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Integrating STEM into Preschool Education; Designing a Professional Development Model in Diverse Settings

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Abstract
High quality early childhood education and science, technology, engineering, and mathematics (STEM) learning have gained recognition as key levers in the progress toward high quality education for all students. STEM activities can be an effective platform for providing rich learning experiences that are accessible to dual language learners and students from all backgrounds. To do this well, teachers need professional development on how to integrate STEM into preschool curricula, and how to design experiences that support the dual language learners in the classroom. To address this need, a professional development model was designed to empower preschool educators to provide rich, high-quality STEM learning experiences, with particular emphasis on working in schools serving children from culturally and linguistically diverse backgrounds. This model was created based on best practices in adult learning and teacher professional development, on developmentally appropriate STEM concepts and teaching interactions, and in collaboration with educators to design professional supports that were responsive to their needs. We worked in under-resourced communities in a North East state in the United States to design a model that is culturally appropriate, and that is flexible enough to be implemented within any curricula and with a variety of materials. In this article, we outline the main components and the iterative design process we undertook to ensure that the professional supports are relevant and effective for teachers and children. Finally, the article presents feedback from educators who participated in the design and implementation of the model, as well as discussion of how our process can inform other teacher educators and those interested in promoting early STEM in diverse preschool settings.

Keywords Professional development · Early childhood · STEM · Teacher education · Preschool · Dual language learners · Coaching

Introduction

Researchers, policy makers, and educators around the world have increasingly focused on the positive benefits of high quality early childhood education on children's ongoing development (Bertram and Pascal 2016; Campbell-Barr and Bogatić 2017; Friedman-Krauss et al. 2018). One lever that has been identified to significantly contribute to young children's later school achievement is early science, technology, engineering, and mathematics (STEM)[1] knowledge and skills (Morgan et al. 2016; Watts et al. 2014). Rich early STEM experiences can provide rich content with which to engage all students, including dual language learners (DLLs)[2] (Lee 2005).

Researchers have studied international trends and strategies, and identified elements of effective professional development that enable and empower educators to create rich learning experiences (Blank et al. 2007; Wei et al. 2009;

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[1] Technology and engineering can be conceived as being a part of the larger umbrella of science (National Research Council 2012). We include the full STEM acronym here because we intentionally weave aspects of each throughout our approach.

[2] Dual language learners (DLLs) are "children learning two (or more) languages at the same time, as well as those learning a second language while continuing to develop their first (or home) language" (Administration for Children and Families and U.S. Department of Health and Human Services 2013; National Academies of Sciences, Engineering, and Medicine 2017).

Zaslow et al. 2010b). Studies show that early childhood educators rarely receive in-depth professional preparation in math and science, resulting in insufficient content knowledge and lack of confidence in their own abilities to implement high quality STEM learning experiences for young learners (Brenneman et al. 2009; Greenfield et al. 2009). This article will outline our efforts to employ evidence-based elements of effective professional development for early childhood educators into a professional development model that focuses on STEM. We aim to positively influence preschool teachers' attitudes and beliefs, increase STEM knowledge, and improve teaching practice in schools serving students from low-SES homes, with a large population of dual language learners. While our research takes place in the United States, the design strategy and elements of effective professional development are based on principles relevant to all researchers working with educators in settings that support diverse families.

Background

Mathematics skills at kindergarten entry predict later math and reading achievement (Duncan et al. 2007; Watts et al. 2014) and general knowledge of science and social studies predicts later math, reading, and science achievement (Morgan et al. 2016; Grissmer et al. 2010). Many children, however, do not get the rich preschool STEM experiences that could influence their school readiness and ultimate school success. Few planned or spontaneous math and science learning experiences occur in preschool classrooms (Brenneman et al. 2009; Ginsburg et al. 2008). Farran and colleagues report that during a 6-h day, less than one minute was dedicated to mathematics, and some children showed a *decrease* in math skills from the beginning to the end of the year as a result (Farran et al. 2007; Varol et al. 2012). Further, math lessons that do happen often are not high quality (Brown 2005; Graham et al. 1997; National Mathematics Advisory Panel 2008; Stipek 2008). Supports for science learning are equally sparse; teachers spend little time engaged in either planned or spontaneous science-relevant activities (Tu 2006) and rarely visit the classroom science area, if one exists, during children's free choice time (Nayfeld et al. 2011).

Globalization has had a profound effect on immigration, and thereby the diversity of the student population in the education systems worldwide (Spring 2008; Vallet 2007). In the Unites States, an increasing number of young students speak a language other than English at home (García and Frede 2010; Friedman-Krauss et al. 2018), and almost half of all English language learner (ELL) students are concentrated in grades pre-K to three (Matthews and Ewen 2005). This calls for a clear need for teaching practices that effectively support diverse students in ways relevant to their language and culture (Richards et al. 2007; Friedman-Krauss et al. 2018). By integrating the child's native language into instruction and providing appropriate feedback, teachers can leverage a young dual language learner's (DLL's) home language as a strength, rather than as a challenge to be overcome (Castro et al. 2011; Cheatham et al. 2015; Tabors 2008). Studies that focus on DLLs have found that students can benefit greatly when their teachers know how to support their specific needs (Hendricks 2014; Méndez et al. 2015; Zepeda et al. 2011). However, most teachers are not professionally prepared to use effective strategies that invite dual language learners to engage with academic content in meaningful ways (Administration for Children and Families and U.S. Department of Health and Human Services 2010).

Language, math, and science skills for preschoolers are enhanced by participation in high quality, comprehensive, sustained math and science learning experiences (Clements and Sarama 2011; French 2004; Peterson and French 2008). Positive effects of combining science teaching and supports for DLLs have been found for upper grades learners (see Lee 2005 for a review). Rich early science and math experiences have both been found to benefit language and literacy as well as STEM learning in linguistically diverse, low-income populations (Fantuzzo et al. 2011; Sarama et al. 2012). Supporting teachers in integrating STEM into their preschool curricula can be a lever to create a rich learning environment that is accessible to all students in the classroom.

Preservice educational programs, however, tend not to adequately prepare preschool teachers in how to support learning of math and science content and process skills or in how to support DLLs (Anthony and Walshaw 2007; Buysse et al. 2005; Perry et al. 2007). Early childhood teachers report lacking confidence in teaching math and science (Copley and Padrón 1999; Greenfield et al. 2009) and uncertainty about how to best work with young DLLs (Freedson 2010). Some teachers believe that math is not as important as literacy in preschool (Ginsburg et al. 2008), report that they need to focus on literacy and social-emotional learning instead of science (Greenfield et al. 2009), and express discomfort with incorporating children's home languages into their teaching (Espinosa 2010; Freedson 2010; Garcia and Rodriguez 2000).

One critical step to improve outcomes for children, then, is to improve supports for their teachers so that educators are empowered to provide high quality STEM experiences in preschool. Teachers deserve resources and professional support to address the possibility of negative attitudes and beliefs about STEM, to increase their knowledge, and ultimately, to improve their teaching practice. Our project was designed to fill this gap in effective, high quality professional development that supports early childhood teachers to teach STEM and work with DLLs in their classrooms in ways that are engaging, developmentally appropriate, and educative.

The design of our model was informed by extant literature on high quality, effective professional development efforts that impact classroom practice and child outcomes (Design-Based Research Collective 2003; Drago-Severson 2009; Wei et al. 2009; Zaslow et al. 2010b). The content of the professional development is based in research on children's development of STEM-relevant concepts and thinking skills and on effective pedagogical techniques for teaching STEM to all learners, including DLLs. Specifically, the intention of the work is to address teachers' beliefs, knowledge, and practice around STEM learning, provide teachers with rich content and pedagogical strategies that make STEM accessible to all preschoolers, and support preschool teachers so they may confidently and successfully incorporate rich STEM experiences in their classrooms and into their support of the diverse students in their classrooms. Our hope is that our model can serve as an example to other researchers and practitioners interested in teacher education and professional development around early childhood STEM and supporting diverse learners in all settings.

SciMath-DLL Professional Development: Three-Component Model

Our model, SciMath-DLL, was built on a theory of change that aims to impact children's STEM learning by fostering changes in participating teachers and their instructional interactions with children. The SciMath-DLL professional development model accomplishes this through three main components: (1) Workshops, which deliver content to a large group and support content learning and development of teaching strategies in hands-on small group learning experiences, (2) Reflective coaching cycles, which provide individualized coaching, goal-setting, and feedback, and (3) Professional learning communities/workgroups, which bring together teachers and district coaches in small groups to discuss a common problem of practice. These components are described in this section to give the reader a framework of the model. They are contextualized in the subsequent section as part of the description of each intentional aspect of our professional development design.

Workshops

Four whole-day workshops are planned across the school year to deliver modules that focus on a particular math or science concept (e.g., geometry; senses as tools for observation). During each workshop, teachers are given an overview of the research and best practices pertaining to that topic as well as science and engineering practices, relevant content knowledge, and concrete implementation strategies. After our early workshops, teachers asked for more-hands on activities. Our team responded by developing small group learning experiences (SGLEs), or model lesson plans, that are part of every workshop and that provide "something to do on Monday" with children. The activities were intentionally designed to use materials already present in a preschool classroom, materials easily found at home, or those inexpensively purchased. Now in each SciMath-DLL workshop, teachers engage in small group experiences based on these plans and plan together how to implement the activities in their classrooms.

Reflective Coaching Cycles

The second component of the SciMathDLL model is reflective coaching, designed to follow the reflective coaching cycle protocol (Costa and Garmston 2002; Riley-Ayers and Frede 2009). Following each workshop, participating teachers implement a STEM lesson based on one of the model lessons provided and practiced during the workshop. All materials, books, and steps are listed in the model lesson guides, along with suggestions for modification to fit the teachers' available resources, students' needs and interests, and to differentiate instruction. During the research project, any specific materials beyond those typically found in a preschool classroom needed for the lesson were provided for each teacher. The district coaches are encouraged to support teachers in planning this lesson. During the development process of the program, a member of the research team works together with the district coach to facilitate a reflective coaching cycle. This serves to model research-grounded practices for district coaches as well as to create ongoing sustainability of the program beyond the participation in the research project.

The coach and a member of the research team with science, math, and/or DLL expertise then come and observe this learning experience. After lesson implementation, teacher and coach each complete a brief reflective evaluation of the lesson. The teacher, the district coach, and a member of the research team meet together to reflect on the lesson. The conversation starts with the teacher's self-assessment of their instructional practices during the observed lesson. The team then reflects on what went well and what could be improved using specific evidence from the implemented lesson. Using the teacher's completed self-evaluation, teacher and coach set objectives for improvement. Following up on this, the coach conducts future classroom observations, models teaching practices, and provides resources to support the teacher. Observation notes and teachers' written self-reflections are reviewed by the coach and teacher and become the focus of future coaching. A SciMath-DLL research team member co-coaches alongside the district coach, providing support

Table 1 Research-based features of professional development model

1.	Includes ongoing, educator-driven design
2	Includes supporting coaches
3	Builds teachers' content knowledge
4	Attends to teachers' attitudes and beliefs
5	Engages with teachers at multiple levels (large group, small group, and one-on-one)
6	Is connected to classroom practice
7	Involves educators reflecting on practice, with feedback
8	Creates a community of practice
9	Is sustained and long term
10	Is individualized

for science and math content and pedagogy as needed. Focused cycles are scheduled every 4–6 weeks.

Professional Learning Communities

Every 6–8 weeks, a member of the SciMath-DLL research team, a district coach, and 6–8 teachers from the same district gather to form a professional learning community, or a teacher workgroup. These meetings last for about an hour and focus on a teaching or learning issue on which one or two teachers would like feedback. Workgroups follow a specific protocol. The teacher who is presenting first shares some background information about her students and presents the areas or questions on which she wants feedback. After teachers ask clarifying questions, the presenter shows a video clip of a math or science learning experience that was offered in her classroom. Teachers and coaches have 2 min to write down thoughts and suggestions, subsequently sharing them with the group. Discussion and debriefing conclude the meeting.

Research Foundations

The SciMath-DLL model used research-grounded best professional development practices to guide the design of the model, the content of the workshops, and the structure of the support and resources for coaches and teachers. Table 1 summarizes the ten key intentional features of high quality professional development reflected in our approach. In the section that follows, we describe each of these features, and how they are accomplished, in more detail.

Ongoing, Educator-driven Design

In SciMath-DLL, we encouraged buy-in of our partner school districts by soliciting their support and involvement from the start. We invited administrators in each district to join a design group that worked to advise on each aspect of the model including duration of professional development supports, feasibility in their district, and content. Original members of the design group were drawn from three school districts and included an assistant superintendent, a principal, each district's early childhood education supervisor, an early childhood coach from each district, and a teacher from each. Our goal was to co-create a professional development model that, while intensive, would nonetheless be practical for use in real districts and schools. Administrator and teacher voices were critical to meeting this goal. This project was developed over the course of 4 years. The first year of the project was spent designing the professional development under the guidance of the design group and implementing small-scale pilots of initial workshops and reflective coaching and learning community protocols. While we found that administrators soon pulled back their participation, the teachers and coaches participating in the design group and the pilot gave extensive feedback. This feedback and the research team's observations were the key drivers for revisions to the model prior to implementation the next year. During implementation in years 2 and 3, we kept in regular contact with the administrators and they were invited to attend all professional development events. We collected feedback from coaches and teachers through surveys, reflections, and conversations throughout the project to improve the usefulness of resources. In year 4, the project was implemented with a new cohort of coaches and teachers, drawn from the same three districts, using materials and resources designed based on the work over the last 2 years.

To ensure that the project was informative and enjoyable for teachers and sustainable for districts, we relied on teachers' feedback to make adjustments and revisions that made participation more feasible and useful for the teachers. Valuable aspects of our program emerged as a result of seeking and incorporating this feedback. For example, during the first year of implementation, participating teachers requested more hands-on activities. As a result, we re-designed subsequent workshops evolved to include small group learning experiences (SGLEs) that gave teachers direct practice with implementing and discussing a group of conceptually connected learning experiences (such as three lessons about shape or three about change and transformation). These experiences provided opportunities to learn about children's understandings of these concepts and to think about pedagogical techniques, but they also gave teachers lessons that could immediately be used in the classroom with young learners. The SGLEs blended theory and pedagogy with teachers' practical need to engage children in meaningful learning experiences every day. Participating in hands on learning also made the workshops more active and engaging. Co-creating the model with educators and incorporating feedback was critical to the ultimate success of SciMath-DLL. One educator reported that she was pleased that the research team had "really listened to [educators'] constructive feedback" in revising our approach.

Supporting Coaches

Professional development for early childhood educators is more successful and effects are sustained when the model includes ongoing coaching and support for teachers beyond the involvement of the researcher and the timeline of the intervention (Poglinco et al. 2003; Rudd et al. 2009; Zaslow et al. 2010a). SciMath-DLL supports district coaches alongside the teachers at every point of the intervention. Coaches attended the workshops, participated in hands-on practice during the small group learning experiences, and supported as they worked with teachers to implement the STEM/DLL activities in their classrooms. During the reflective coaching cycles, the research team member worked alongside the coach, to model best coaching practices as documented in the reflective coaching cycle and other literature on coaching (Costa and Garmston 2002). At first, the researcher structured the reflective coaching meetings to ensure that coaching was consistently aligned with best coaching practices. Over the course of the project, the district coaches gradually took the lead in guiding the reflective coaching conversations. The capacity of coaches (and the researchers) was also strengthened through conversations between the researcher and coach that occurred before and after each meeting with a teacher.

Support for coaches was also provided during additional meetings for district coaches and the research team, explicitly planned to provide coaches with extra resources and to discuss coaching strategies. Combined, these efforts build capacity within district coaching staff and contribute to sustainability beyond the researchers' involvement in the school district. Further, the co-coaching alongside the district coach and the additional conversations and meetings provided valuable information about tools that are most helpful to coaches in supporting their teachers in enacting high-quality STEM experiences. Through this collaboration, the research team became aware of topics and resources around STEM content and pedagogy that would enable future district coaches and school leadership to faithfully and effectively enact this program outside the scope of the researcher-led intervention.

Building Teachers' Content Knowledge

Teachers' lack of content knowledge is an obstacle reported in implementation of early education programs in both mathematics (Anthony and Walshaw 2007; Perry et al. 2007) and science (Roehrig et al. 2011). Understanding content is related to the development of pedagogical content knowledge (Smith and Neale 1989). Teachers' PCK for math is related to gains in children's math learning (Hill et al. 2005; McCray and Chen 2012), which means that helping teachers develop pedagogical content knowledge will help their students learn.

During workshops and throughout the coaching cycle, our goal was to build content knowledge that is deep and lasting. We tried to avoid the pitfall of including content that is a "mile wide and an inch deep" by including a select group of topics but exploring them deeply over time (National Research Council 2000; Tout et al. 2006). The topics covered during workshops are listed below in Table 2. The math content for SciMath-DLL resources reflects recent position statements for early mathematics learning (National Research Council 2009; Clements et al. 2002; National Council of Teachers of Mathematics 2006) that call for introducing teachers to children's abilities across a range of mathematical skills. For science, our approach reflected recommendations that teachers should learn about children's knowledge and reasoning skills in the broad content areas associated with state standards and curricula for preschool science, as well as the science practices required to study science content: observing, describing, comparing, questioning, predicting, experimenting, reflecting, and cooperating (Greenfield et al. 2009; National Research Council 2006). The topics covered were chosen based on national and state math and science standards for early childhood, as well as previous work in developing STEM interventions by the authors. Each workshop module is one of two types: those that focus on foundational ideas (e.g., using the senses as tools to observe the world; basics of two-dimensional shapes in geometry), and those that are illustrative of particular STEM content and its integrations or links with other domains (e.g., DLLs and change; measurement in the garden).

Addressing Teachers' Attitudes and Beliefs

Negative attitudes and beliefs about math and science certainly contribute to the lack of math and science learning experiences observed in preschool classrooms. Although little research has addressed the actual math and science competencies of early childhood educators, many report lacking confidence in their abilities to teach these subjects and a belief that these are hard to incorporate when literacy and social-emotional learning should take precedence in preschool (Copley and Padrón 1999; Greenfield et al. 2009). Others might hold the idea that math and science are not appropriate for preschool children (Platas 2008).

Providing sustained, connected, in-depth professional development experiences can lead to changes in attitudes and beliefs about STEM and issues impacting DLLs (Copley

Table 2 Workshop topics

Foundational experiences in STEM		STEM across the curriculum	
Title	Concept(s)	Title	Concept(s)
Senses are tools for observation	Science: Life/physical science	DLLs, language strategies, and change	Science: Physical science (change/transformation of matter)
Introduction to number	Math: Number, subitization, counting	Exploring science journals	Science: Documentation; change in seasons
Introduction to geometry	Math: Geometry	Form and function in the garden	Science: Physical science, engineering, technology
Exploring water	Science: Physical science—properties of water; sink & float	Measurement in the garden	Math: Measurement, technology
Exploring movement	Science: Physical science—physics of movement, Engineering	DLLs, vocabulary, and Sorting	Math: Sorting; data analysis
Beyond the weather chart	Science: Earth and space science & technology	Patterns	Math: Patterns
Operations	Math: Operations/arithmetic/number composition		
Comparing/ordering/estimating	Math: Comparing/ordering/estimating		
Animals' adaptations	Science: Life science—animal adaptations		

and Padrón 1999; Espinosa 2010). SciMath-DLL addressed these issues by introducing educators to research findings about attitudes and beliefs and their effects on teaching and learning and by fostering explicit conversations about our teacher collaborators' attitudes about science and math. Further discussion occurred during coaching and PLC interactions. We planned workshop learning activities that linked to familiar preschool activities, such as block building and making play dough, to illustrate that teachers were already doing science and math in their classrooms and that these could be effectively enhanced to support more domains of development and learning and to do so in a way that was appropriate and accessible for young children.

Preschool teachers report that they do not have time to teach science and math because of competing requirements, such as socioemotional and literacy concerns (Ginsburg et al. 2008; Greenfield et al. 2009). Science and math can actually help *improve* language and literacy. One approach to teaching early math that encouraged teachers to use and ask children to use rich vocabulary and verbally explain their reasoning positively influenced both children's math and language skill (Sarama et al. 2012). Likewise targeted science curricula can support language readiness (French 2004; Greenfield et al. 2009) and other readiness areas such as approaches to learning, creative arts, and math (Brenneman 2014; Fuccillo 2011; Greenfield et al. 2009).

SciMath-DLL explicitly introduces math and science as content for students to think, talk, read, and write about. Science and math content words are often uncommon words. Exposure to uncommon vocabulary words (such as *rhombus* or *chrysalis*) predicts vocabulary development, which predicts reading achievement (Strickland and Riley-Ayers 2006). Math teaching that incorporates math books can enhance learning for children (Casey et al. 2008; Flevares and Schiff 2014). Strategies for using science journals and STEM books to support the growth of both literacy and STEM skills were incorporated into the first SciMath-DLL workshop (Brenneman and Louro 2008).

Levels of Engagement

Professional development workshops with large groups serve to introduce and disseminate ideas and strategies to all participating educators. In practice, this is often the extent of the dissemination of new content—teachers must then take whatever they learned and do their best to apply in to their classrooms (Wei et al. 2009). However, such workshops can only skim the surface of the topic and its application to practice. High quality professional development models present information and facilitate discussion and interaction at multiple levels—large group, small group, and individual (Sarama and diBiase 2004). Like younger students, adult learners benefit when the same, or related, content is presented and repeated in several formats; this allows the learner to engage with the material and build understanding in a deeper way. To this end, each of the three components of SciMath-DLL engage educators at a different level.

Workshops are created for all participating educators in the district or districts to come together to introduce each module and facilitate discussion across all participants. The reflective coaching cycle creates a component of individual support; the district coach and the teacher come together to individualize the content from the workshop to her students and curriculum. The professional learning communities bring participants together in small groups to discuss and build further on the concepts covered in the workshops and the teachers' experiences with enacting them in their classrooms.

Connecting Content with Classroom Practice

Early childhood interventions that are effective combine delivery of content with direct practice in implementing the content learned in the classroom (Zaslow et al. 2010a). In-service professional development for teachers is often delivered in short, one-time workshops, without sufficient chance for practice, observation, or follow-up; this violates best practices for adult learning and does not lead to sustained changes in practice (Donovan et al. 1999; National Research Council 2000). The SciMath-DLL model gives teachers hands on practice with teaching the content during the workshops as well as after the workshop in their own classrooms. During a workshop, the topic is first introduced, and time is spent unpacking why it is important, what it is, and how to teach it. Teachers are then introduced to three different small group learning experiences, each paired with a model lesson plan, as part of each workshop—these experiences deal with the topic being discussed and are designed to build children's experience with that content in a hands-on way over time. During the second half of the workshop, teachers engage in each learning activity in a small group based on the model plans, and then discuss how to implement it in their classrooms. As teachers participated in and talked about the rich STEM activities such as making orange juice or mixing ingredients to make play dough, they also discussed specific ways that dual language learners were supported by using props and emphasizing actions, and saw from their own experience how exploring and experimenting with materials would lead to interest and inquiry.

SciMath-DLL was purposefully designed as a flexible professional development approach that could be connected to and integrated with the curriculum that teachers were already implementing (Sarama and diBiase 2004). Further, we wanted the activities to be actionable across classrooms in all settings. The program took place in schools that were in under-resourced settings. While classrooms had materials required by state standards, neither the school nor the teachers had abundant resources to spend on elaborate equipment or new materials. We took this into account when designing the model lesson plans; while the activities did often require some extra materials to implement, an effort was made to design experiences using things easily found in the teacher's home (e.g., a piece of clothing with a pattern on it for a lesson on Patterns) or local grocery store (e.g. oranges for orange juice for a lesson on Change and Transformation), with suggestions for alternate materials or modifications. We also provided materials for the chosen activity to be observed for each participating classroom.

In the weeks following each workshop, coaches and teachers work together to plan how these small group learning experiences could be integrated into the existing curriculum and schedule and to schedule observation of one of these lesson implementations. The lesson is then observed by a coach and/or someone with science, math, and/or DLL expertise (for purpose of the development of SciMath-DLL, both the district coach and a member or the research team observed the lessons). Reflective, one-on-one coaching is crucial for teachers to successfully translate information from out-of-class workshops to the classroom (Poglinco and Bach 2004). Teachers, together with their coaches, reviewed their teaching and grounded next steps in the content and relevant teaching practices presented at the workshops.

Reflecting on Practice

The reflective coaching and the professional learning communities were both designed to give educators the time and space to reflect on their practice. Professional development models found to be effective in impacting classroom practice include coaching as a component that is crucial for teachers to successfully translate information from out-of-class workshops to the classroom (Poglinco and Bach 2004; Russo 2004). During the reflective coaching cycle, the teacher, her district coach, and member of the researcher team met to reflect on the lesson that was observed that day. When possible, the lessons were videotaped by the coach and then reflected upon during the coaching meeting. Research suggests that watching a video of their own teaching allows teachers to observe themselves objectively, reflect more deeply, and analyze their own practice (Dymond and Bentz 2006; Gün 2010). This component of the model creates a framework in which teachers and coaches purposefully reflect on their practice and work together to use that reflection to make further improvements. The conversation starts with the teachers' self-assessment of their instructional practices. The team then reflects on what went well and what could be improved using specific evidence from the lesson. After these reflections, teachers and coaches set objectives for improvement and a plan to implement these in an upcoming lesson. This reflective coaching takes place every 4–6 weeks throughout the year.

Reflection is also a key component of the professional learning communities that bring teachers together to reflect together in small groups. The goal of these meetings is to create a structured space and time for teachers to reflect on, and share, their experiences in bringing the STEM concepts into their teaching. Over the course of the project, teachers found it helpful to share the videos of themselves teaching with each other during these group meetings. By sharing their practice with others and discussing their reflections, teachers become aware of their own strengths and reflect on how to further improve their students' educational experiences.

Creating a Community of Practice

Professional development approaches that include opportunities for teachers to collaborate in teacher work groups or professional learning communities are effective because they allow teachers to work together on shared problems of practice and provide learning opportunities that are highly relevant to teaching practice (Ballenger 1992; Ball and Cohen 1999; Bambino 2002; Vescio et al. 2008). Participation in professional learning communities has been shown to exert a positive impact student achievement (Kiggins 2016). This third aspect of the SciMath-DLL model, the professional learning communities, accomplish just that; they bring teachers and district coaches together in small groups to discuss experiences and receive peer support, with a member or the research team as a facilitator. For SciMath-DLL, these meetings focus on a particular teaching or learning issue on which one or two teachers would like feedback. Teachers get a chance to show a video of their lesson, and then hear about other teachers' approaches to the same lesson. Through these regular meetings, teachers get to know each other and form relationships with colleagues, creating lasting support systems that can be sustained beyond the intervention.

Sustained and Long-term

Implementation of the SciMath-DLL model was designed to last at least one full year, preferably two, and included three main kinds of professional development supports. This model addresses best practices in early childhood education professional development that call for intense, sustained and classroom-based approaches (Tout et al. 2006; Loeb et al. 2007; Ryan et al. 2004). SciMath-DLL was designed to respond to recommendations that professional development for mathematics and science must move beyond 1-day workshops and into models that allow teachers to explore content and pedagogy deeply (Clements et al. 2002; Sarama and diBiase 2004). These approaches can lead to better teacher attitudes about math, broadening of the content addressed in the classroom, and positive learning outcomes (Copley and Padrón 1999) and teacher attitudes and knowledge about bilingual acquisition can be improved through sustained, in-class coaching (Espinosa 2010).

Individualization

Several researchers have found that self-reflection and individualization of support is central to improving teaching (Gallacher 1995; Neuman and Wright 2010; Zaslow et al. 2010b). Individualization of professional development is intentionally supported by the SciMath-DLL model's use of flexible model lesson plans that teachers are encouraged to adjust based on their curricula, their children's interests, and their learning needs. The reflective coaching cycle described above facilitates individualization by providing teachers with direct coaching to create their lesson, carry it out, and then reflect on it together with their coach. Evidence suggests that this component is important as some teachers struggle to translate information from out-of-class meetings to the classroom (Poglinco and Bach 2004). As a part of the reflective coaching cycles, we encourage videotaping teachers engaged in STEM lessons because video allows teachers to reflect on their practice away from the intensity of the teaching moment (Tripp and Rich 2012; Zhang et al. 2011). Over the course of the RCC, teachers get individualized feedback from both the district coach and a member of the research team. Importantly, each teacher works with the same coach and team member to build relationships, set goals, and allow for a sustained progression of support for the teacher.

Feedback and Response

The following section presents preliminary qualitative data that document the effects that participation in SciMath-DLL had on teachers. Further qualitative and quantitative effects, and effects on children are currently being analyzed. The focus of this article is to present a model of STEM professional development that purposefully enacts best practices in professional development. Initial feedback and response from participants suggests that educators responded positively to the overall model, and to each of the three components. Two cohorts of educators participated in this project; 25 lead preschool teachers and four master teachers in years 2 and 3 as Cohort 1, and 19 lead teachers and four master teachers in year 4 as the second cohort. Teachers' experience was recorded over the three implementation years in multiple ways: data sources included feedback documents for the workshops, reports from each observation and reflective cycle from each teacher, district coach, and researcher, minutes and records from the design group, minutes from end-of-year meetings, anecdotal reports, and surveys from external project evaluators. Meetings were audio recorded and transcribed.

Feedback demonstrates that SciMath-DLL had a positive impact on teachers and their experience as participants. All of the master teachers and 81% of teachers in cohort 1 reported that they had observed or experienced a specific

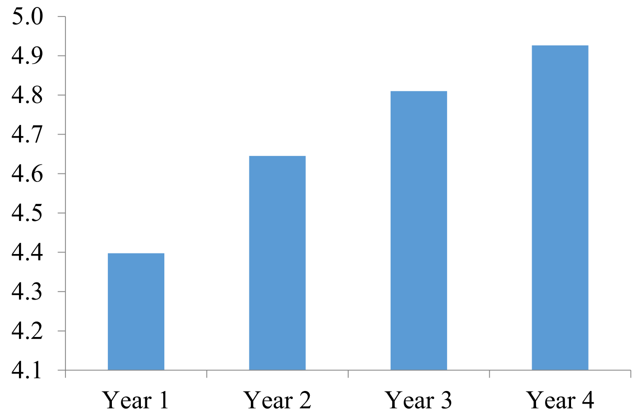

Fig. 1 Average workshop rating out of 5 by project year

change in their science and/or math teaching that can be directly attributed to the SciMath-DLL project. Of cohort 2 respondents to an external evaluator survey, 95% rated the overall project to be "very beneficial" in providing better strategies for teaching science and math to dual language learners. One teacher noted, "I truly value the way the program has challenged my perspective on teaching science. It's refreshing to have solid examples about the way science is around us. This allows our students to become permanent observers of the world around them." (educator, external evaluation survey, year 2). Another teacher from cohort 1 commented, "I am a different teacher now. This experience changed the way I teach science and math and my students are now science and math kids."

Workshops

After every workshop, teachers were asked to fill out a feedback survey where they rated positive statements about the workshop on a 5-point Likert scale. Ratings ranged from 1—strongly disagree to 5—strongly agree. Questions were designed to assess how helpful the participating educators found the workshop they just attended. Questions varied based on the content of the workshop but included such questions as "The (workshop) introduction gave me some ideas about how to modify my questioning according to students' language or comprehension ability" and "The small groups encouraged me to think about the mathematical learning trajectories of my students." The workshop ratings for the first ScIMath-DLL workshop (average over 3 days) was 4.3, with a range of 1–5. The total average rating for the final three days of workshops (spaced out across year 4) was 4.9 out of 5, with a range of 4–5 (Fig. 1). While we certainly might have improved naturally as providers of professional development workshops over years, we attribute the improvement in ratings to the integration of educator feedback into the workshop model.

External evaluator survey data showed that the workshop component was very popular with the overwhelming majority of participants. In cohort 1, 95% of teachers responded "very" to the question, "How important is it to continue this (type of) support for your own teaching in this area?" in relation to workshops. In cohort 2, 100% of respondents rated workshops as "very beneficial" to their teaching." Comments from workshops were overwhelmingly positive, with such feedback as: "Enjoyed every minute of workshop. Hands-on activities are helpful to me as we share and gather info to bring back to our classrooms." (educator, workshop feedback, year 2).

Reflective Coaching Cycles

The observations of STEM lessons by the district coach and the individualized reflective coaching meetings that followed resulted in positive changes noted by both coaches and teachers. One coach said, "I could truly see a distinct change in the teachers I was working with immediately following each coaching session. It not only made the teachers feel more confident, but they demonstrated that the feedback we shared was constructive as they often applied the suggestions given." (district coach, year-end survey, year 4). Teachers also commented on the value of reflection: "It's amazing how much I learn just talking about what just happened, and not focusing on what went wrong, but just what worked, and what could be tweaked for next time. I think that it's so important." (teacher, design group, year 2)." One teacher noted that she learned about her teaching by reflecting that she needs, "…to keep lessons short and concrete." (teacher, reflective coaching cycle, year 3). Some teachers started to break science activities into smaller pieces and to build on them throughout the week over the course of participating in our professional development (workshop observation notes, year 2). "At this time [after 2 years of participation in SciMath-DLL], I go one step at a time; I make sure that my students understand little by little, not like before. I used to plan activities that have a little of everything and it was a little confusing for them." (teacher, external evaluation survey, year 3).

In response to an external evaluator survey question about the importance of maintaining the reflective coaching sessions in the model, 84% of cohort 1 and 78% of cohort 2 agreed this feature was "very important" to include. In response to a workshop for the district coaches that focused on reflective coaching, one coach noted that, "…it was great to see examples of supportive feedback that was more thoughtful and specific. The example of poorly done feedback was also a good reminder of what not to do." (coach, workshop feedback, year 4). One coach commented, "This project has really helped me understand the true meaning of the reflective cycle…it made me understand and be more clear what my role is...” (coach, design group, year 3).

Classroom observations that form part of the reflective coaching cycle have allowed teachers to see the math and science in what they already do. One teacher said that she was not sure how to incorporate science into her classroom, but when the research team observed her teaching, it became clear that she was doing science (researcher, informal visit notes, year 2). The teacher was using a read-aloud of *The Three Little Pigs* as the jumping off point for small group learning experiences about the different materials used for building the houses and the relationship between the type of material and the ease of blowing it down. Children in her class were trying to blow the items across the table to try it out themselves. The teacher's prior understanding was that science required an experiment (researcher, reflective coaching cycle observation notes, 2012).

Another impact on teachers' behaviors was on teaching style with respect to the tendency toward teacher-directed instruction rather than child-directed instruction. One district coach observed one of her teachers early in the project who "…seems a little tentative to encourage children to talk or respond too much—much of the lesson was teacher directed. She mentioned in the conference that she recognizes that it can be good to hear their thoughts, but potentially isn't sure how to let this happen without the activity getting out of control." (district coach, reflective coaching cycle, year 2). In a classroom with similar issues that tended to be teacher-directed and dominated by adult talk early in the first year, district coach noted changes after participating in SciMath-DLL. By the end of the year in this classroom, the teacher spoke less, and the children said and participated more (district coach, reflective coaching cycle, year 2).

Preliminary evidence shows that teachers learned to incorporate research-based supports for DLLs in their classrooms. For example, coaches observed that teachers added lessons to reinforce shapes through multisensory activities and differentiated lessons for DLLs, which were based on activities from our workshops. (coach, reflective coaching cycle, year 4). Teachers also added home language supports (coach, reflective coaching cycle, year 3), and introduced books in the students' home language before introducing them in English to build the students' background knowledge and to expose them to new vocabulary (teacher, reflective coaching cycle, year 3).

Professional Learning Communities

A protocol for professional learning communities/educator workgroups already existed in the state and was available on the state's Department of Education website. However, these workgroups were not implemented systematically and teachers and coaches participating in SciMath-DLL had not had experience learning about or using the precise protocol. In response, we provided additional experience using the professional learning communities protocol in the initial kick-off workshop for cohort 2. While we cannot be certain that the additional support was the cause, ratings from teachers about the clarity of the professional learning community model and goals overall increased from those of cohort 1 (4.3 out of 5) to those of cohort 2 (4.8 out of 5).

The protocols for these meetings were individualized for each particular center or site based on the needs of the participating teachers. In one district, teachers asked to add time at the end of the session for everyone to debrief together. This time was not part of the original protocol. Teachers reported that the revised format that was individualized for a site was effective. In response to an external evaluator survey of participants following year 3 implementation, 95% of respondents answered "very" or "moderately" when asked "How important is it to include this support if the program is expanded to other districts?"

Discussion

SciMath-DLL aims to improve STEM teaching in preschool classrooms by creating a three-part, high quality professional development model that delivers science and math content knowledge, addresses teachers' attitudes and beliefs towards science, and highlights evidence-based practices for early childhood education and education of DLLs. This model was designed to fill the need for STEM professional development, and supports for teachers of dual language learners, in a way that uses research foundations and best practice for adult learners and educator professional learning.

The ten best practices of professional development that underpin this model are: (1) includes educators and administrators in the ongoing design; (2) includes supporting coaches; (3) builds teachers' content knowledge; (4) attends to teachers' attitudes and beliefs; (5) engages with teachers at multiple levels (large group, small group, and one-on-one); (6) is connected to classroom practice; (7) involves educators reflecting on practice, with feedback; (8) creates a community of practice; (9) is sustained and long term; and (10) is individualized. We worked together with educators to create and revise the model over the course of 4 years, ensured that training built capacity of coaches, addressed attitudes and beliefs as well as content knowledge and practice, linked content to practice, created a learning community, allowed room for reflection and individualization, and supported teachers in a sustained, multi-level approach, Based on feedback from participating educators, the final SciMath-DLL model that emerged met the goal of providing high quality STEM professional supports while simultaneously being practical to implement, enjoyable, and useful to educators and their practice.

Implications and Future Directions

This paper was written to outline what it looks like to design a professional development model that is research based, collaboratively created, and realistic when put into practice in settings serving diverse learners. Teacher professional development that focuses on high quality science and math teaching and intentional support for DLLs can support educators in creating effective early childhood education programs for all children, and in particular children from low-income, culturally and linguistically diverse homes. It is our goal to bring attention to STEM teaching and education that supports all children, including DLLs, and to provide a foundation that informs other similar ventures and guide development of STEM interventions that benefit educators and children across various contexts and populations.

To build on the findings presented, we will explore patterns in educators' descriptions of the perceived value of the model and for evidence of positive changes in practice. We will use what we learned from this 4-year study to inform an expansion of SciMath-DLL resources, tools, and procedures. New research and development activities will include the design of online, asynchronous coaching supports that would enable teachers to video-record themselves teaching, and would allow coaches, researchers, and teachers to reflect at a time that is convenient for them rather than requiring schedule coordination. We will also develop online versions of our workshop modules.

Along with developing a broader suite of SciMath-DLL supports, SciMath-DLL is being evaluated as part of a randomized control trial. This trial allows us to study effects on classroom quality and teaching practices, and to measure changes in educators' content knowledge, knowledge of child development in math and science, and attitudes and beliefs about teaching science and math and teaching DLLs. Student learning outcomes in mathematics and science will be assessed to determine whether gains in readiness in these domains occur and, if so, whether they do so without compromising instructional quality and language and literacy learning in Spanish and English (Barnett et al. 2007).

Conclusion

The SciMath-DLL model was designed to address a need for stronger professional learning opportunities for early childhood teachers to integrate rich STEM experiences, and experiences that support DLLs, in preschools serving underserved and diverse families. We considered best practices when designing the professional development model and followed these to create and then revise its three dimensions. The ongoing partnership with educators throughout the design and iteration process led us to collect feedback and revise our approach accordingly. In turn; teachers and district coaches were very satisfied with the resulting model and reported that each of the three main components were enjoyable and beneficial for their practice. Ongoing research is testing the effectiveness of the model for changing teacher attitudes, beliefs, and teaching practice and for improving learning for their students.

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CORRECTION

Correction to: Integrating STEM into Preschool Education; Designing a Professional Development Model in Diverse Settings

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The original version of this article unfortunately contained a mistake in Funding section. Some of the vital information is missing in the published article. The complete funding information is presented with this erratum.

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