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4.7 Six Years Of Measuring Effects Of Professional Development On Mathematics Knowledge For Teaching: Reflections On The Process Of Evaluation

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4.7 SIX YEARS OF MEASURING EFFECTS OF PROFESSIONAL DEVELOPMENT ON MATHEMATICS KNOWLEDGE FOR TEACHING: REFLECTIONS ON THE PROCESS OF EVALUATION

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Introduction

The professional development of mathematics teachers should reflect the design and implementation practices noted in research to be effective such as the exploration of mathematics and student thinking through the inquiry process and collaboration among teachers, leaders, and administrators through a sustained, coherent professional development program (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). This is generally the format for mathematics teachers' professional development associated with the Texas Regional Collaboratives (TRC) within a Mathematics and Science Partnership (MSP) project. Each year, 20 to 26 TRC mathematics projects recruit 20 to 50 teachers from different schools, districts, and grade levels within the same geographic region. Teachers explore content that may or may not be an expectation of the grades they teach, and teachers often engage in content for the purpose of improving their own mathematical knowledge. A unifying feature of these projects is that they involve a two-tier system of teacher development focused on building teacher leaders (Teacher Mentors) who in turn work with local teachers (Cadre Members). All projects share a similar content focus each year, and project leaders collaborate together to learn about the delivery of research-based professional development and to consult with one another about their practices. Close relationships with state leaders allow these projects to get firsthand information on legislation and implementation of mathematics standards and integrate state-mandated training with the projects' other Professional Development (PD) programs.

This chapter discusses the process of designing meaningful internal evaluation aimed to answer the question, "*What is the relationship between teachers' Mathematics Knowledge for Teaching (MKT) changes and TRC professional development experiences?"* MSP guidelines require projects to report on teachers' content knowledge, instructional change, and student achievement and the guidelines strongly encourage a scientific research design. However, most projects are led by individuals whose primary concern is the delivery of professional development and they possess limited research background. The TRC internal evaluation serves to support these projects by collecting data on the number of teachers served and professional development hours delivered as well as evaluating the project success in improving content knowledge, instruction, and student achievement.

Professional Development Program Design

Project leaders within the TRC participate in a common set of professional development experiences that they deliver in turn to their teachers. Each leader customizes the professional development sequence for their teachers to meet local needs, and all projects share a common goal of improving teacher content knowledge in the area of algebra. Each project's design reflects best practices for the delivery of professional development and observes a common structure of intensive long-term professional development. Teachers within each project receive support and guidance to develop their leadership skills through mentoring other teachers in their local schools and districts throughout the year. Project leaders meet twice a year to share successes and challenges and to further develop their own professional development skills.

TRC Math Teacher Mentors (MTMs) participate in a minimum of 100 professional development hours in one year. Teachers participate in 1- to 2-week summer institutes, and teachers are supported throughout the year with follow-up and complementary professional development. The TRC utilizes a mentoring model that encourages teachers to become leaders in their schools. Mentees are called Cadre Members (CMs). In a typical program year, Collaboratives within the TRC serve approximately 700 teachers at the MTM level and 5,000 teachers at the CM level. The distribution of mathematics teachers (both MTMs and CMs) in a typical program year are approximately 45% elementary school teachers, 25% middle school teachers, 20% high school teachers, and 10% administrators and mathematics coaches (Fletcher, 2012)

Teacher leaders for the TRC are professional development specialists who also serve as project directors, instructional team members, or are outside consultants. The strength of the TRC professional development is the experienced project leaders who teach the professional development. Data from the state reports indicate that in 2012-2013, there were 235 teacher leaders who led 8-hour to 40-hour events. Of those, 50% were mathematics specialists, 21% were master teachers or coaches in mathematics, and another 20% were university professors. Nine percent of the teacher leaders specialized in other disciplines such as science and behavior management.

Teacher professional development is an avenue to help students learn complex and analytical skills necessary for the 21st century. Available research offers very little guidance about how to design and implement PD for particular purposes in particular kinds of situations (Horizon Research, 2010). Darling-Hammond and Richardson (2009) suggested that professional development programs in the past have not been very effective in promoting needed outcomes. However, there is a potential to positively influence student outcomes when teacher professional development focuses on student learning and pedagogical content knowledge (Blank & de las Alas, 2009).

Each year, the TRC offers Professional Development Academies (PDAs) designed to increase leaders' capacity to deliver high-quality effective professional development. Participation in state-level project meetings and PDAs provides opportunities to learn to use strategies described in research on effective professional development practices. These practices include the study of children's work, designing curriculum, solving mathematics problems, engaging in mathematics discussion, and providing coherence between implementing effective teaching practices and state standards (Garet, Porter, Desimone, Birman, & Yoon, 2001). The trainings listed in Table 1 include state-developed PD and nationally developed PD. The PDAs offered to project leaders through the TRC are part of a coordinated effort with the state to provide coherent, high-quality, research-based instruction to teachers.

Table 1

Professional Development Academies Taken by Project Leaders 2008-2011

Professional Development	Content Focus	Researched /Reported Effective
Children's Thinking in Measurement	Measurement	X
Fostering Algebraic and Geometric Thinking	Algebra, Geometry	X
TEXTEAMS Institutes	Algebra, Math Models	
Math State Standards, Assessments, and Curriculum	All	
Assessing Children's Thinking	Fractions, Whole Number Computation, and Algebra	X
Developing Mathematical Ideas	Whole Number Operations, Base Ten, Algebra	X
Young Mathematicians at Work Series	Whole Number Operations, Fractions and Decimals	X
Lesson Study	General	X
Journaling	General	
Supporting ESL Students	General	

Theoretical Framework

The National Council of Teachers of Mathematics (NCTM) established standards for the professional development of mathematics teachers (NCTM, 1999). The council contended that professional development should focus on six standards, four of which parallel recent findings on effective PD (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet et al., 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007): (a) knowing mathematics content and school mathematics, (b) knowing students as learners of mathematics, (c) knowing mathematics pedagogy, and (d) developing as a mathematics teacher.

Little (1987) defined professional development as "any activity that is intended partly or primarily to prepare paid staff members for improved performance in present or future roles in the school districts" (p. 491). However, professional development is often viewed as being fragmented, on a need basis, and relatively superficial (Loucks-Horsley, et al., 2003). Researchers have suggested that there should be longer, extended professional development programs that have a meaningful focus on content (Garet et al., 2001).

Teachers' content knowledge makes a difference in the quality of instruction (Ball, Thames, & Phelps, 2008; Hill, Rowan, & Ball, 2005; Mewborn, 2003). The Math Science Partnership Knowledge Management and Dissemination (MSP-KMD) project (Horizon Research, 2010) is a meta-analysis of studies on mathematics teachers' content knowledge published since 1990. For all studies, the authors conclude, "Based on a number of research studies identified in a large-scale literature review, teachers' mathematics content knowledge makes a difference in their professional practice and their students' achievement" (Horizon Research, p. 1).

Mathematics Knowledge for Teaching components emphasize the mathematics taught and acknowledge that teachers may know and use mathematics differently from what is necessary in other professions (Ball et al., 2008). Previous studies have established the importance and specialized nature of teachers' knowledge (Leinhardt & Smith, 1985; Shulman, 1987). Mathematics education researchers in the past 10 years or so have strived to define what counts as content knowledge needed for teaching mathematics (Ball, Lubienski, & Mewborn, 2001). Loosely, Mathematical Knowledge for Teaching (MKT) is specific mathematical knowledge needed to do the work of teaching. For example, teachers need to know a variety of strategies to solve problems and how to evaluate their generalizability. Hill et al. (2005) categorized this knowledge into subcategories, and subsequently, developed and tested assessment items that would account for teachers' MKT (Hill, Schilling, & Ball, 2004). Their results from the MKT assessments given to elementary mathematics teachers showed that teachers' MKT scores are positively correlated to student achievement. The correlation was statistically significant, and they found that mathematics content knowledge makes a difference even for primary elementary teachers.

Professional development can support the development of teacher knowledge (Hill & Ball, 2004). Effective professional development is that which has a positive effect on student achievement (Bell, Wilson, Higgins, & McCoach, 2010; Loucks-Horsley et al., 2003). Professional development activities that may improve teachers' knowledge and skills range from formal, structured, topic-specific workshops to informal discussions in hallways. Factors contributing to effective PD include the quantity and quality of the professional development and the increase in teachers' content knowledge (Guskey & Sparks, 2002).

Data Sources

TRC projects had similar goals, similar guidelines, and the leaders of these programs had similar experiences through TRC and state PDAs. Our data includes teacher demographics, professional development program descriptions, and math knowledge for teaching assessments. MTM characteristics are found in Table 2. Each year, projects were required to enter data detailing their professional development activities. Each entry included a title and description, content addressed, instructor name(s), the number of hours for each event, and names of teachers who attended. These data could then be exported as needed and could be sorted by project name and connected to teachers' names. Projects also were assessing teachers' content knowledge using a similar instrument. The Learning Mathematics for Teaching assessments, developed for the Study of Instructional Improvement at The University of Michigan, were used to capture teachers' MKT (Ball et al., 2008). Depending on the content focus of the professional development programs, different forms were administered to teachers.

Table 2

Characteristics of 2011-2012 Math Teacher Mentors (n=583)

Item	Teachers (%)	Number of Teachers
Gender		
Female	91	531
Male	9	52
Teacher Ethnicity		
White	72	420
Black	8	46
Hispanic	17	99
Other	3	18
Teaching Level		
Elementary	37	215
Middle School	34	199
High School	25	145
Other (e.g., Math Coach)	4	24
Education		
B.A./B.S.	75	437
M.A./M.S.	24	140
Other (e.g., Ph.D.)	1	6

All of the assessment data comes from the Patterns, Functions, and Algebra form for Middle School because it was the most common assessment given and the focus of the TRC projects was algebra with an emphasis on middle and high school teachers. Project leaders administered the assessments before the program year began and after the last program day. Only MTMs took the pre- and post-assessments, since MTMs received the majority of the professional development. Scores were reported as Item Response Theory (IRT) scores, which meant that each score was represented by a position on a scale from -3.00 to +3.00. Only teachers with both pre- and post-assessment scores were included in the analysis. Assessments of MTMs' mathematics knowledge for teaching consistently showed significant positive gains in content knowledge with effect sizes ranging from 0.16 to 0.46 (Cohen's *d* calculated for the years between 2008 and 2012). These data can be seen in Table 3.

Table 3

Assessment Gains by Effect Size and Year

Program Year	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**
Projects	13	14	13	14
Teachers	293	323	299	366
Effect size	0.16	0.30	0.46	0.32

The interpretation of effect size for Cohen's *d* suggests that an effect size of 0.2 is a low effect, 0.5 is a medium effect, and 0.8 is a high effect. Education researchers do not necessarily use this interpretation of effect size as a strict guideline because the context of the research matters (Barnette & McClean, 1999). Data from the Teacher Knowledge Assessment System (TKAS), the online system designed to administer the learning Mathematics for Teaching assessments, reveal that the average effect size for 2,297 teacher pre-post scores from over 200 mathematics professional development projects across the nation for the Middle School Patterns, Functions, and Reasoning form was 0.12 (Phelps, Jones, Kelcey, Shuangshuang, & Zahid, 2013). Using this number as a benchmark suggests that the TRC effect sizes can be considered meaningful and as an indicator of successful programming. However, variation between individual projects' effect sizes ranged from a negative effect size to above one standard deviation. These variations provide an opportunity to study the relationship between teachers' involvement in TRC activities by project and MKT changes.

Part One: MKT and Professional Development Hours

Comparing MKT changes to program design was challenging. Professional development hours were entered by teacher, but MKT pre- and post-assessments scores were submitted without teacher names. Within projects there were many teachers missing pre- or post-assessments or both. Some projects did not use the MKT measures or used a locally designed assessment. Comparisons between MKT and content hours had to be conducted between projects instead of individual teachers which reduced the power of the analysis.

Research on professional development has shown that the number of hours spent in professional development matters. However, results are mixed on how much matters, and what to measure to account for the effects. Data from each of the program years—2008-2009, 2009-2010, and 2010-2011—were used to analyze the relationship between content hours taken by teachers and changes in MKT (Patterns, Functions, and Algebra Form). We were able to quantify the number of hours described as algebra within each project using the descriptions and titles submitted by each project.

There were projects that documented high numbers of algebra hours, but had small MKT gains. Other projects that reported fewer content hours had larger MKT gains. The identification of algebra hours was dependent on the descriptions of each event submitted by project leaders, but because of the lack of detail and consistency of the professional development descriptions, some of the hours may have been misidentified. Therefore it is not surprising that a positive but insignificant relationship was found between projects' average MKT gains and projects' average PD hours focused on mathematics content.

Part Two: Evaluating Characteristics of Professional Development

For the 2011-2012 program year, the TRC changed reporting requirements in three ways: (a) projects were asked to provide more detail about their professional development events in the database, (b) reporting guidelines required projects to report assessment data by teacher name (to be kept anonymous in any reports), and (c) the rate of a projects' reporting of teachers' pre- and post-assessments was added to the final evaluation of each project. These changes improved our chances of detecting factors that were related to differences in MKT.

The details of event descriptions improved and better inferences could be made about the PD content and activity. We could now code each professional development event according to effective characteristics. This was an alternative to the previous evaluation approach that was dependent on hours reported, not the quality of the PD. Characteristics of effective professional development described in the NCTM (1999) *Standards for the Professional Development of Teachers of Mathematics* and Garet et al. (2001) were used to develop a system of coding TRC PD.

Table 4

Coding for Scheme One

Codes	NCTM Professional Development Standards	Core Features of Professional Development (Garet et al., 2001)
Direct Content (DC)	Standard 2: Knowing mathematics and school mathematics	Knowing mathematics content and school mathematics
Grounded in Student Thinking (ST)	Standard 3: Knowing students as learners of mathematics	Opportunities for active learning
Grounded in Instruction (I)	Standard 4: Knowing mathematics pedagogy	Opportunities for active learning
Grounded in Curriculum and Standards (CS)		Opportunities for active learning Coherence with other learning activities
Developing Professional Community (PC)	Standard 5: Developing as a teacher of mathematics	

To test this coding scheme (see Table 4), we applied it to the events of six projects. Within each project, their teachers' professional development records were analyzed using coding scheme one. Each event received a code that reflected the most dominant event characteristic. Event codes were weighted according to the number of hours per event. These hours were totaled to give a percentage of hours devoted to each type of PD. Figure 1 shows the results of this coding for all six projects.

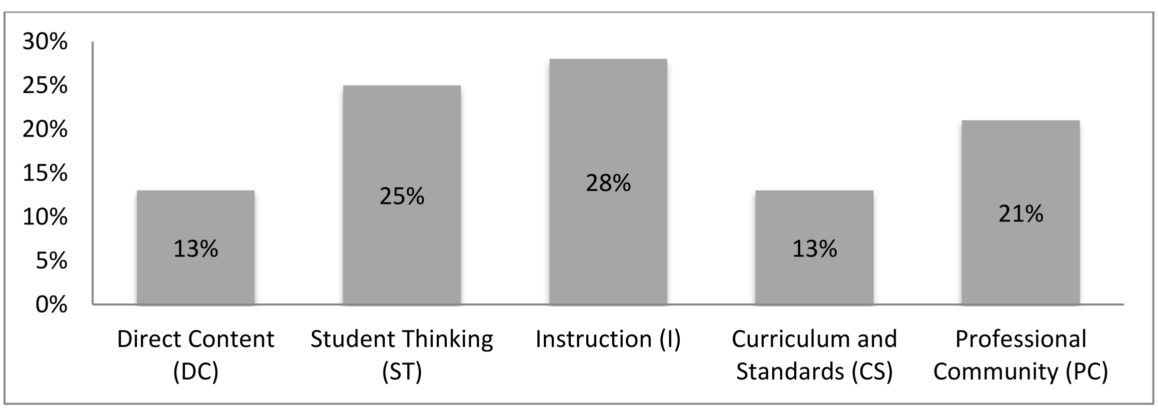

Figure 1. Characteristics of mathematics professional development, 2011-2012.

However, when individual projects were compared to each other, the PD differences in the characteristics of the PD did not explain changes in MKT. For example, Figure 2 illustrates a comparison between two projects that had moderate effect sizes of 0.37 and 0.40 on the MKT measures; yet they are very different in the type of PD events. Direct Content in mathematics content was minimal (1%) for Project 3 (PRJ3), while Project 5 (PRJ5) had only 3% coded as Student Thinking. The PD emphases on the other categories in combination appear to have a positive impact on mathematics teachers' MKT; however, the lack of similarity in the two programs makes the connection between MKT and PD inconclusive.

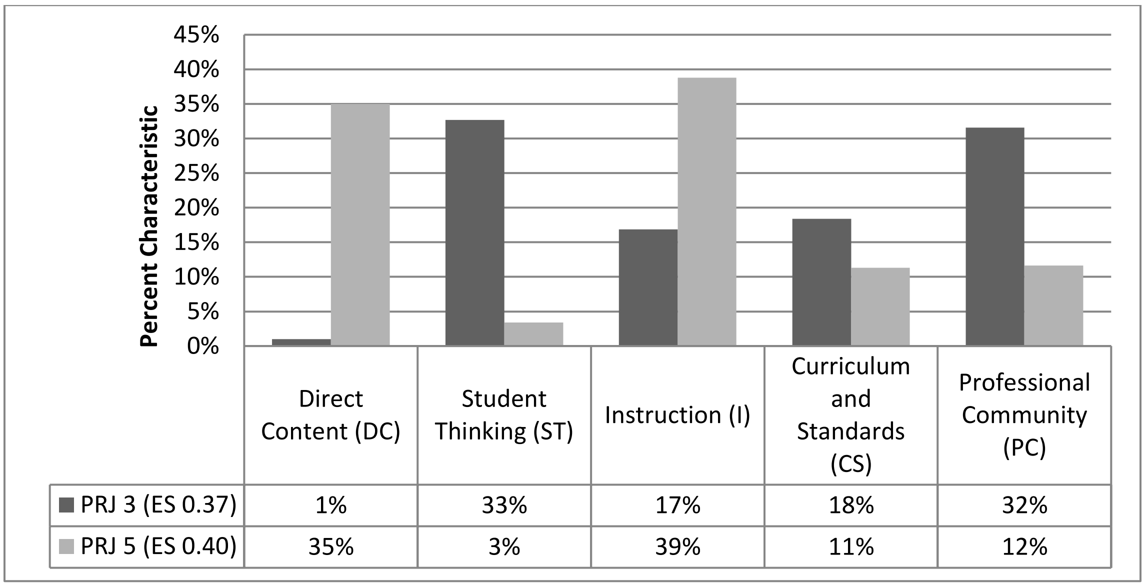

Figure 2. Comparison of two projects' PD characteristics.

Part Three: Identifying Effective Professional Development Practices

We decided to take a closer look at all projects' professional development programs using a modified coding scheme to better understand the differences. In this phase, the professional development events completed by 24 individual TRC projects were downloaded from the database for sorting and coding. Each event coded contained a title, date of the event, detailed description, and number of hours for the event. Out of total of 1,861 events listed in the database, 1,429 separate events were coded for effective PD characteristics. A total of 432 events were listed as either business meetings or mentoring activities. MTM hours of mentoring other teachers were not coded since each mentor had exactly 12 hours, and the data only included information about meeting times and names of mentors and mentees.

Coding for Context Type, Active Learning, and Content Focus

Garet et al. (2001) classified PD contexts as either traditional or reform. For our coding scheme, we identified two distinctive contexts: the workshop (traditional) and study group (reform). Effective professional development can then be described as having two core features: active learning and content focus. Active learning "concerns the opportunities provided by the professional development activity for teachers to become actively engaged in meaningful discussion, planning and practice" (Garet et al., p. 925). Codes for active learning reveal *how* mathematics knowledge for teaching was addressed. For TRC PD, we coded for the presences of each of the four dimensions of active learning: (a) observing and being observed, (b) classroom implementation, (c) examining student work, and (d) presenting and leading. Then we added a fifth dimension to the description provided by Garet et al.: (e) solving mathematics problems. Content focus is defined as "what teachers actually [are intended to] learn in professional development activities" (Garet et al., p. 923), and closely aligns with Shulman's (1987) PCK. We identified five dimensions used in Garet et al: (a) curriculum and standards, (b) mathematics pedagogy, (c) general pedagogy, (d) using technology, and (e) college mathematics.

Context type. Codes for context type describe the professional development setting. All events were coded as one of these two types: (a) study group or (b) workshop. Study groups (9%) were events held in small groups settings and were short in duration, such as Professional Learning Community meetings or Lesson Study groups. The remaining events (91%) were coded as workshops since they occurred in more traditional contexts such as summer institutes or whole-day sessions with the entire group of teachers in the cohort.

Next, the descriptions and titles provided for each event were coded for each of the dimensions within the two core features: active learning and content focus. Using a binary coding system, an event received a code of 1 for the presence of an effective PD practice and a 0 for not present. To receive credit, the event had to have convincing evidence within the description or title. If an event lacked detail in the description or title, we collected more information about PD through examination of materials and agendas collected from the PD event, conversations with the event's PD leader, and researching internet resources. Most events received more than one code.

To code such a large quantity of events, a sifting process was used. First, the titles for each event were searched for key words and phrases that would indicate a particular type of professional development and codes were assigned for that event. Approximately half of the events could be coded by their titles alone. Event titles that contained similar phrases were assigned the same codes. For example, one of the professional development curriculum commonly used by the projects was Fostering Algebraic Thinking (Driscoll, 1999). This PD is designed to address teachers' content needs through the activity of solving math problems and discussion, and then examining samples of student work. Any title or description that indicated this PD curriculum was being used received a 1 for examining student thinking and a 1 for solving math problems (both active features). After as many titles were coded that could be coded in this way, the event list was sorted by title and checked for consistency of coding between events coded so far.

Events that could not be coded by title were coded through key words and phrases within their descriptions. A master list of events was created with these searched phrases and associated codes. Each time the phrase was found in a description, the same set of codes was assigned to the PD event. Next, the event list was sorted by code to check for consistency between codes. Plainly, events with the active learning code of "student thinking" should bear some similarity. If an event seemed out of place, its descriptor and titles were re-examined and the event was recoded if needed.

Some descriptions contained multiple key phrases and the coding for these events was done individually. For example a 6-hour event with this title "PISD 8th Grade Region 13 Math Cohort Meeting" had this descriptor: "This training is for the 8th Grade teachers (Cadre members) and MTMs in Prudence School District. The training utilized pieces from Fostering Algebraic Thinking, Math Journaling, and from Math Tools." This event was identified with codes associated with events that were titled, "Fostering Algebraic Thinking" and "Math Journaling" and "Math Tools".

Active learning. Five codes were used to identify events characterized by active learning.

***Observing and being observed*.** Counted in this group were those events in which teachers engaged in Lesson Study, observing children through interviews, or watching videos of teaching and interviews. A few descriptions cited that the participants practice-taught as a part of the event.

***Classroom implementation*.** Descriptions included activities such as discussions about applications to classrooms, allowing time to make and present plans, and providing evidence of the PD on classroom implementation.

***Examining student work*.** This included studying children's work to make intervention decisions and talking about the concepts demonstrated in the work. Workshops in which teachers brought in written and or videotaped samples of students' work from their own classrooms were coded as examining student work. The in-depth treatment of student work within the Young Mathematicians at Work series and the Fostering Algebraic and Geometric Thinking are examples of PD that received this code.

Presenting and leading. These were event descriptions noting that teachers presented at a meeting or conference, practiced presenting to others, or that teachers were learning how to be mentors or take on leadership roles in mathematics.

Solving mathematics problems. PD descriptions indicated that either the teachers were solving problems, solving problems with a variety of strategies, or solving problems in a way that would help them understand the mathematics better. The activity opportunity here was to solve a mathematics problem or problems and discuss and examine the strategy as a part of the activity. In many kinds of mathematics PD, there are problems solved or demonstrations of problems solved, but often this is just a precursor to discussing something else, not a discussion of the mathematics involved in the problem, comparing strategies, or probing the teachers' thinking. To receive this code, the event had to indicate that teachers were actively problem solving.

Content focus. Six codes were used to identify a content focus.

***Student work*:** Student work is presented as content to be learned. Teachers study these samples to learn exemplars of student work. These examples could be actual student work or invented examples.

Curriculum and standards. Building an understanding of curriculum and standards is at least a small part of most PD. Events received this code only if the express purpose of the PD was to learn about standards, student expectations, or new curriculum material.

***Mathematics pedagogy*.** If the content focus was how to teach mathematics, better or differently, it received this code. How to teach mathematics had to be evident in the description. Events that described general activities like journaling without a mathematics focus; AVID (Advancement Via Individual Determination, a high school tutoring program); “Literature Throughout the Day;” or general Response to Intervention (RtI) did not receive this code.

General pedagogy. This code was assigned if how to teach was addressed, but not specific to mathematics. For example one event coded as general pedagogy describes a book study in which teachers read a book on the principles of good teaching.

***Using technology*.** If a PD was intended to help teachers effectively use a current or new piece of technology, it received this code. Coded events included teachers learning how to use online learning environments, websites, computer-based programs like Geogebra, and technologies such as calculators or flip cameras.

College mathematics. Many of these were graduate level programs hosted at a local university that taught traditional upper level mathematics. These events accounted for few teachers but for large amounts of time for those teachers.

Results and Summary of Coding for Effective PD Practices

Most events received multiple codes, and we do not report the codes that were assigned to less than 10% of the events. Eighty-four percent of the events received at least one active learning code. Eighty-two percent of the events were coded as classroom implementation, 21% as examining student work, and 20% as solving mathematics problems. Notably, 53% of the events coded as classroom implementation had no evidence of examining student work or solving math problems while just 8% were coded with all three. The majority of events received at least one content code. We identified 63% of the events as curriculum and standards, 49% as mathematics pedagogy, 19% coded as student work, and 12% as general pedagogy.

Discussion

Following the announcement of new state standards and new graduation requirements in the years 2011 and 2012, the professional development throughout the state emphasized PD based on learning curriculum and learning about state assessments. Our data shows that this is true for our TRC projects as well.

As Table 3 shows, gains on MKT have been in the moderate range for the TRC projects. This could have been due to the variety of PD events, idiosyncratic to each project, which may have hidden true gains in mathematical knowledge for teaching. Researchers have shown that effective PD includes curriculum and standards components. They are features of effective PD because they are important to instruction and student achievement (Garet et al., 2001). However, this type of teachers’ math knowledge for teaching is not assessed in the Learning Mathematics for Teaching measures. The weak to moderate gains in MKT and weak relationships between PD experiences and gains in MKT may be explained as the result of a mismatch between the knowledge assessed and the PD experienced by teachers. In any case, a close look at the features of delivered professional development on a large scale suggests a direction for change and improvement in professional development designs that will improve potential to increase student achievement, and make clear what types of effective PD practices make the most impact on teacher knowledge.

Assessment scores from 2008 to 2012 showed that teachers in the TRC overall have improved Mathematics Knowledge for Teaching. Data on the quality of teachers' professional development experiences were collected by a close analysis of the features of those experiences. Professional development activities for project leaders noted in Table 1 are designed to emphasize key components in effective mathematics professional development such as student thinking, interpreting student work, and engaging teachers in the study of mathematics. In 2008, projects were required to implement summer institutes. School year follow-up trainings and opportunities for teachers to work more regularly together increased. This combination of programming context and features contributes to the presence of effective professional development features such as examining student thinking and solving mathematics problems. It is our belief that these effective PD practices also contribute to meaningful positive changes in teachers' MKT as noted in Table 3. Future evaluation will include comparisons of individual teacher's MKT change to the presence of effective PD characteristics within their individual PD experiences.

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