locally-developed	9	29%	5	15%

	M	**SD**	**Range**	***M***	***SD***	**Range**
Age (years)	37.87	12.08	20 - 61	41.09	11.49	22 - 61
Early childhood teaching experience	9.61	8.04	0 - 34	11.22	8.40	0 - 25
Class size[a]	17.14	3.88	9-25	17.91	4.60	12-34
Pre-professional development						
Total observation duration (minutes)	99.40	37.42	47 - 203	103.06	38.03	45 - 188
Math opportunities (minutes)	26.61	29.04	0 - 120	22.54	21.83	0 - 79
Science opportunities (minutes)	19.33	18.87	0 - 77	32.70	28.39	0 - 102
Post-professional development[b]						
Total observation duration (minutes)	107.25	21.14	62 - 167	110.81	22.83	81 - 183
Math opportunities (minutes)	38.72	21.86	2 - 84	43.07	23.48	5 - 97
Science opportunities (minutes)	42.10	36.19	1 - 174	25.05	25.91	0 - 106

Note. Percentages may not sum to 100% due to rounding or data that were unreported.

[a] Class size was unreported for 13 educators.

[b] Post-professional development data were available only for 43 educators (23 math and science professional development, 20 comparison) who participated through the end of the study.

Table 2

Child characteristics

	Math and Science PD (*n* = 191)		**Comparison** (*n* = 194)	
	n	**percentage**	***n***	**percentage**
Female	88	45%	87	46%
Ethnicity				
Hispanic/Latino	11	6%	11	6%
Race				
White/Caucasian	130	68%	135	70%
Black/African-American	37	19%	34	18%
Other/Multiracial	15	8%	17	9%
Maternal education (highest degree earned)				
<High school diploma	8	4%	4	2%
High school diploma	45	24%	40	21%
Associate degree	13	7%	8	4%
Bachelor degree	61	32%	71	37%
Master degree	37	19%	45	23%
Doctoral degree	26	14%	23	12%
Additional language(s) spoken at home				
Spanish	6	3%	7	4%
Other	19	10%	13	7%
Yearly family income level				
≤$25,000	45	24%	35	18%
$25,001 - $50,000	23	12%	23	12%
$50,001 - $75,000	16	8%	15	8%
>$75,001	101	53%	115	60%

	M	***SD***	**Range**	***M***	***SD***	**Range**
Age (years)	51.20	5.95	36 - 64	51.65	6.19	36 - 64
Pretest						
Applied Problems, raw score	12.16	4.57	1 - 24	12.32	5.04	0 - 25
Applied Problems, standard score	107.82	12.19	67 - 134	107.91	13.47	72 - 147
TEAM, T-score	3.46	14.16	−44 - 37	5.08	15.05	−44 - 39
CK-PAT science, raw score	78.18	14.90	28 - 106	80.38	16.19	0 - 105
Scientific Reasoning, raw score	4.17	1.46	0 - 7	4.40	1.39	0 - 7
Posttest[a]						
Applied Problems, raw score	14.41	4.77	0 - 25	14.94	4.77	3 - 26
Applied Problems, standard score	108.17	12.63	60 - 139	109.17	12.59	79 - 136
TEAM, T-score[b]	10.84	14.97	−44 - 40	12.69	15.32	−44 - 59
CK-PAT science, raw score	85.97	13.15	39 - 107	88.43	12.69	43 - 110
Scientific Reasoning, raw score	4.24	1.51	0 - 7	4.37	1.26	1 - 7

Note. Percentages may not sum to 100% due to rounding or data that were unreported.

[a] Due to withdrawals, the sample size for posttest measures was 301 (150 math and science professional development, 151 comparison).

[b] TEAM posttest t-scores represent 293 children: 8 children were missing data due to their raw scores falling below 3, for which a t-score could not be computed. Children with missing t-scores were equally distributed across the two conditions, χ^2 (1, N= 301) < .01, p = .992, and the pattern of results was replicated when TEAM raw scores were analyzed rather than t-scores.

Table 3

Correlations among variables

	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**
1. CK-PAT pretest	–	.891	.312	.436	.876	.867	.798	.768	.185	.252	.114	.234	−.080
2. CK-PAT posttest	.828	–	.355	.348	.861	.911	.766	.820	.218	.219	.053	.181	−.064
3. Scientific Reasoning pretest	.149	.145	–	.351	.346	.375	.242	.394	.121	.182	−.070	.026	−.185
4. Scientific Reasoning posttest	.155	.185	.082	–	.365	.377	.326	.304	.187	.257	.243	−.007	.024
5. Applied Problems pretest	.663	.641	.097	.183	–	.864	.813	.775	.132	.220	.070	.187	−.023
6. Applied Problems posttest	.599	.656	.041	.100	.620	–	.759	.885	.164	.155	.150	.275	−.050
7. TEAM pretest	.715	.667	.173	.131	.612	.569	–	.733	.133	.102	.086	.224	−.031
8. TEAM posttest	.695	.732	.020	.128	.613	.701	.640	–	.174	.113	.072	.306	−.084
9. Condition	.000	.000	.000	.000	.000	.000	.000	.000	–	.089	−.100	−.267	.264
10. Math opportunities pre-PD										–	.162	−.075	.000
11. Math opportunities post-PD											–	.227	−.117
12. Science opportunities pre-PD												–	.259
13. Science opportunities post-PD													–

Note. Correlations within classrooms listed below diagonal. Correlations between classrooms listed above diagonal. PD = professional development.