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Scaling Professional Development for Mathematics Teacher Educators

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SCALING PROFESSIONAL DEVELOPMENT FOR MATHEMATICS TEACHER EDUCATORS

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Scaling Professional Development for Mathematics Teacher Educators

There have been multiple calls (Adler, Ball, Krainer, Lin, & Novotna, 2005; Conference Board of the Mathematical Sciences, 2012; Kilpatrick, Swafford, & Findell, 2001) and extensive evidence (Hiebert, 2003; Lemke et al., 2004; National Math Panel, 2008; OECD, 2010) regarding the need to change K-12 mathematics education from procedural and memorization-driven to more conceptual and application-based. Professional development is viewed as an important mechanism to influence these changes in instructional practices (Fennema et al., 1996; Franke, Carpenter, Levi, & Fennema, 2001; Swafford, Jones, & Thornton, 1997) and student outcomes (Jacobs, Franke, Carpenter, Levi, & Battey, 2007). However, professional development is a broadly used term that encompasses a wide array of mechanisms designed to impact practice and student achievement. Our specific focus is on large scale professional development involving hundreds or thousands of teachers across multiple instructors and settings. Districts, regional centers, and governmental agencies often provide this type of large-scale professional development. However, the processes and logistics are rarely described in the research literature. Borko (2004) provides a framework for conceptualizing research on scaling professional development. Phase I involves implementing a professional development program at a central site and examining its influence on teachers (e.g., Jacobs et al., 2007; Laura, McMeeking, Orsi, & Cobb, 2012). Phase II examines the integrity with which a professional development program is implemented across multiple instructors and settings, and analyzing differences in participant outcomes across instructors and settings (e.g., Bell, Wilson, Higgins, & McCoach, 2010; Borko, Koellner, & Jacobs, 2014). Phase III compares multiple, well-defined professional development programs based on resource requirements, implementation, and participation effects (e.g., Heller, Daehler, Wong, Shinohara, & Miratrix, 2012). While phase I research is relatively common in the research literature, there have been few phase II and III studies (Borko et al., 2014; Wayne, Yoon, Zhu, Cronen, & Garet, 2008). Thus, there is a need to engage in phase II research to better understand mechanisms for scaling professional development effectively.

The MTI project described in this paper involved the phase II scale-up of a successful phase I mathematics professional development program – modified for phase II delivery – provided to over 12,000 teachers and administrators by over 30 instructors. The purpose of our research is to describe an apprenticeship-based professional development model for developing course instructors and evaluate the model by examining the consistency in course participants' changes in mathematical knowledge for teaching (MKT) (Ball, Thames, & Phelps, 2008) and self-efficacy across instructors. Our hypothesis is that if an apprenticeship-based professional development model for developing course instructors is effective, we should find positive and consistent patterns of change in course participants' knowledge and self-efficacy.

Research Framework

Desimone (2009) provides a conceptual framework for examining the impact of professional development on teachers and their students. We adapted Desimone's (2009) framework to include a focus on the impact of professional development for mathematics professional developers (MPDs) and to highlight the different groups – mathematics professional developers, teachers, and students – likely impacted within a professional development project (see Figure 1). Examining the impact of professional development is extremely complex and adding the MPD component only increases the complexity. Therefore, it is often necessary to explore a subset of the constructs impacted within a professional development project. In this article we focus on the following four elements; professional development for teachers, shifts in

MPD's knowledge and beliefs, professional development structures for MPDs, and shifts in teachers' knowledge and self-efficacy (these elements are highlighted by italics in figure 1). We address each of these elements throughout this article in the order listed above. Our two research questions are:

1. Is there a change in teachers' knowledge (operationalized as MKT) and self-efficacy from before to after MTI course participation?
2. And, is there a significant difference in the nature of the variation across instructors in teachers' knowledge (operationalized as MKT) and self-efficacy from before to after MTI course participation?

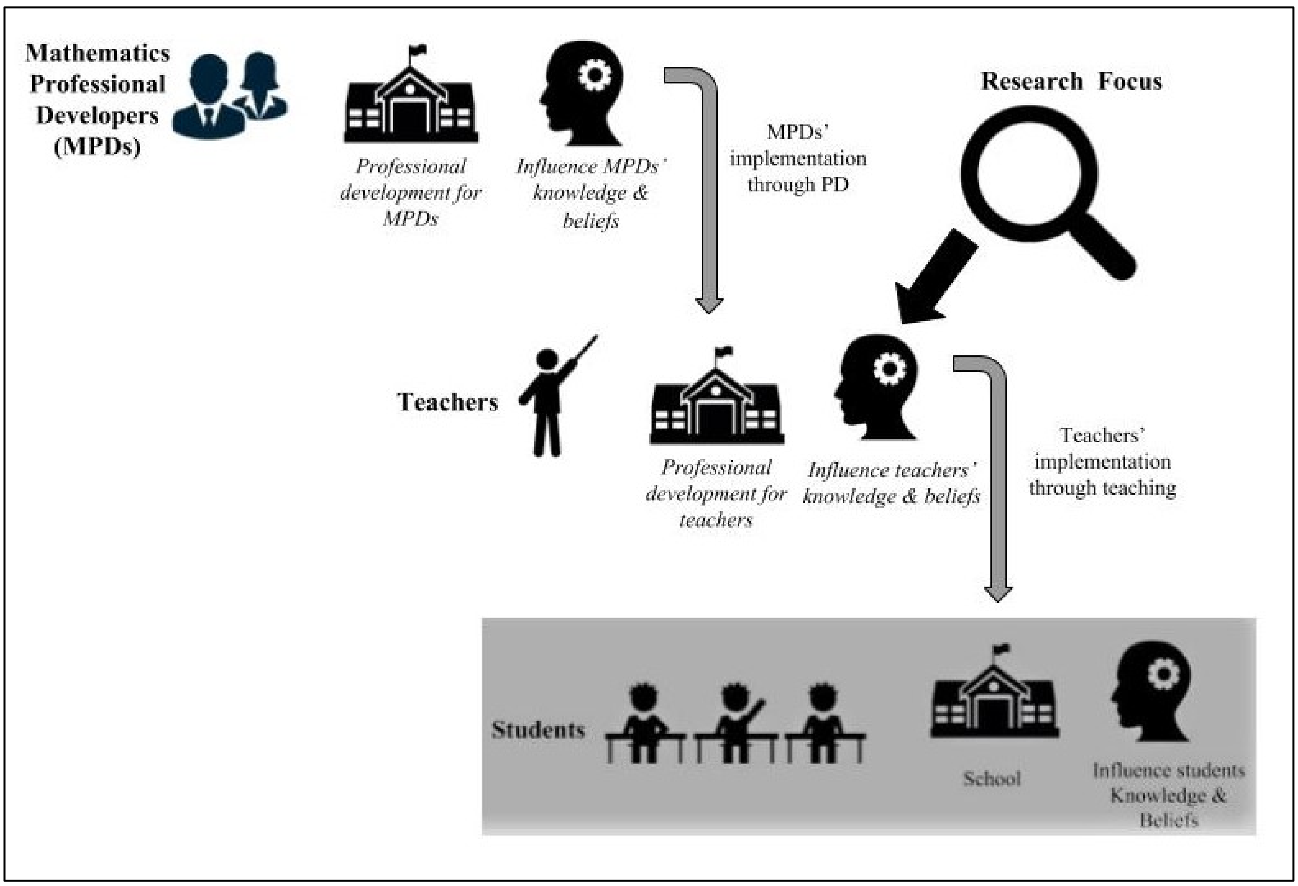

Fig. 1. Adaptation of Desimone's (2009) framework for studying professional development. The student row is included as a reference to Desimone's original framework but are not
included in the present research (and are therefore greyed out).

Professional Development for Teachers

While the focus of this article is on the professional development for MPDs, we briefly explore the structure and focus of professional development more generally because knowledge necessary to be an effective MPD is highly dependent upon the type of professional development they will be providing. The structure and focus of professional development can vary significantly; therefore, it is useful to think about how varying these elements could influence the knowledge necessary to be an effective MPD.

The following two frameworks are useful in conceptualizing the focus and structure of professional development. The first framework comes from Koellner and Jacobs (2015) who describe professional development along a continuum of highly adaptable to highly specific. For example, a one-to-one coaching format is likely to be highly adaptable when the content of the coaching session is focused on the needs of the individual teacher; a large group workshop with an explicit focus (e.g., mathematical models) is likely to be highly specified. The second framework was developed by Park Rogers et al. (2010) and then used by Marra et al. (2011) for categorizing professional development based on orientations. They describe five professional development orientations: activity-driven, science/mathematics content-driven, pedagogy-driven, curriculum materials-driven, and need-driven. We briefly describe these five professional development orientations, including where they are likely to fall on a continuum from highly adaptable to highly specific, followed by the type of knowledge likely needed by MPDs in each setting.

Professional development with a(n):

- *Activity-driven* orientation engage participants in activities - typically hands-on - appropriate for use with students. The activities and facilitation are typically well-specified but the structure around facilitation can vary from adaptable to highly structured. MPDs in an activity-driven oriented professional development setting would need to be knowledgeable in the facilitation of the activities and focused on engaging participants in interesting mathematical tasks that address grade-band appropriate content.

- Science/mathematics content-driven orientation are focused on teachers' learning new content, often through lecture or laboratories. The activities and facilitation are relatively structured and tend to lie towards the specific side of the continuum. MPDs in a science/mathematics content-driven oriented professional development setting should be highly-knowledgeable content experts who are focused on delivering content knowledge to participants.
- Pedagogy-driven orientation are focused on learning about and modeling particular instructional strategies, often inquiry-based. The activities and facilitation are specific in terms of the use of a particular instructional strategy but depending upon the strategy could range from specific to adaptable. MPDs in a pedagogy-driven oriented professional development setting would likely be knowledgeable and skilled in a particular pedagogical strategy or strategies, and focused on facilitating this instructional strategy with participants.
- Curriculum materials-driven orientation guides teachers on the use of particular materials in their classroom. The activities and facilitation are relatively specific to the curricular materials. MPDs in a curriculum materials-driven oriented professional development setting are likely highly knowledgeable experts in the curricular materials and focused on developing expertise in the use of the materials with participants.
- Needs-driven orientation is focused on the particular needs of professional development participants. The activities and facilitation are adaptable to the needs of the participants.

MPDs in a needs-driven oriented professional development setting are likely knowledgeable about a wide-range of topics with a breadth of experience focused on supporting participants in exploring areas of improvement particular to the professional development participants' setting or needs.

Following the description of the MTI project (below), we return to these two frameworks for conceptualizing the focus and structure of professional development to situate where MPDs in the MTI project might lie in terms of their professional development needs with a specific focus on the knowledge necessary to facilitate the MTI courses.

The MTI Project

In 2008 our state government mandated a 45-hour mathematics professional development course, titled MTI, for recertification. The MTI course focuses on topics in number and algebra in conjunction with pedagogical approaches designed to develop students' deep mathematical understanding. Three versions of the 45-hour course were developed based on content knowledge grade bands: Kindergarten through third grade (K-3), fourth through eighth grade (4-8), and sixth – twelfth grade (6–12). Although there is broad overlap in content between courses, each course addresses specific grade-band appropriate topic: K-3 is early number, 4-8 is rational number, and 6-12 is algebraic modeling. The overlap in grades 6-8 was due to overlap in the state certification system. Teachers in these grades could select the course most closely aligned to their interests.

The pedagogical approach is built on the Developing Mathematical Thinking (DMT) framework which focuses on taking students' ideas seriously, encouraging multiple models and strategies, pressing students' conceptually, focusing on the structure of mathematics, and addressing misconceptions - more fully described in our previous work (Carney, Hughes, &

Brendefur, 2014; Carney, Brendefur, Hughes, & Thiede, 2015; Carney, Brendefur, Thiede, Hughes, & Sutton, 2016). Briefly, the DMT framework developed from Carpenter and Lehrer's (1999) description of learning with understanding, which stipulates that students need to build connections, apply and extend concepts, and evaluate and communicate their own understanding. From a pedagogical perspective, the framework builds upon Hiebert and Carpenter's (1992) vision of teaching for understanding, which incorporates cognitive and social learning theories. In addition, it draws upon progressive formalization (e.g. Gravemeijer and van Galen, 2003) and the concept of modes of representation (Bruner, 1964).

The MTI project takes a 'transformative' stance towards professional development with a focus on both developing teachers' MKT and shifting classroom practice (Stein, Smith, & Silver, 1999) This contrasts with more traditional or 'additive' forms of professional development that focus on providing strategies or activities for teachers to add to their repertoire but does not focus on significant changes in classroom instructional practice. Transformative professional development works to influence teachers' knowledge, beliefs, and practice towards a more student-focused form of instruction. In whole group professional development this often includes utilizing contextual problems to elicit a wide range of solution strategies and representations and providing opportunities for participants to discuss and share their mathematical ideas as a model for student discourse. These practices require a high level of MKT and often differ significantly from the mathematics instruction teachers experienced in their own education. The role of transformative professional development is to shift teachers' perspective towards a stance of inquiry so they can meaningfully enact and reflect upon these practices in their classrooms (Elliott, 2005).

MTI Example. This illustration of the MTI professional development setting, provides a perspective to think about the professional development needs of MPDs who must not only build teachers' MKT but also shift their instructional practice. Midway through the 6-12 MTI professional development course, the MPD presents participants with the T-Shirt and Drink problem (see Figure 2). Participants initially work on their own but quickly begin discussing approaches to solving the task in their groups. In the meantime, the MPD walks around the room examining representations, facilitating small group discussions, and assisting individuals in creating their representations as needed. In particular, the MPD identifies a range of participant-generated models for the upcoming class discussion. For this particular problem, the MPD looks for (1) substituting $22 for a t-shirt and drink unit, (2) eliminating a variable, and utilizing the difference in price of $14 between a shirt and drink in a (3) table or (4) picture (see bottom of Figure 2 for strategy details). As the MPD finds a model that highlights an important idea, they ask the participant or group to recreate the model on poster paper for whole-class discussion. These models are then posted around the room. When the MPD does not observe a particular model, she/he looks to find a participant whose work and thinking connects to the 'missing' model and then presses the participant via questioning to generate the model based on existing work. For example, a MPD may ask, 'What happens if we continue to trade out one t-shirt for one drink?' to press for the rate of change solution or 'Focus on the first row – how much would one t-shirt and one drink cost?' to press for substitution of that unit.

The MPD typically begins the class discussion with a focus on an informal solution strategy and model. From there she asks course participants to articulate their understanding of each model and press for connections that can be established among the models, with the goal of demonstrating the instructional practice of using multiple participant-generated models to

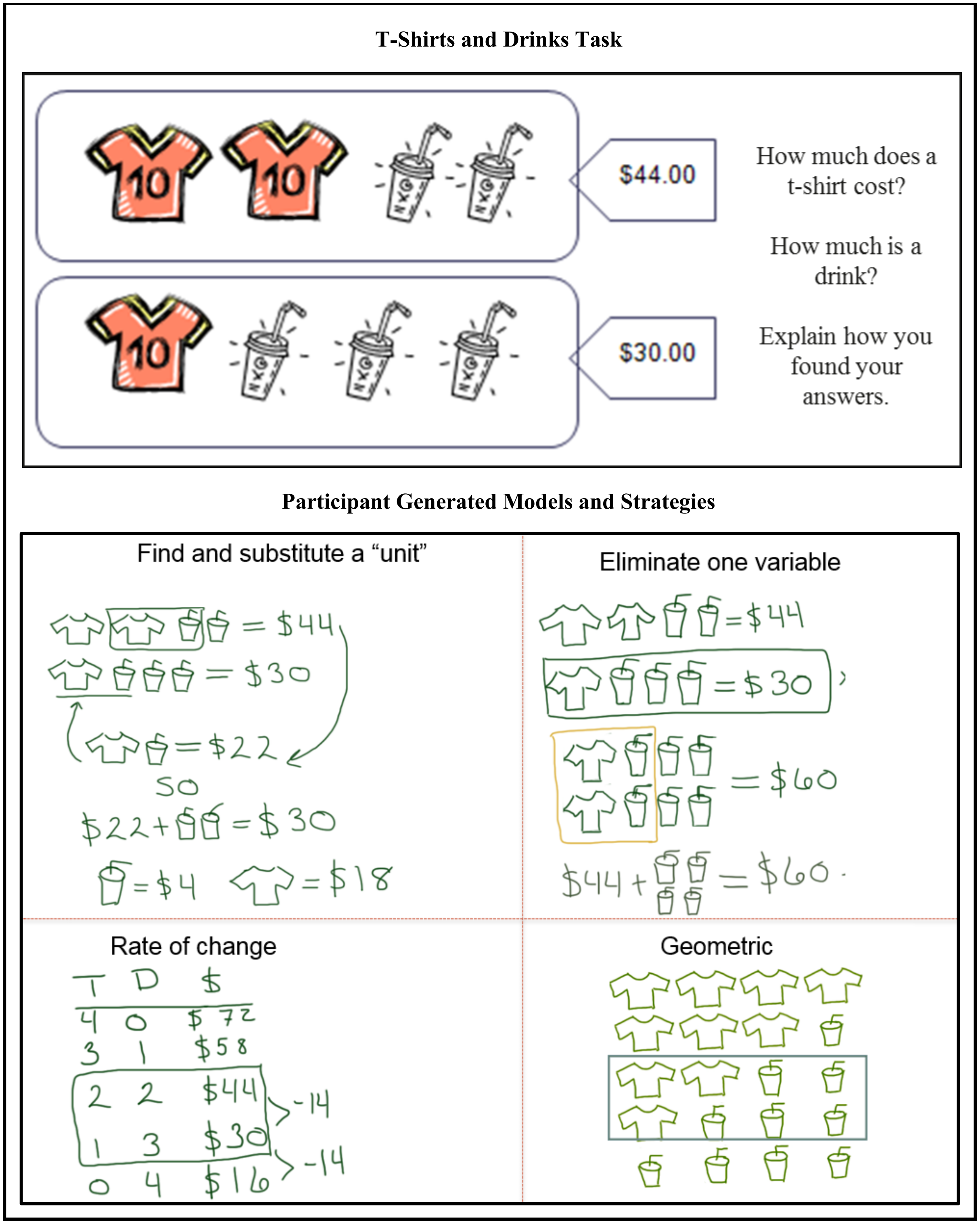

Figure 2. Spending Money at the Game Task

demonstrate progressive formalization and build mathematical ideas and understanding. During the professional development, this process generally goes well, but the conclusion of the discussion often brings up comments from participants such as, ‘I think this is great to understand but I have too much to teach to take this amount of time on one problem’ or ‘I would have to show my students the different models, they would not be able to come up with these on their own’ that must also be addressed by the MPD. This example highlights the multiple aspects of knowledge an MPD must possess to provide transformative professional development. Not only do they need to possess deep MKT (Ball et al., 2008) and an understanding of task facilitation, but they must also respond to implementation concerns and questions in ways that promote teachers’ reflection and growth while acknowledging and honoring their professional opinion.

From the perspective of the two frameworks for conceptualizing the structure and focus of professional development, the MTI courses have both activity and pedagogically-driven orientations and range in levels of specificity and adaptability depending upon the specific professional development activity or discussion topic at hand, with a consistent focus on developing a student-focused orientation to instruction. The courses are highly specified in terms of the professional development tasks and their facilitation, including MPDs pedagogical modeling of how to use multiple models generated during instruction to frame discussion. A significant amount of time is also spent addressing classroom implementation ideas and questions that arise during class. This aspect of the professional development is much more adaptable to the particular course and the local context of the course participants. While there are many aspects of MPDs knowledge and beliefs relevant to providing transformative professional development, we see two key areas of knowledge development necessary for MPDs to effectively facilitate MTI courses. The first is knowledge for facilitating mathematics professional development tasks. This is a relatively highly specified aspect of the MTI course. The second is knowledge for facilitating discussions around shifting teachers' mathematics instructional practice. This is a more adaptable aspect of the MTI course.

MPD Knowledge Development

This section examines previous research related to MPD's knowledge for facilitating mathematics professional development tasks and knowledge for shifting teachers' mathematics instructional practice. This is followed by an examination of the research related to the mechanisms for developing MPD's knowledge.

Knowledge for Facilitating Mathematics Professional Development Tasks

The facilitation of mathematics professional development tasks involves building professional development participants' MKT, often through high quality discussion of their solutions. An MPD typically has multiple goals to attend to when facilitating tasks, and this is further complicated by the need to use the mathematical work produced by professional development participants to address these goals. For example, facilitation of mathematics professional development tasks includes anticipating likely solutions and sequencing of models or strategies to purposely develop teachers' MKT (Elliott et al., 2009). In the 't-shirts and drinks' task this involves knowing that providing a context which can be solved multiple ways makes the problem accessible to *all* course participants regardless of mathematics background, and that sequencing solutions in class discussion from informal to formal provides scaffolding for the progressive formalization of participants' thinking (Hughes, Brendefur, & Carney, 2015; Gravemeijer, 1999).

Developing MPDs' knowledge for task facilitation involves developing their own MKT while also building pedagogical awareness of how to facilitate tasks with adult learners. Elliott (2005) found mathematics teacher educators more readily adopted a stance of inquiry around their own development of MKT for mathematical topics but had a more difficult time adopting a similar stance of inquiry towards others. Despite meaningfully engaging in an inquiry approach to support their own mathematical development, they focused on the need to 'correct' the solution strategies of teachers in case study videos rather than viewing them as a starting place for discussion. This highlights the importance of purposefully developing MPDs knowledge for facilitating mathematics professional development tasks.

Examples can be found in the literature of focusing on building MPDs' knowledge for task facilitation (e.g., Elliott et al., 2009; Koellner, Jacobs, & Borko, 2011; Zaslavsky & Leikin, 2004). The processes varied but typically involved some or all of the following components; (a) participation in the task as a participant (Koellner et al., 2011), (b) intense pre-planning for task implementation as a MPD (Koellner et al., 2011; Zaslavsky & Leikin, 2004), (c) planned reflection with a more experienced mathematics teacher educator following implementation (Borko et al., 2014; Zaslavsky & Leikin, 2004) and/or (d) analysis of professional development case studies through video or written transcripts (Elliott, 2005; Schifter & Lester, 2002).

Knowledge for Shifting Teachers' Mathematics Instructional Practice

While building MPD knowledge for task facilitation was generally accepted as important, multiple authors recognize MPDs must also "…learn to attend to the particularities of the local cultures (e.g., student background, school characteristics, district expectations) in which teachers work" (Stein et al., 1999, p. 266). Schifter and Lester (2002) and Remillard and Kaye (2002) highlight the importance of instructors' ability to negotiate interpersonal relationships and 'openings in the curriculum'. This involves those instances where professional development participants' questions or comments deviate from the mathematical task at hand. MPDs must possess knowledge of how to respond to questions, comments, and concerns around implementation in participants' local context that arise throughout professional development (Stein et al., 1999), and they must "…find ways of acknowledging the expertise that teachers brought with them while maintaining a stance of critique and inquiry" (Remillard & Kaye, 2002, p. 19).

Similar to the comments and questions highlighted at the end of the T-shirts and Drinks task, professional development participants often share questions and concerns related to the implementation of new instructional practices in their own schools and classroom (Schifter & Lester, 2002). During the ensuing discussion, the MPD must call upon various aspects of their knowledge related to implementation of instructional practices in a local context. Skilled MPDs are able to weave together personal experience, published research, and classroom examples to address concerns about the affordances and constraints of various learning theories, research frameworks, and their implementation in practice, while maintaining fidelity to the theoretical frameworks upon which the professional development is built (Elliott et al., 2009). For example, in the opening task, questions commonly arise related to a lack of time for implementation of more social-constructivist learning approaches. The MPD must honor the reality and experience of the participant while stressing that, although a more student-focused approach may take longer in the short term, it has the potential to present immense benefits in the long term if deep mathematical content is drawn out and emphasized.

While examples can be found regarding the need for MPDs to possess knowledge for shifting teachers' mathematics instructional practice (Remillard & Kaye, 2002; Schifter &

Lester, 2002; Stein et al., 1999), less research is available around the specific process of how an MPD develops this knowledge. Schifter and Lester (2002) describe instructor guides in the Developing Mathematical Ideas professional development materials. Other projects focused on close collaboration between MPDs and their own mathematics teacher educators to build this knowledge through discussion and reflection upon situations that arose during professional development facilitation (Koellner et al., 2011; Zaslavsky & Leikin, 2004). As a generally agreed upon core feature of the development of MPDs, more description and research needs to be conducted regarding how to develop this knowledge in MPDs.

Mechanisms for Professional Development of MPDs

Mechanisms for Professional Development of MPDs

We identified three mechanisms within the research literature for knowledge development of novice MPDs; (1) an iterative process of constructing knowledge, (2) investigations of practice, and (3) co-participation in professional development activities with experts. The *iterative process of constructing knowledge* took on many forms, such as the adaptation of the Problem Solving Cycle, which involved an initial focus on developing MKT through personal engagement with a mathematics professional development task, followed by cycles of planning, implementation, and reflection as an MPD (e.g., Borko et al., 2014; Koellner et al., 2011; Koellner et al., 2007). Other processes were less structured, but still centered on iterative knowledge construction through taking on increasingly complex roles in professional development settings (Zaslavsky & Leikin, 2004), or through a semi-structured reflection process (Stein et al., 1999). *Investigations of practice* often occurred through videos or case studies (Elliott, 2005; Elliott et al., 2009; Schifter & Lester, 2002) or reflection of an MPD on his or her own practice with an expert (Zaslavsky & Leikin, 2004) or individually (Stein et al., 1999). Lastly, *co-participation with experts* often utilized Lave and Wenger's ideas of legitimate peripheral participation (1991) and communities of practice (Smith, 2003). For example, Zaslavsky and Leikin (2004) describe the development of MPDs within a professional community of mathematics teacher educators. Through adoption of various roles within the community - learner, observer, and instructor in the presence of an expert - novices were able to build their knowledge over time.

While the literature on the development of MPDs knowledge development, and mechanisms to support knowledge development, provide a global perspective on structuring MPD development programs, more research and reporting is needed on specific programs of development, including examining evidence of their effectiveness.

Methods

In this methods section we first describe our intervention - an apprenticeship-based model for developing MPD's – specific to MTI course instructors. We then detail the operationalization of variables from our project in relation to Figure 1. Lastly, we detail the setting, timeline, MPD demographics, and course participants, as well as data collection, instruments, and analysis.

Apprenticeship-based model for developing MPDs

The following section details our process of selecting MPDs, our initial development model, and the ongoing support provided to MTI course instructors. The requirement of the MTI course for teacher recertification required rapidly scaling the number of MPDs with the skills and knowledge to provide a transformative mathematics professional development course across our state. In addition, the course developers were strongly focused on maintaining the quality and integrity of the course as it was scaled statewide. We needed instructor selection, development, and support mechanisms that could be scaled while also maintaining the quality of the course instruction.

MTI Instructor Selection. The majority of MTI course instructors were identified during their initial participation in the MTI course. During MTI courses we looked for individuals who demonstrated a combination of the following knowledge and characteristics; (a) the candor and personality to impact teachers' beliefs and practice, (b) rich and varied professional experiences relevant to mathematics teaching, including at least three years' experience teaching K-12 mathematics, (c) leadership skills enabling them to foster communication and collaboration, (d) familiarity with multiple teaching and assessment strategies, with emphasis on reform-oriented approaches and models, and (e) a reasonable level of knowledge of mathematics at a specific grade band, student thinking and development, and facilitation of mathematics professional development tasks. Typically, individuals held these characteristics and knowledge at differing levels; thus, what was perhaps deemed most critical was their interest and aptitude in further developing these areas. We focused on individuals who wanted to be part of a mathematics professional development community with both a personal and professional interest in improving mathematics teaching and learning for students. Once an individual was identified as a potential course MPD, they began to engage in the activities described below.

MTI Instructor Development Model. A transformative mathematics professional development model was rather novel (in our state) at the time. There were only a handful of individuals with experience in offering the MTI course. The MTI instructor development model grew out of the need to train a large cadre of course instructors' with a strong focus on maintaining course consistency and quality while allowing the flexibility to respond to local implementation questions and concerns. The development model included the following activities, although the order varied slightly depending upon the specific circumstances. Initial development involved; (a) completion of the MTI course as a participant, (b) apprentice through at least one entire MTI course with an experienced MTI instructor, including co-planning and facilitation of tasks, and (c) mentorship during initial solo MTI course facilitation with an experienced MTI instructor. The on-going support involved regular participation in the bi-annual two-day MTI Instructor conferences, including completing multiple reading assignments from the mathematics education research base.

Through co-participation with experts, these activities (more fully described below) focused on establishing a community of practice in which developing MPDs engaged in critically constructive discourse to co-construct their knowledge about providing transformative professional development from typically no or little experience to full participation as an MPD (Lave & Wenger, 1991). Specifically, they needed experience in knowing how to facilitate mathematics tasks including how to press teachers' understanding and meaningfully address concerns regarding implementation to assist teachers in shifting their practice.

MTI Course as a Participant. Every MTI course instructor began as a participant in the MTI class, with a focus for all course participants on developing MKT relevant to classroom instruction and understanding of the DMT instructional framework. Through the lens of our model of developing MPDs, participants were also engaged in learning about the course tasks, progressive formalization of models as a facilitation approach, and listening to the discussion between instructor and teachers regarding implementation concerns and questions. After acting as a contributing member in this culture and being identified as a potential instructor, the next shift was to become an apprentice with a seasoned instructor (Lave & Wenger, 1991).

MTI Course as an Apprentice. At this level, the apprentice's knowledge began to include more cognitive processing (e.g. why a task is facilitated in a particular manner) and further discourse around the DMT framework from both a K-12 classroom and professional development perspective, including its goals and practices (Lave & Wenger, 1991; Vygotsky, 1978). More specifically, the apprentice MPD was asked to understand more deeply the structure of task facilitation, including common facilitation moves and mechanisms to build upon or press participants' MKT. This aspect of the model focused intensively on building MPDs knowledge for task facilitation. For example, MPDs became more explicitly aware of the types of solution strategies likely to be elicited by particular contextual problems and how to structure discussion to press participants MKT. In addition, they participated in course discussions and engaged in listening or responding to participants' questions and concerns in the presence of an experienced MPD. This provided them an opportunity to build their knowledge related to questions and concerns that commonly arise.

Mentorship during First MTI Course Facilitation. Finally, the apprentice shifted to becoming a instructor. During their initial course facilitation, the new instructor met with a mentor to plan before, discuss ideas during, and reflect after each class to ensure movement into the community of instructors with a common discourse (Glazer & Hannafin, 2006; Hank, 1991). The initial development activities – MTI course as a participant, apprentice, and with mentorship - provided a strong foundation for MTI instructors to facilitate tasks and respond to local implementation concerns. However, the project staff also found it important and necessary to provide ongoing support to MPDs.

MTI Instructor Conference. The bi-annual conference was intended both as an initial development activity and an ongoing support structure for MTI instructors. It involved ongoing readings and discussion of the research, in-depth facilitation discussions around course tasks, and sessions around commonly raised participant concerns (e.g., fact fluency and addressing the needs of struggling students). MPDs were asked to read and discuss a series of seminal articles from such authors as Carpenter, Fennema, Gravemeijer, Hiebert, Simon, and Treffers. This background in the research in conjunction with the sessions on participant concerns provided MPDs a better understanding and appreciation for the DMT instructional framework and built their knowledge related to responding to local implementation concerns from a research perspective.

The complete instructor professional development and apprenticeship process created a community of practice around the MTI course implementation across course MPDs and developers.

Operationalization of Research Question Variables

The italicized sections of Figure 1 highlight the constructs focused on in our research: providing professional development for MPDs to influence their knowledge and beliefs, MPDs' implementation of the MTI professional development course for teachers, and ideally positive and consistent changes in teachers' knowledge and self-efficacy. The regular interaction between MPDs and MTI project staff allowed for continual evaluation and feedback on MPDs' development of knowledge and beliefs, and their implementation of the PD. Individuals who did not demonstrate the necessary knowledge, beliefs, and practice did not continue on to become MPDs. Thus, our focus on examining the quality and consistency of our professional development for MPDs by evaluating change on inventories of course participants' knowledge and self-efficacy across MPDs. Our prediction is that if MPDs were consistently prepared in knowledge of task facilitation, their teacher participants should have positive and consistent gains in MKT. Similarly, if MPDs were consistently prepared in knowledge for shifting teachers' mathematics instructional practice, their course participants could have positive and consistent gains in self-efficacy. These predictions lead to our two primary research questions.

1. Is there a change in teachers' knowledge (operationalized as MKT) and self-efficacy from before to after MTI course participation?
2. And, is there a significant difference in the nature of the variation across instructors in teachers' knowledge (operationalized as MKT) and self-efficacy from before to after MTI course participation?

Setting and Timeline

The 45-hour MTI courses were located at school buildings across our state. During summers, the courses were typically held over five consecutive days. During the school year courses were conducted after school with one to two full-day Saturday courses spanning six to ten weeks. Participation in the course was mandated.

For the present study we selected data from the summer of 2011 through the fall of 2012. This represents year 3 and 4 of the project. This time frame was selected due to the large number of experienced MPDs teaching the course during this time period. A total of 263 sections were taught during this time frame with 141 K-3 sections, 88 4-8 sections and 34 6-12 sections. Due to the need to adjust for sample size by MPD (described below), a total of 252 sections from this time frame were included for analysis with 131 K-3 sections, 87 4-8 sections and 34 6-12 sections.

MPD Demographics

A total of 26 MPDs are included in the analysis. There were seventeen K-3 MPDs, eleven 4-8 MPDs and five 6-12 MPDs. There were two MPDs who taught all three course levels and three MPDs who taught two course levels. Each MPD at each grade level was assigned a unique identification number. For the sake of anonymity, MPDs who taught multiple versions of the course (e.g. K-3 and 4-8) were given a different number within each course analysis. We eliminated instructors who had course participant samples sizes of less than 50 on matched pre and post MKT inventory scores for the time period of the analysis. This eliminated new MPDs who had just started teaching the MTI course because we expected these individuals could have increased variability in the way they facilitated the MTI course due to minimal experience and their lack of opportunity to have participated in multiple MTI Instructor Conferences. The professional roles of these individuals, at the time they started facilitating courses, ranged from (1) current or retired classroom teacher – nine individuals, (2) mathematics district office personnel or administrator – seven individuals, and (3) MTI project staff – ten individuals. It should be noted that all MPDs had, at some time, been employed as classroom teachers.

Course Participants and Data Collection

The course participants came from across the state, representing a mix of urban, suburban, and rural participants. The course was required for recertification but participants selected when and where to participate. During the selected time frame a total of 6,918 participants took the MTI course with 3,814 K-3 participants, 2261 4-8 participants and 843 6-12 participants. Two factors reduced the sample size for analyses, (1) the aforementioned adjustment for sample size by MPD, and (2) matching of participant scores across the measures. The ability to match scores was limited due to mistakes by participants in keeping their self-generated ID consistent across the measures. However, we had no indication that the elimination of these individuals occurred in a manner that would have biased the data. There is no reason to think that individuals who did not consistently enter their self-generated ID on post assessment would differ in a consistent and/or biased manner in their knowledge and self-efficacy gains. The final participant data set for analysis included: 2559 K-3 participants with matched pre/post MKT scores and 2000 with matched self-efficacy scores, 1286 4-8 participants with matched pre/post MKT scores and 1010 with matched self-efficacy scores, and 459 6-12 participants with matched pre/post MKT scores and 373 with matched self-efficacy scores.

Instruments

Two types of instruments were used to gather information from course participants; a knowledge inventory and survey of teacher demographics and beliefs. The knowledge inventory differed by the course grade-band level; K-3, 4-8, and 6-12. The same survey of teacher demographics and beliefs was administered across all three course grade-band levels. Due to the fact the instruments had to be administered on such a large-scale, the focus was on ensuring they were relatively quick and easy to administer (i.e., between the two instruments it would take less than an hour for participants to complete).

Knowledge Inventories. Three knowledge inventories were created using items developed by the Learning Mathematics for Teaching project at the University of Michigan (Learning Mathematics For Teaching, 2005). The knowledge items correspond to the construct of Mathematical Knowledge for Teaching (MKT) further described by Ball et al. (2008). The specific MKT items selected for the content and pedagogical knowledge inventories align to the typical instructional content related to number, operations and algebra found at the K-3, 4-8, and 6-12 grade levels, creating specific knowledge inventories for each course. However, while the content of the inventories and the MTI courses are similar in terms of their focus on number, operations, and algebra, the inventories were not created to tightly align to the particular content of the MTI courses. Our purpose in not tightly aligning to the particular content of the MTI course and focusing on typical instructional content found at each grade level, was to determine if the ideas generalized beyond the specific tasks and topics addressed in the course.

The K-3 MKT inventory consisted of 31 items, the 4-8 MKT inventory consisted of 27 items, and the 6-12 MKT inventory consisted of 28 items. Items were scored as being right or wrong, and a total items correct score was calculated. A requirement for use of the knowledge items by the LMT project is that the total items correct scores be converted into standardized z-scores for analysis and reporting. A pre-inventory MKT score based on the total items correct was calculated for each participant within each course grade-band sample as a standardized variable (i.e., M=0, SD=1). The post-inventory MKT score was calculated for each participant within each course grade-band sample as a standardized variable using the pre-inventory mean and standard deviation for each course and section [(total correct on the post-inventory – mean total correct of the pre-inventory)/SD of the pre-inventory]. Inventory scores were matched from pretest to posttest using a unique identifier number generated by the course participant.

Self-Efficacy Survey Scale. One scale within the beliefs survey focused on teacher self-efficacy, teachers' educational beliefs about their level of preparedness to teach mathematics to students (Pajares, 1992). A goal of the course was to influence teachers' instructional practice and given that '…beliefs are the best indicators of decisions individuals make' (Pajares, 1992, p. 307), we felt influencing teachers' self-efficacy to teach mathematics improved the likelihood of implementing the practices we used and discussed in the course. Items for the scale were gathered using instruments designed by RMC Research and Math in the Middle project staff at the University of Nebraska, Lincoln in 2005. Items were developed or adapted from existing measures including the *Mosaic II Rand Teacher Survey for Eighth Grade Mathematics* (Rand, 2003), the *Survey of Classroom Practices in Middle School Mathematics* (WCER, undated), and the *TIMSS Teacher Questionnaire for Eighth Grade Mathematics* (Martin, Mullis, & Chrostowski, 2004). The full survey scale can be found in Carney et al., 2016.

The instrument used a retrospective pre- and post-test format to collect information about teacher confidence regarding their level of preparedness to teach mathematics using what was learned in the course. A retrospective format is the recommended method of evaluating change in circumstances where participants' pre-intervention responses may be biased based on an overestimation or underestimation due to lack of knowledge or understanding regarding the area the intervention is designed to influence (Lam & Bengo, 2003; Lamb & Tschillard, 2005; Rohs, 1999).

Teachers' self-efficacy regarding their level of preparedness prior to and following course participation was measured using ten items rated on a three-point scale (1=Limited, 2=Well, 3=Very Well). These items assessed teachers' level of preparedness on topics such as, teaching classes to students of diverse abilities, providing a challenging curriculum to all students, and sequencing mathematics instruction to meet instructional goals. The scale based on these ten items was found to be reliable ($\alpha = .90$). Scores for this scale were calculated by averaging across the ten items, resulting in self-efficacy scores for both before and after course participation (interpretable on the original metric from 1-3).

Data Analysis

The descriptive statistics for the MKT z-scores and self-efficacy scores are presented in Tables 1 and 2, respectively. To address the research questions, a two-way ANOVA was conducted for each course type (i.e., K-3, 4-8, 6-12), with Time (pretest versus posttest) as one factor and Instructor as the other factor. In these analyses, a main effect for Time would indicate that scores are significantly different from pretest to posttest (Research Question 1). A significant interaction would indicate that the change from pretest to posttest is different for various MPDs (Research Question 2). In these analyses, a main effect for Instructor would indicate that individual MPDs worked with teachers with significantly different levels of knowledge or self-efficacy—this is not linked to a research question and therefore is not reported.

Results

Mathematical Knowledge for Teaching (MKT)

For the K-3 courses, there were 17 different MPDs; therefore, this was a 2 (Time: pretest versus posttest) x 17 (Instructor: the 17 different MPDs) ANOVA. There was a significant main effect for Time, $F(1, 2542) = 1790.74$, MSe = .32, $p < .001$, $\eta^2 = .41$. As seen in Panel A of Figure 3, MKT scores increased from pretest to posttest (Research Question 1). More important, the interaction was not significant, $F(16, 2542) < 1$, MSe = .32, $p = .54$; which suggests the change from pretest to posttest did not differ across MPDs.

The same analysis was conducted for the 4-8 courses. There were 11 different MPDs; therefore, this was a 2 (Time: pretest versus posttest) x 11 (Instructor: the 11 different MPDs) ANOVA. There was a significant main effect for Time, $F(1, 1275) = 488.92$, MSe = .36, $p < .001$, $\eta^2 = .28$. As seen in Panel B of Figure 3, MKT scores increased from pretest to posttest. More important, the interaction was not significant, $F(10, 1275) < 1$, MSe = .36, $p = .92$; which suggests the change from pretest to posttest did not differ across MPDs.

Finally, the same analysis was conducted for the 6-12 courses, in which there were 5 different MPDs. The 2 (Time: pretest versus posttest) x 5 (Instructor: the 5 different MPDs) ANOVA revealed a significant main effect for Time, $F(1, 454) = 73.73$, MSe = .15, $p < .001$, $\eta^2 = .14$. As seen in Panel C of Figure 3, MKT scores increased from pretest to posttest. More important, the interaction was not significant, $F(4, 454) = 1.44$, MSe = .15, $p = .22$; which suggests the change from pretest to posttest did not differ across MPDs.

Self-Efficacy for Teaching

For the K-3 group, there were 17 different MPDs, this was a 2 (Time: prior versus after) x 17 (Instructor: the 17 different MPDs) ANOVA. There was a significant main effect for Time, $F(1, 1983) = 4247.9$, $p < .001$, $\eta^2 = .68$. As seen in Panel A of Figure 4, self-efficacy scores increased from prior to after (Research Question 2). More important, the interaction was significant, $F(16,1983) = 3.768$, $p < .001$, $\eta^2 =.03$; which suggests the change from prior to after course self-efficacy differed across MPDs.

The same analysis was conducted for the 4-8 courses. There were 11 different MPDs; therefore, this was a 2 (Time: prior versus after) x 11 (Instructor: the 11 different MPDs) ANOVA. There was a significant main effect for Time, $F(1, 999) = 1466.92$, $p < .001$, $\eta^2 = .60$. As seen in Panel B of Figure 4, self-efficacy scores increase from prior to after (Research Question 2). More important, the interaction was significant, $F(10,999) = 3.542$, $p < .001$, $\eta^2 = .03$; which suggests the change from prior to after course self-efficacy differed across the 4-8 MPDs.

Finally, the same analysis was conducted for the 6-12 courses. There were five different MPDs; therefore, this was a 2 Time: prior versus after) x 5 (Instructor: the 5 different MPDs) ANOVA. There was a significant main effect for Time, $F(1, 368) = 338.41$, $p < .001$, $\eta^2 = .48$. As seen in Panel C of Figure 4, self-efficacy scores increase from prior to after (Research Question 2). More important, the interaction was significant, $F(4, 368) = 6.826$, $p < .001$, $\eta^2= .07$.

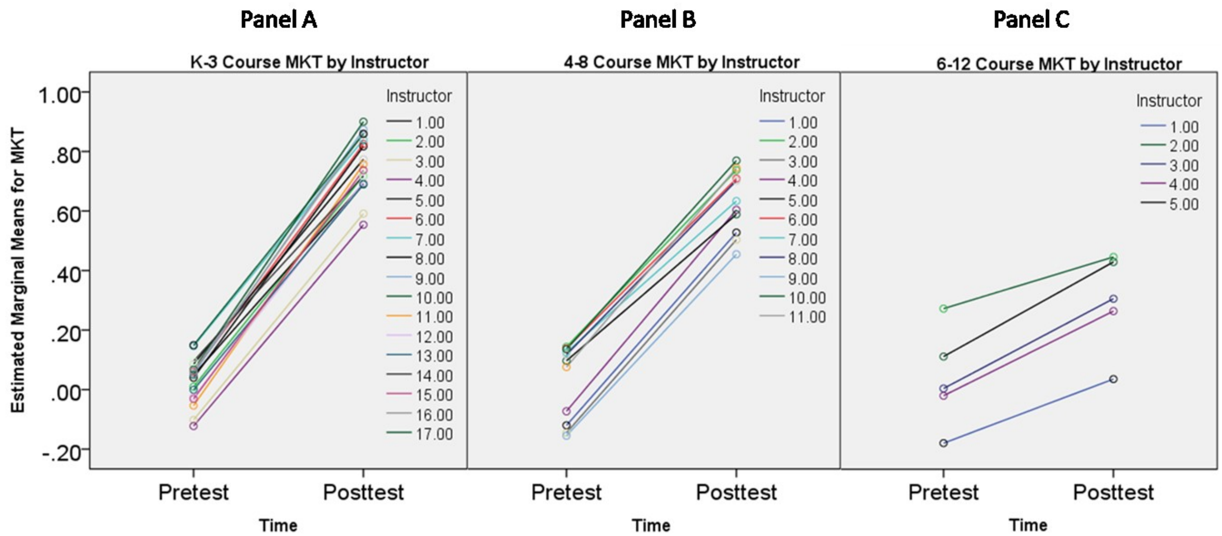

Figure 3A-C: Estimated marginal means for MKT pretest and posttest by instructor for each course.

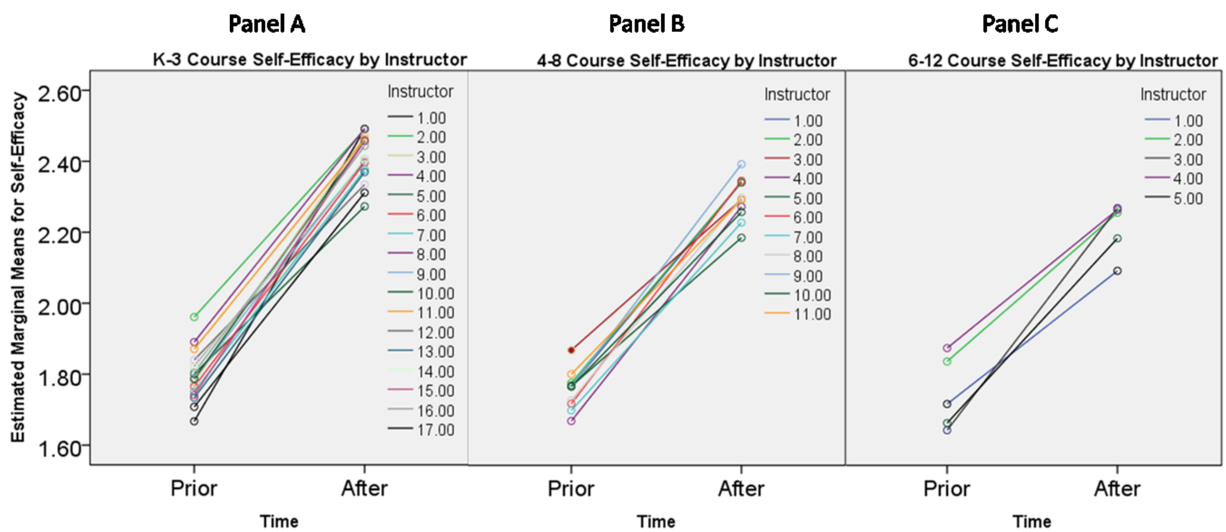

Figure 4A-C: Estimated marginal means for self-efficacy from prior to after by instructor for each course.

Discussion

The purpose of this research was to describe an apprenticeship-based model of professional development model for developing MPDs and evaluation of the model by examining the consistency in course participants' changes in knowledge and self-efficacy across instructors. The focus on examining the influence of the MTI course on course participants' knowledge and self-efficacy addresses Borko's call for phase 2 research examining the integrity with which a professional development program can be implemented across multiple instructors. The results indicate there were positive and consistent changes in teachers' MKT across MPDs. In other words, teachers who took the MTI course typically experienced an increase in their MKT and the rate of change for the increase was relatively consistent across MPDs. The results also indicate there were positive changes in teachers' self-efficacy across MPDs but the rate of change differed across instructors. In other words, teachers who took the MTI course typically experienced an increase in their self-efficacy but the amount of increase varied by MPD.

MKT Change across MPDs

To situate the change in teachers' MKT across MPDs, we return to our original prediction; if MPDs were consistently prepared in knowledge of task facilitation, there would be some uniformity in the way MPDs facilitated this aspect of the professional development; therefore, their teacher participants would have positive and consistent gains in MKT. Our results indicate MPDs developed under an apprenticeship-based model were associated with course participants whose MKT was positively and consistently influenced across MPDs. Therefore, it is likely that our apprenticeship-based model increased MPDs' knowledge of task facilitation in a relatively consistent manner that allowed for some level of uniformity in the way MPDs facilitated this aspect of the professional development. Through the lens the Koellner and Jacobs (2015) and Park Rogers et al. (2010) frameworks, the development of MPDs knowledge of task facilitation – while very constructivist in approach - occurred in a relatively specified manner and had both an activity and pedagogically-driven orientation. The mathematical tasks facilitated throughout the course provided the primary structure for course activities. MPDs were given several opportunities to develop their knowledge of task facilitation; first as a participant, then they shadowed/co-participated in the course, and lastly as they were provided mentorship during their first course. Across these different events they watched, co-participated, and then lead facilitation, respectively. We suspect the apprenticeship model provided them a means to construct a well-developed understanding of task facilitation in terms of the mathematical models likely to arise, the connections that could be pressed across the models, and how to pedagogically facilitate discussion focused on building teachers' MKT from course participant generated models. Although the format was adaptable to the models developed by participants within a specific course, the overall structure was relatively specified both within a particular task - in terms of the likely models and connections to press for - and across tasks - in terms of a common approach to task facilitation.

The link between the consistent changes in course participants' MKT and our development of MPDs' knowledge for facilitating mathematical tasks is promising but requires further investigation. Our instructor development process required a great deal of time and effort on the part of project staff. While we argue this level of effort is needed to allow MPDs to meaningfully construct knowledge of task facilitation, this is an important assumption to investigate further, due to the time and effort needed to implement this type of development process. There are very few other descriptions in the literature specifying the development process of MPDs. Borko et al. (2014) provide the most detailed description we could find of the development of MPDs, followed by examination of their influence on the MKT of professional development participants. However, likely due to small sample sizes, Borko et al.'s examination was not conducted at the individual MPD level but instead across the entire group. Therefore, conclusions regarding the consistency of changes related to the development process cannot be made. Bell et al. (2010) examined the implementation of Developing Mathematical Ideas (DMI) professional development materials across multiple instructors. However, their description of the specific development process of the instructors was very limited – most likely because that was not the focus of their study. They found no difference across instructors for the Learning Mathematics For Teaching (2005) MKT inventory they utilized.

Changes in Self-Efficacy across MPDs

To situate the change in teachers' self-efficacy across MPDs, we return to our original prediction; if MPDs were consistently prepared in knowledge for shifting teachers' mathematics instructional practice, there would be some uniformity in the way MPDs facilitated this aspect of the professional development; therefore, their teacher participants would have positive and consistent gains in self-efficacy. Our results indicate MPDs developed under an apprenticeship-based model had course participants whose self-efficacy was positively but inconsistently influenced across MPDs. Therefore, it is likely that our apprenticeship-based model increased MPDs' knowledge for shifting teachers' mathematics instructional practice but perhaps in a somewhat inconsistent manner that did not allow for uniformity in how this aspect of professional development was facilitated. Through the lens the Koellner and Jacobs (2015) and Marra et al (2011) frameworks, the development of MPDs knowledge for shifting teachers' mathematics instructional practice was relatively adaptable and the focus was a needs-driven orientation. Conversations around how to implement the DMT framework for instructional practice in classrooms was a common topic in the MTI course. While certain questions commonly arose, MPDs responses to these questions were adapted to the particular situation and context under discussion and therefore varied between MPDs, likely providing for less uniformity across instructors. During the apprenticeship-based model of the MPD development, there were multiple opportunities for MPDs to voice, hear, and respond to implementation questions. Some questions arose so commonly that course materials were developed to address these questions, such as a module on fact fluency. However, it is likely that the variation across instructors in participants responses to implementation questions were a factor in the lack of consistency in increases across MPDs.

Bell et al. (2010), who found consistent MKT gains across instructors, found differences across instructors for an open-ended assessment of course materials. These differences were linked to instructors' level of learning opportunity regarding the DMI materials. This open-ended assessment included a large focus on the implementation of the course topics at the instructional level. While we did not have an open-ended measure related to teachers' implementation of the course materials, our self-efficacy scale provided a proxy for teachers' perceived level of preparedness to implement the ideas from the course.

The relationship between course participants' self-efficacy and the specific aspect of course instructors' knowledge for assisting teachers to shift their instructional practice requires further investigation. It follows that the better a course instructor can respond to the 'openings in the curriculum' or implementation questions that occur throughout a professional development session, the more improvement there would be in participants' self-efficacy at the conclusion of the course. It also logical to conclude that it is easier to develop consistency in MPDs' abilities to facilitate tasks – a relatively highly specified activity - than in their ability to respond to participants' questions and comments about implementation of practices – a relatively adaptable activity. As authors, course instructors, and MPD mentors, we found the use of our own personal implementation stories, with K-12 students, very helpful to course participants in visualizing and transferring the instructional practices to their reality. However, these types of responses are necessarily tempered by the background experience of the MPDs themselves and perhaps the development process can only provide so much consistency across instructors. It is possible that other mechanisms beyond personal implementation stories could provide more consistent gains across MPDs, and while we did attempt to provide for consistent mechanisms across MPDs – e.g., the inclusion of a session on learning theories and their implementation in the classroom – it may be that the use of personal stories had a larger influence overall, hence the lack of consistency across MPDs. This is an area that requires more investigation, and is particularly important because, while influencing MKT is important, increases in MKT alone will not produce the necessary changes needed in actual classroom instructional practice.

Limitations

The strengths of the claim we can make linking our model of developing MPDs to changes in teachers' MKT and self-efficacy are limited by our ability to isolate and measure these variables in our study. Future research could focus on having a comparison group of instructors who received a different method of professional development. However, research examining the integrity with which professional development can be scaled-up across multiple instructors is so limited (Borko, 2004; Borko et al., 2014) that the present study, while primarily descriptive in nature, provides an important example of the successful development of instructors through an apprenticeship-based model in the literature.

Our research is also limited by not examining how MPDs responded to implementation questions. We suspect there was variance due to our own personal experiences in teaching the MTI course and mentoring MPDs. However, we did not specifically collect analyzable data. We recommend this data be collected in the future and used to develop frameworks for how MPDs respond to implementation questions. This would assist with moving towards a more highly specified approach to this aspect of our professional development. Similar to van Es, Tunney, Goldsmith, and Seago's (2014) development of a framework for MPD facilitation of teacher noticing in video cases, development of a framework for responding to implementation questions could potentially provide a more structured approach for MPDs responses and potentially provide for more consistency in the changes.

Lastly, the study of professional development, particularly on a large-scale, is methodologically difficult (Wayne et al., 2008). Our ability to extrapolate to teachers' MKT and self-efficacy is limited by the use of measures that are easily quantifiable. Specificity is always lost when relatively short and easy to administer measures are used. More specificity could provide additional important details to better situate results. In the future, a mixed-methods research design for a large-scale research project could provide a more detailed view of the impact of a development model for MPDs on teacher participants' knowledge and self-efficacy.

Conclusion

Koellner and Jacobs (2015) continuum related to the specificity versus adaptability of professional development activities is useful when examining changes in professional development participants' knowledge, beliefs, and instructional practice. We are left wondering if highly adaptable aspects of professional development settings are less likely to have consistency in changes, due to the adaptable focus of the professional development. Similarly, we wonder if consistency should be the goal in adaptable aspects of professional development. Future research and discussion needs to help our field frame these types of questions in ways that can be meaningfully researched.

If professional development is noted as an important mechanism for improving student outcomes in mathematics, and a primary goal of mathematics professional development is transformative change in teachers' instructional practice, then we must have high-quality research across multiple settings about how to best provide that mechanism. The lack of investigations related to the development of MPDs, and more particularly to understanding the knowledge and professional development MPDs need, is thus a significant hole in the research literature. The lack of research or even reporting is particularly problematic given the large number of professional development efforts occurring on a daily basis in schools and districts around the country in response to recent shifts in standards, curriculum, and assessment. Our description of scaling professional development to multiple MPDs within a large-scale professional development project, provides an example to others of how this can be accomplished. Our investigation provides promising evidence related to apprenticeship-based models for developing MPDs, particularly in regards to consistent changes in MKT. The finding of increased variability across instructors in participants changes in self-efficacy when compared to MKT is similar to Bell et al. (2010) and provides important considerations for the field in terms of both preparing MPD’s and an increased focus in research that examines the consistency of changes in multiple variables (including self-efficacy) across professional development scenarios.

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Table 1. MKT Descriptives

Course	Instructor	*n*	Prior MKT z-score		After MKT z-score	
			mean	SD	mean	SD
K-3	1	78	0.04	1.07	0.82	0.76
	2	137	0.01	0.97	0.72	0.87
	3	271	-0.10	0.89	0.59	0.75
	4	99	-0.12	0.95	0.55	0.95
	5	95	0.05	0.97	0.69	0.88
	6	101	0.06	1.06	0.83	0.83
	7	146	0.15	1.06	0.84	0.78
	8	248	0.09	1.00	0.77	0.81
	9	206	0.05	0.96	0.87	0.76
	10	108	0.07	1.00	0.90	0.81
	11	179	-0.05	0.95	0.76	0.86
	12	57	-0.02	1.10	0.70	0.90
	13	269	0.00	0.97	0.69	0.85
	14	136	0.10	1.01	0.72	0.89
	15	146	-0.03	1.05	0.74	0.89
	16	172	0.06	1.03	0.86	0.79
	17	111	0.15	0.95	0.86	0.84
4-8	1	138	-0.12	0.87	0.53	0.90
	2	68	0.14	1.03	0.74	0.82
	3	132	-0.15	1.06	0.50	0.87
	4	78	-0.07	0.92	0.60	0.88
	5	92	0.10	0.93	0.59	0.91
	6	176	0.14	0.98	0.71	0.83
	7	42	0.13	1.15	0.63	0.95
	8	55	0.12	1.13	0.70	0.99
	9	97	-0.15	0.93	0.45	0.81
	10	322	0.14	0.92	0.77	0.86
	11	86	0.08	1.06	0.74	0.93
6-12	1	45	-0.23	0.94	0.00	0.86
	2	154	0.24	0.97	0.42	0.91
	3	145	-0.04	0.97	0.28	0.83
	4	87	-0.06	1.05	0.23	0.99
	5	28	0.07	1.18	0.41	0.79

Table 2. Self-Efficacy Descriptives

Course	Instructor	*n*	Prior Self-Efficacy score		After Self-Efficacy score	
			mean	SD	mean	SD
K-3	1	67	1.67	0.43	2.49	0.41
	2	96	1.96	0.48	2.49	0.40
	3	220	1.78	0.45	2.47	0.37
	4	75	1.89	0.52	2.49	0.46
	5	72	1.80	0.48	2.27	0.42
	6	81	1.77	0.48	2.40	0.43
	7	102	1.75	0.44	2.38	0.45
	8	205	1.82	0.46	2.40	0.41
	9	166	1.79	0.50	2.41	0.38
	10	85	1.79	0.46	2.46	0.41
	11	139	1.87	0.49	2.46	0.41
	12	48	1.84	0.43	2.33	0.43
	13	226	1.73	0.47	2.37	0.43
	14	95	1.82	0.50	2.41	0.41
	15	109	1.74	0.44	2.46	0.36
	16	127	1.80	0.46	2.44	0.41
	17	87	1.71	0.48	2.31	0.46
4-8	1	102	1.77	0.49	2.34	0.44
	2	54	1.78	0.52	2.34	0.45
	3	94	1.87	0.57	2.29	0.49
	4	55	1.67	0.46	2.27	0.46
	5	69	1.77	0.54	2.19	0.52
	6	151	1.72	0.47	2.35	0.44
	7	32	1.70	0.53	2.23	0.40
	8	44	1.73	0.47	2.30	0.51
	9	75	1.77	0.41	2.39	0.42
	10	267	1.77	0.50	2.26	0.44
	11	67	1.80	0.50	2.29	0.43
6-12	1	34	1.72	0.49	2.09	0.51
	2	122	1.84	0.54	2.26	0.51
	3	130	1.64	0.45	2.27	0.41
	4	65	1.87	0.50	2.26	0.45
	5	22	1.66	0.61	2.18	0.64