Examining the Effect of Combining Mathematics and Science Professional Development on Teachers' Mathematical Knowledge for Teaching and Quality of Instruction.

Dionne Cross Francis, dicross@indiana.edu
Meredith Park Rogers, mparkrog@indiana.edu

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Abstract

This study examines ways in which participation in a dual-focused (math and science) PD compared to a math only PD influences elementary teachers' mathematical knowledge for teaching and quality of instruction. Targeting the development of *Mathematical Knowledge for Teaching* and Science *Teacher Professional Knowledge and Skill*, the integrated PD model draws on an iterative approach that includes four research-based PD activities. The results from three different data sources indicate the dual-focused PD facilitated growth in both math content knowledge and student's mathematical thinking compared to the math only PD, with notable differential impact on teachers' knowledge of students' mathematical thinking. Additionally, teachers in the dual-focused PD on average improved on two more indicators of high-quality teaching than teachers in the other PD. Implications for leveraging science teaching approaches to support quality math instruction and how to design teacher education and PD programs to support elementary teachers will be discussed.

Problem

Although science and mathematics are separate and distinct disciplines, the approaches to teaching children core concepts in each share important similarities. In addition to the notion that mathematics problems can be situated meaningfully in science contexts and vice versa, supporting students to acquire disciplinary knowledge in both necessitates engaging students in investigations of phenomena (NCTM, 2001); developing knowledge through experience, enabling children to test their own ideas (Harlen, 1993); encouraging generalizations across contexts; supporting students in communicating their own ideas (NRC, 2012). In this regard, there is enormous potential for supporting teachers by designing professional development that foregrounds these principles (Park Rogers et al., 2007). Leveraging the similarities of the two disciplines, while acknowledging the distinctions, we engaged teachers in a professional development (PD) program designed to support elementary teachers in developing the specialized knowledge to teach both mathematics and science. In this study, we specifically focus on the ways in which participation in this PD influenced teachers' mathematical knowledge for teaching and quality of instruction in comparison to teachers who were involved in PD solely focused on math.

Professional Development Approach and Research Design

To deliver high-quality instruction encompasses a wide range of knowledge and skills considered specialized and unique to the work of teaching. Building on Shulman's (1986) notion of pedagogical content knowledge (PCK), researchers and teacher educators in both fields have expanded our ideas of what we conceptualize as the essential knowledge needed to teach the core content of the discipline successfully. Mathematics educators, Ball and colleagues (e.g., Ball, Thames, and Phelps, 2008; Hill, Ball, & Schilling, 2008) refined Shulman's categories by encapsulating this knowledge under the umbrella of mathematical knowledge for teaching (MKT) and further subdividing content knowledge and pedagogical content knowledge (PCK). As defined by Ball and colleagues, Common Content Knowledge (CCK) refers to mathematics knowledge that is common to individuals across professions. Specialized Content Knowledge (SCK) on the other hand, represents subject matter knowledge and skills that are unique to the work of teaching, and therefore is not commonly used in those ways by most other professionals (Ball et al., 2008). Knowledge of Content and Students (KCS) represents a combination of knowledge of the subject matter with knowledge about how students engage with that content. Knowledge of Content and Teaching (KCT) refers to knowledge of the content combined with knowledge of ways to teach that content (Hill et al., 2008). KCS and KCT are the aspects of mathematical knowledge for teaching that aligns most closely with Shulman's concept of PCK. These aspects of teacher professional knowledge also align with Gess-Newsome's (2015) description of topic-specific professional knowledge for teachers of science. Topic-specific knowledge is a core level of knowledge described within the Teacher Professional Knowledge and Skill (TPK&S) model that bridges the theoretical and content knowledge teachers attain in preparation programs, to their actual practice of teaching science. Although named differently, we see significant overlap in the two teacher professional frameworks used in our disciplines of mathematics and science education. As such, we designed the PD program that drew from the research that identifies core aspects of successful PD (see Garet, Porter, Desimone, Birman & Suk Moon, 2001) and extended it to provide teachers support in their day-to-day activities of teaching science and math.

Dual-focused Professional Development Model

The study involves participants from two year-long professional development programs. The first, the ITQ project, was math-focused and included the activities described below. The second, the PIMSII project, was math and science focused and included the activities described below focused on the two disciplines. Table 1 shows the different dimensions of knowledge for science and math and the activities we designed to support the teachers in developing this knowledge. Teachers in ITQ engaged in about 104 hours of math PD while teachers in PIMSII engaged in an integrated PD consisting of 72 hours of math and 72 hours of science.

Content sessions. Each morning of workshop days we began with a Morning Math session. In these sessions teachers worked on problem solving activities for an hour. The problems selected did not resemble the typical problems in the school curriculum; rather, they represented *true* problems meaning "situations for which a procedure for solving the problem is not readily at hand" (p. 38, Lester, 1987) and can be extended to lead to generalizations (Schoenfeld, 1994). Following this session, teachers participated in elementary science activities that integrated the three dimensions of learning as noted in current reforms (NRC, 2013).

Table 1. *Comparing dimensions of teacher knowledge with PD activities*

Dimensions of Mathematical Knowledge for Teaching	Dimensions of Science Teacher Professional Knowledge & Skill	PD Activities
Common Content Knowledge	Teacher Professional Knowledge (Content)	Content Sessions: • Morning Math • 3-dimensional science learning (i.e., content, practices, and crosscutting concepts)
Specialized Content Knowledge	Topic-Specific Professional Knowledge	TPK&S/MKT Sessions
Knowledge of Content and Students	Teacher Professional Knowledge (Content & Students) Student Outcomes	Coaching Sessions TPK&S/MKT Sessions Video Discussions
Knowledge of Content and Teaching	Topic-Specific Professional Knowledge in action in Classroom Practice	Coaching Sessions TPK&S/MKT Sessions Video Discussions

MKT and TPK& S sessions. Sessions focused on teachers developing the necessary knowledge and practices to (a) improve their own instruction, and (b) support their teaching colleagues in inquiry-based science and mathematics; and, learn teaching strategies that align with the mathematical and scientific practices and foreground students' thinking and reasoning in planning for instruction.

Video discussions. These conversations used video clips of the teachers' instruction with the goal of identifying aspects of instruction that support and hinder students' thinking and how to attend to them appropriately. Discussions of students' thinking involved the teachers watching clips of their own students' responses to math problems or scientific phenomenon with the goal of building knowledge of students' misconceptions and understanding the trajectory of students' thinking about particular mathematics and science concepts.

Coaching. The professional developers served as coaches. Coaching cycles involved a 3-step process: i) teacher-coach pre-planning of a lesson, ii) teaching of the planned lesson which is videotaped, and iii) teacher-coach collaborative post-lesson reflection driven by the data from the videotaped lesson.

Research Study Design

The study included 15 participants from the ITQ project and nine teachers from the PIMSII project. All participants were elementary teachers from eight schools across three school districts. The following three data sources were gathered from all participants and analyzed for the study.

Learning mathematics for teaching (LMT) instrument. The LMT Instrument includes items that measures teachers' content knowledge (CCK) and knowledge of content and students (KCS).

Interviews. Teachers were asked about their experiences as participants in the PD programs.

Mathematical quality of instruction (MQI) instrument. This instrument provides scores for teachers on four core dimensions (subdivided into 17 attributes) of classroom mathematics instruction. This instrument provides a good measure of teachers CCK, KCS, SCK and KCS as enacted in instruction. Eight minutes of the most meaningful mathematical activity was selected from an instructional video of each teacher and scored using the MQI instrument.

Analysis and Findings

Results from LMT

Differences in scaled scores from pre and post tests for both groups were calculated for Knowledge of Content and Students (KCS) and Common Content Knowledge (CCK). Differences in pre to post scaled scores for KCS were not statistically significant ($t=0.978$, $p=0.340$). However, the effect size for PIMSII is noteworthy (0.32) but the effect size for ITQ was not substantive (-0.01). The participation in PIMSII supported substantial changes in teachers' KCS which were notably different than the minimal changes participation in ITQ yielded.

An independent t-test showed that gain scores for CCK were not statistically significant ($t=0.170$, $p=0.867$). However, the effect size for PIMSII and ITQ are noteworthy (0.51 and 0.57). The difference in effect sizes is not substantial (0.06). These findings suggest that both interventions were useful for supporting notable changes in CCK. However, there was not a significant difference in the impact of the two PD programs on CCK.

Table 2. *Scaled scores for the pre and post MKT assessment*

	MKT			
	KCS		**CCK**	
	Pre Yr1	Post Yr 1	Pre Yr 1	Post Yr 1
ITQ (n=13)	0.41	0.39	-0.15	0.41
PIMSII (n=9)	-0.23	0.10	-0.73	-0.22

Results from Interviews

Teachers in PIMSII group when interviewed spoke about the ways the organization of the program to include science supported their teaching. When asked about the ways in which the program supported her teaching, Natasha B mentioned that she was now less frustrated and anxious. A core reason being that she was now able to challenge her students as she now had access to meaningful math and science activities. She also mentioned that being able to make connections in science supported the students in making connections with math. She explained,

> There was this idea they [her students] wouldn't be able to do it [solve challenging problems]. Then you know, [I] challenged the kids and they were able to step up to the plate so the program really did help as far as the activities - we duplicated those a lot. With science they liked doing the experiments and coming up with questions…and they were making connections to the world. One activity they liked was poison [math activity] so we would start with that sometimes and you know after a while they were able to start [asking questions] and making connections like in science.

Science can provide context for meaningful exploration of mathematical ideas. Teachers in the dual-focused PD also noted the science PD activities reinforced for them Math practices and teaching.

Results from MQI

Eight minutes of two instructional videos [one prior to the start (T0) of the PDs and another towards the end of the first year (T1)] from each teacher was scored using the MQI. We identified dimensions where there was an increase, decrease and those that remained the same from T0 to T1. For both groups each teacher had an increased score on at least one attribute. On average, for ITQ teachers increased scores on approximately six attributes and for PIMSII, teachers increased scores on approximately eight attributes by at least one level.

Discussion of Contribution

Findings showed that teachers who participated in PIMSII had noteworthy changes in both CCK and KCS. However, only changes in KCS were substantially different from the changes in ITQ. While the dual-focused PD facilitated growth in both CCK and KCS, results show a notable differential impact on teachers' KCS. Additionally, related to the quality of mathematics instruction, teachers in the PIMSII group improved on two more attributes on average than teachers in the ITQ group. These results suggest having the opportunity to consider how to unpack content knowledge, students' misconceptions and ways of thinking across two distinct but complementary disciplines seemed to support teachers in expanding and enhancing their understanding of students' mathematical thinking (broadly conceived), effective mathematics teaching approaches and enact them with differentially higher quality than teachers who only engaged with these ideas in discipline-specific ways. Implications include considerations for how we can better leverage science teaching approaches to support quality math instruction and how to design teacher education and PD programs to support elementary teachers. In other words, should ***S***te***M*** (with a strong focus on math and science) PD be emphasized over discipline-specific PD?

Potential for Partnership with UW SOE Faculty

We view the potential for a partnership with University of Warsaw education faculty as being symbiotic in nature. With greater global competitiveness in preparing students for STEM associated careers (Committee on STEM Education & National Science and Technology Council, 2013) there is a need for supporting teachers in all contexts with the knowledge and skills for constructing learning experiences that naturally integrate core disciplinary ideas and practices shared across STEM subject areas. We believe our Dual PD model, which focuses on the integration of two core aspects of STEM – science and mathematics, demonstrates one such method. Our evidence shows that through careful and purposeful integration of mathematics and science content and pedagogy that teachers knowledge for teaching mathematics can improve. Considering these results, we would be interested in collaborating with faculty in both mathematics and science education to offer PD on the design and implementation of our Dual PD model; reciprocally, we are interested in learning from UW faculty what efforts they are making with integrating STEM teaching and learning for the purpose of further enhancing our model.

References available upon request