# AN ANALYSIS OF SECONDARY MATHEMATICS TEACHER LEARNING IN THE MIDWEST MASTER TEACHER PARTNERSHIP

by

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**ABSTRACT**

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This case study investigates the professional learning and changes in teaching practices and leadership of four experienced, mid-career secondary mathematics teachers as a result of participation in the Midwest Master Teacher Partnership, a professional development partnership between a research university and a large, urban school district. The design of the professional development was based primarily on teacher action research; it placed the teacher at the center of the learning experiences, and included considerations of teachers' existing knowledge, contexts, community, and assessment.

The primary research question is, "How have teachers' practices changed through their participation in a practice-based professional development project?" To answer this question, this study considers three aspects of teacher learning and practice: (1) The trajectories of teachers' changes in practice and the way the nature of their participation in MMTP impacted their pedagogical practice; (2) The evolution of teachers' mathematical knowledge for teaching and beliefs about teaching mathematics over the course of MMTP; and (3) The pathways that teachers took in their professional learning with MMTP, the factors that shaped their movement on the pathways, and ways that the nature of their participation in MMTP impacted teachers' attitudes toward professional development and their thoughts about future engagement in professional learning.

A qualitative analysis was performed on written, video recorded, and audio recorded artifacts collected over the duration of the Midwest Master Teacher Partnership and the teachers' work was examined for changes in knowledge, beliefs, and teaching practices over time. The findings provide evidence that the four teachers each experienced individual changes in practice: changing notions of student success, building trust in students to take ownership over their learning, building a community of learners, and changing beliefs about students and how they learn. In addition, the four teachers each experienced individual changes leadership: establishing credibility, sharing knowledge with the larger community, gaining confidence as an expert, and shared leadership and collective vision. This case study demonstrates that consideration of experienced teachers needs when planning and implementing practice-based professional development and using teacher action research to drive teacher learning can promote productive changes in teachers' mathematical knowledge for teaching, teaching practices, and beliefs about teaching and learning.

To

my husband Scott Renchin and my parents Mick and Lynn Sagrillo

for all of the love and support you've given me throughout this journey.

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| Abbreviation | Meaning |
|---|---|
| AP | Advanced Placement |
| CCSS | Common Core State Standards |
| CCSSM | Common Core State Standards for Mathematics |
| CLADE | Chronicles of Learning and Development Episodes |
| CRP | Culturally Relevant Pedagogy |
| IB | International Baccalaureate |
| LPS | Lakeside Public Schools |
| LU | Lakeside University |
| MC | Micro-credential |
| MKT | Mathematical Knowledge for Teaching |
| MMTP | Midwest Master Teacher Partnership |
| NCTM | National Council of Teachers of Mathematics |
| NGSS | Next Generation Science Standards |
| NSF | National Science Foundation |
| PCK | Pedagogical Content Knowledge |
| PD | Professional Development |
| PI | Principle Investigator |
| STEM | Science, Technology, Engineering and Mathematics |
| Y1, Y2, etc. | Year 1. Year 2, etc. |
| 5 Practices | The 5 Practices for Orchestrating Productive Mathematics Discourse (Smith & Stein, 2018) |

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# Chapter 1: Introduction

I spent 20 years as a secondary mathematics teacher. In both schools where I taught, professional development was often presented to the entire staff regardless of the subject. Professional learning was something done *to* teachers: it was planned by building administrators, learning committees, and school support teachers or was mandated by the district's leadership. Occasionally, a select group of teachers were asked to assist, but these opportunities were few and far between. At times, the presenters offered a caveat: "Math teachers, you might have to adapt what we're talking about. It might not be applicable to what you're teaching." Occasionally, we were able to engage in work by department, but more often, these sessions required us to follow a specified agenda and fill out some form or other in the name of accountability.

We all looked forward to attending conferences because we could have a say in choosing our learning experiences. However, over the years, these opportunities became increasingly rare. As much as these short presentations inspired us, there was never follow-up and we were not always able to find ways to integrate what we learned into our teaching, aside from adding in a cool activity or two. Consequently, our teaching never really changed over the long-term.

As we gained experience, some of my colleagues came to resent professional development days. Colleagues would choose to take a sick day rather than sit in the library and watch PowerPoints about ideas that did not connect well with what we were doing in our own classrooms. We were expected to formulate plans for what we would do with the latest expectation for teaching, although follow-up and feedback were virtually nonexistent. There was a sense that "this too shall pass," and if we waited long enough, the "Powers That Be" would move on to the next big fad in education.

My experiences reflect decades of teacher disempowerment. In 2011, Wisconsin teachers protested for several months against Act 10, a state law that gutted collective bargaining rights for unions that represented public employees and introduced more restrictive working requirements on teachers (Johnson, 2021). In 2018 and 2019, teachers in states such as West Virginia, Oklahoma, and Colorado called statewide strikes to protest their working conditions, lack of resources, and budget cuts that have left teachers earning at least 15% less than other professionals with similar educations (Van Dam, 2019). These laws and policies have chipped away at teachers' resources, professionalism, and even their dignity. Currently, young teachers leave the profession in droves, with between one-fifth and one-third leaving within five years (L. Gray & Taie, 2015).

When I left my classroom position to begin a PhD program, I began working with the Midwest Master Teacher Partnership (MMTP). I quickly learned that professional development could be different. Teachers could craft learning experiences for themselves using their classrooms. They could decide what they wanted to investigate in their practice, get input from other teachers, create the means to investigate their questions, see what students did in response to changes, share the results with their colleagues, and get feedback that would allow them to refine their inquiries. The professional development in which they engaged centered the teacher and took into account their individual classrooms, school contexts, and students. It honored their years of experience and knowledge as educators while helping them build new knowledge. It provided a space for both the individuals and the community as a whole to wrestle with important questions that they raised about their beliefs and practices. It allowed the community to learn together through the sharing of research results and collective feedback.

I visited the classrooms of every participating teacher each spring to conduct observations. As the years passed, I began to notice changes in the teachers' practice. Teachers were choosing different tasks for their students. There was more of a focus on students' understanding of mathematics and ways of using mathematics rather than on practicing mathematical procedures. Students were working in different configurations and were having different conversations. As the teachers engaged in action research, I perceived a shift in attitude that indicated that they were not completing the work just because it was expected—another hoop to jump through—but because they started seeing the benefit of teaching differently. Their professional learning appeared to make a difference, and I became more and more interested in examining how these teachers' knowledge, teaching, and attitudes toward professional learning changed over the course of their five years with MMTP.

## Problem Statement

Even though teachers have common experiences as professionals, they have different learning needs at different points in their career (Broad & Evans, 2006; Day & Sachs, 2004; Huberman, 1995; Steffy & Wolfe, 2001). In the first two to three years, new teachers are still learning. They are focused on building their understanding of the mechanics of teaching. In their preservice programs, beginning teachers were exposed to a multitude of practices that they now need to figure out how to implement. These beginning teachers are often focused on getting through each day. (Hargreaves, 2000)

Between approximately the third and fifth years, teachers begin to experiment with different methods (Broad & Evans, 2006; Huberman, 1995). They start building routines for the day-to-day work of teaching and refining their initial practice. They hone their practice as they build their pedagogical knowledge and make connections between their mathematical knowledge and their classrooms. As teachers learn what works (or does not work) for themselves and their students, they refine some practices and reject others. They tinker with different practices they learned about in their preservice years. They begin to adapt these practices for work with different groups of students and students with different needs. They see how the adaptations play out. They make adjustments based on their observations. These newer teachers are still learning and can be receptive to the professional development (PD) presented at their schools.

As teachers gain experience, they become settled into their routines. Their pedagogical knowledge and mathematical knowledge used in teaching become more solidified (Broad & Evans, 2006; Huberman, 1995). Experienced teachers have a better sense of students' knowledge at the beginning of an academic year, owing to their stronger mathematical knowledge for teaching (Ball et al., 2008). They hold stronger opinions about students' mathematical understandings (Beswick, 2012). Experienced teachers' beliefs about teaching and learning become solidified through their years of experience and their observations about what students will do, for instance, when presented with new material or with material that builds on concepts that were previously taught. Although experienced teachers can still be receptive to learning about new practices and adapting existing practices, overall, their practices are likely to become more difficult to impact. Experienced teachers' practices are deeply tied to their pedagogical knowledge and so transforming practice means that they need to engage in professional learning that transforms their knowledge and understanding about teaching and learning.

These experienced teachers can become less receptive to the PD at their schools (Day & Sachs, 2004). Previous PD may have emphasized contradictory practices, not received sufficient follow-through, or not taken their position as teachers of mathematics into account. Previous PD may have been focused superficially on practices and routines rather than on the pedagogical knowledge that supports effective practices (Banilower et al., 2018). Experienced teachers may become resentful if they feel like they are being taught as though they had no prior knowledge on a topic or if they think that the topic has no relevance for them as math teachers (Supovitz & Zief, 2000). Although they may love learning and be receptive to learning about new practices, they can become discouraged when they perceive a lack of agency and a lack of consideration for their needs as experienced teachers.

## Background

Teachers have a special kind of knowledge, *Pedagogical Content Knowledge,* that is used specifically for teaching and that other experts in the field do not have (Shulman, 1986). For teachers of mathematics, we call this *Mathematical Content Knowledge* (Ball et al., 2008). Teachers also hold beliefs about teaching, how students learn, and who can learn that influence their teaching (NCTM, 2014). Teachers' knowledge and beliefs influence the content they choose to teach, the ways they have students engage with that content, and student outcomes (Boston, 2013; Boston & Smith, 2009; Copur-Gencturk, 2015; Hill, Blunk, et al., 2008; Wilhelm, 2014), although the connection between teacher learning and student outcomes is not clear-cut.

While we expect all teachers to continue to learn throughout their careers (NCTM, 2014), and despite a consensus on characteristics that make professional development effective, professional development practices for mathematics teachers can vary widely from place to place. Professional development should be coherent over long periods of time rather than fragmented and disconnected from the daily work of teaching (Loucks-Horsley & Matsumoto, 1999; Smith, 2001). Learning should take place within a community of learners (Lave & Wenger, 1991; Smith, 2001). Teachers have knowledge and ways of learning that differ from the children they teach, and teachers' experience, prior knowledge, and needs should be acknowledged and honored in ways that motivate learning and contribute to changes in beliefs and practices (Bransford et al., 2000; Knowles, 1989; Wlodowski, 2008). However, it is also important that teachers encounter ideas that cause cognitive dissonance and discomfort and have enough time to work through this dissonance to transform their teaching practices. Additionally, teachers at different stages in their career have different learning needs and different motivations for learning (Broad & Evans, 2006; Day & Sachs, 2004; Huberman, 1995; Steffy & Wolfe, 2001).

One way to address the learning needs of experienced mathematics teachers is to engage in teacher action research, a cyclic process where teachers ask questions about their own practice, see what previous studies have shown about the question of interest, create a plan to investigate the question within their classroom, collect and analyze data, share the results with the community, and use the results and community feedback to refine the questions and begin a new investigation (Newton, 2006; Pine, 2009). Micro-credentials employ teacher action research as a method to verify teachers' competence in a very specific skill (Center for Teaching Quality & Digital Promise, 2017).

## Statement of Purpose

The purpose of this comparative case study is to explore the professional learning pathways, the changes in knowledge and practices, and the attitudes toward professional learning for four mathematics teachers in the Midwest Master Teacher Partnership, a five-year teacher learning project that was a collaboration between an urban university and a large urban school district.

## Research Questions

In this dissertation, I will answer the following question: How have teachers' practices changed through their participation in a practice-based professional development project? This question has multiple sub-questions that I will consider:

1) What trajectories did teachers' changes in practice take?
    a) How did the nature of their participation in MMTP impact teachers' pedagogical practice?
2) How did teachers' mathematical knowledge for teaching and beliefs about teaching mathematics evolve over the course of MMTP?
3) What pathways did teachers take in their professional learning with MMTP?
    a) What factors shaped their movement on the pathways?
    b) How did the nature of their participation in MMTP impact teachers' attitudes toward professional development and their thoughts about future engagement in professional learning?

## Significance

This study will add to our knowledge of how teachers learn, specifically experienced teachers in the middle of their careers. It will demonstrate the need to design teacher learning opportunities and PD that takes teachers' career stage into account Finally, it will demonstrate that designing PD that allows experienced teachers agency over their learning can result in changes to practice and changes in teachers' attitudes toward professional learning.

## Research Design

This comparative case study focuses on four secondary mathematics teachers in a large urban school district who participated in the Midwest Master Teacher Partnership. Each teacher began the project with eight to nine years of experience. The four teachers came to teaching through different pathways (both as a first career after college and as a second career after time in the business world). They taught at schools with different characteristics and demographics, and they taught classes from Algebra I through Calculus.

Throughout MMTP, we accumulated a large amount of data. I analyzed a subset of the existing data as part of my study, including teachers' original application materials, video recordings of annual classroom observations, pre- and post-observation interviews, the teachers' micro-credential submissions, and the teachers' annual reflections on their learning and teaching practices. Additionally, I conducted a final interview with each teacher that focused on their learning experiences over the five years, their perceptions of how their practices and beliefs have changed since they began MMTP, and their thoughts about their professional learning with MMTP and in the future.

## Limitations/Delimitations

There is a large set of existing data that was largely not analyzed as MMTP progressed. Some data has not been reviewed for several years, and my original thoughts on that data may be lost due to the passage of time.

The four teachers in this case study are all white, middle-class, native English speakers with master's degrees. Consequently, the data is not a representative sample of the district's teachers.

My position on the MMTP leadership team afforded me greater access to the teachers than I would have had if I had been an outside observer. However, my close relationships with each of the teachers may have caused me to construct different meanings from the data and I may not have seen themes that would be evident to an outsider.

This study does not directly or quantitatively measure student learning outcomes or teacher knowledge. These quantitative measurements are beyond the scope of the study.

# Chapter 2: Review of the Literature

As a profession, teachers are continuously learning. Many states have provisions in their licensing requirements that oblige teachers to submit proof of meeting these continuing education requirements, often in the form of college credits. Additionally, professional organizations at the national, regional, state, and local levels offer professional development opportunities to teachers. For instance, the National Council of Teachers of Mathematics (NCTM) hosts an annual national conference, several annual regional conferences, multiple webcasts and webinars, and single-topic workshops. Schools and districts offer professional development at local levels, providing learning experiences to their teachers with the goal of impacting student learning within that school or district. The predominant part of this review of the literature will focus on these local professional learning opportunities.

Local professional development can vary greatly. In some locations, an all-staff meeting or department meeting might be considered professional development. Some teachers work as a community, using their teaching as a learning experience. Others are isolated in secondary schools where they are the only teacher of mathematics or where the school does not provide the time or structures necessary for teachers to collaborate effectively. Sometimes, professional learning is aimed at the entire staff and may contain advice that can harm students' opportunities to learn mathematics deeply; best practices in reading, for instance, may cause harm in mathematics instruction. However, as I will demonstrate, teacher professional development that seeks to impact mathematics teachers' practices and student learning should be based on the practice of those teachers.

In this review of the literature, I will discuss models of pedagogical content knowledge and mathematical knowledge for teaching and how mathematical knowledge for teaching is important for student learning. I will investigate the research base for models of professional development and identify common elements that are considered effective, including research on how adults learn. I will provide examples of teacher professional development that were successful in improving teacher knowledge, changing teacher practices, positively impacting teacher attitudes and beliefs about mathematics instruction, or improving student learning. I will connect these elements to teacher action research as a mode for teacher learning and, in turn, to micro-credentialing as a system that offers support and acknowledgment of learning to teachers engaged in learning through action research.

## Statement of the Problem

Teachers enter the profession with knowledge from many different sources: student teaching experiences, university courses in education, and their own experiences as students when they were children. Some teachers come from other professions and bring with them knowledge gained in their work in that profession. Yet it has been known for decades that this preparation is not sufficient and that many teachers learn and improve through the process of teaching and through their years of experience (Ball & Wilson, 1990; S. M. Wilson et al., 1987).

Teachers begin their careers with multiple kinds of knowledge about teaching and learning. Experiences as students—from the time they were young children and extends through their college years into adulthood—provide the basis of teachers' knowledge about teaching and learning (Lortie, 1975). These experiences can provide a difficult-to-change basis for teachers' own theories of learning and teaching (Lloyd, 1999). Spillane (2000) distinguishes between *principled knowledge* and *procedural knowledge*. Procedural knowledge "centers on computational procedures and involved memorizing and following predetermined steps" (p. 144). Principled knowledge, on the other hand, "focuses on the mathematical ideas and concepts that undergird mathematical procedures" (p. 144). Because many teachers have experiences in their own educational backgrounds of having been taught procedural knowledge, they themselves value and teach procedural knowledge. However, in order for students to develop a deep understanding of mathematics, it is important to develop students' principled knowledge (Kilpatrick et al., 2001; NCTM, 2014). Because of the mismatch between teachers' experiences as students and current expectations for student understanding, teachers often need to examine and transform their beliefs about teaching and learning mathematics to include principled knowledge.

There is evidence that professional learning often does not meet the needs of the teachers involved. Professional development for mathematics teachers may be inappropriate for the needs of the teachers involved and may not be cohesive or consistent enough to enact lasting change in teachers' practices (Sowder, 2007). Professional development often does not contain the types of experiences necessary for teachers to examine their beliefs or time to change those beliefs. More than 25 years ago, Miles (1995) called then-current professional development practices "pedagogically naïve, a demeaning exercise that often leaves its participants more cynical and no more knowledgeable, skilled, or committed than before" (p. vii). Although this may be an alarmist description of the state of teachers' professional learning, in more recent years, Horizon Research has confirmed that over half of all elementary, middle, and secondary mathematics teachers surveyed believe that they are provided with inadequate professional development opportunities (Banilower et al., 2018). Just under half of these same teachers believe that the amount of time allotted for professional development inhibits or has no impact on the effectiveness of instruction in their classroom.

In addition to the inadequacy of professional learning opportunities on impacting teaching and learning, professional development may not account for teachers' experiences and their needs at different stages in their careers. In the first few years, teachers are still learning about and experimenting with different ways to manage their classrooms, understand student thinking, improve student engagement, and assess student learning (Broad & Evans, 2006; Huberman, 1995; Steffy & Wolfe, 2001). In contrast, teachers who have solidified their identities and developed routines can develop a sense of skepticism and even alienation when they are expected to (re)learn previously-learned ideas as if they were new, in ways that do not address their needs as experienced teachers, or in ways that do not address their underlying beliefs about teaching and learning.

Locally-based PD has the potential to impact student learning because it is focused on the needs of specific students and, ideally, on the needs of specific teachers (Smith, 2001; Sowder, 2007). Professional learning modes that are based in a teacher's practice, use the school community, attend to mathematical knowledge for teaching, and provide teachers feedback on their learning (such as action research) are most likely to correlate with increased student learning. It is for these reasons that I will focus my questions and this review of the literature on the intersection of practice-based PD and the learning needs of teachers at the different stages in their careers.

## Research Questions

My questions focus on a locally-based professional development model for experienced secondary mathematics teachers that incorporates teacher action research as a critical component of teacher learning. I am interested in ways that this model engaged participants in ways that were different from previous professional learning and the resulting impacts (if any) on their attitudes toward professional learning. Additionally, I was interested in examining the evolution of their teaching practices and changes in their knowledge and beliefs about teaching and learning.

In this dissertation, I will answer the following question: How have teachers' practices changed through their participation in a practice-based professional development project? This question has multiple sub-questions that I consider:

1) What trajectories did teachers' changes in practice take?
    a) How did the nature of their participation in MMTP impact teachers' pedagogical practice?
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    b) How did the nature of their participation in MMTP impact teachers' attitudes toward professional development and their thoughts about future engagement in professional learning?

## Teacher Knowledge and Beliefs

Many people use mathematics in their everyday lives. Accountants, teachers, chemists, architects, engineers, and baseball statisticians all have a common understanding of mathematics through their extended study of the subject in preparation for their respective careers and through the work they do. However, teachers of mathematics have an additional kind of knowledge of the content they teach, called *pedagogical content knowledge*, that is unique to the work of teaching and not found elsewhere. In this section, I will examine the origins of the study of pedagogical content knowledge. I will outline prominent models of pedagogical content knowledge as it applies to mathematics teachers. I will connect improvement in teacher knowledge with improvement in student learning outcomes using a number of lenses, including examining the types of tasks that secondary mathematics teachers use in their classrooms and ways in which improved teacher knowledge helps teachers examine pervasive deficit narratives present in schools. In turn, these understandings will lead to an examination of models of teacher learning that can support teachers' pedagogical content knowledge.

**Pedagogical Content Knowledge**

Several types of knowledge are valuable for teachers. First, society expects teachers to be knowledgeable in the content that they teach. Physics teachers are expected to know physics. History teachers are expected to know history. Secondary mathematics teachers are expected to have mathematical knowledge equivalent to a college major in mathematics; however, this knowledge alone is insufficient for teachers (Ball & Wilson, 1990). We expect teachers to have a second kind of knowledge as well: a solid foundation of pedagogical knowledge. Over one hundred years ago, Dewey (1902) stated that, "Every study or subject thus has two aspects: one for the scientist as a scientist; the other for the teacher as a teacher. These two aspects are in no sense opposed or conflicting. But neither are they immediately identical" (p. 29). More recently, Ma (1999) expanded upon this idea:

> To lead a thoughtful discussion once students have expressed all their ideas, a teacher needs a thorough comprehension of this topic. He or she should know these various solutions of the problem, know how and why students come up with them, know the relationship between the non-standard ways and the standard way, and know the single conception underlying all the different ways. (p. 14)

The implication of Ma's assertion is that teachers of mathematics must know mathematics beyond that used by a non-teacher since the tasks she listed are exclusive to the work of teaching.

When Shulman (1986) investigated teacher knowledge in the mid-1980s, he found several shifts in how teacher knowledge had been measured over the previous century. In the late 19th Century, exams of teacher knowledge consisted mostly of questions relating to teachers' content knowledge with very few questions related to pedagogy. In contrast, Shulman found that a predominant part of exams in the 1980s consisted of general pedagogical questions without connection to the subject matter: lesson planning, assessment, procedures, and discipline, among other categories. Shulman pointed out that these approaches missed the intersection of content and pedagogy.

Shulman (1986, 1987) proposed that teachers have another type of knowledge that combined knowledge of the subject with knowledge of pedagogy. Shulman labeled this *pedagogical content knowledge* (PCK). This type of knowledge, Shulman said, "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (1986, p. 9). It includes, among other things, the best ways of representing or explaining a topic, common misconceptions that students may bring with them to their learning, ways to diagnose errors in thinking, and strategies for teaching that are specific to certain topics or subject areas.

Shulman (1986) also proposed that teachers possess *curricular content knowledge*, defined as knowledge of the educational progression of a subject through a child's school career, including different programs for teaching the subject, instructional materials, and positive and negative characteristics for each program or set of materials. Shulman asserted that teachers should understand the multitude of curricular options that they could use in instruction.

In subsequent work, Shulman expanded upon the knowledge of teachers to include *knowledge of learners and their characteristics*; *knowledge of educational contexts*; and *knowledge of educational ends, purposes, and values* (Shulman, 1987). However, he asserted that pedagogical content knowledge was of most interest to education researchers because:

> It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from the pedagogue. (p. 8)

Since Shulman's original call to action, researchers have investigated knowledge used by teachers both generally and within specific subject areas. Often, knowledge used in teaching is not fully developed when a teacher begins their career but rather is developed as the teacher gains experience (Ball & Wilson, 1990; S. M. Wilson et al., 1987). Pedagogical content knowledge is shaped by several sources: prior knowledge and beliefs; the apprenticeship of observation, learning about teaching from personal experiences as a student in K-12 and undergraduate education; teachers' personal knowledge of the content area, gained through work in the discipline; teachers' professional coursework as a student of education; and teachers' classroom experience as an instructor (Grossman, 1990; Lortie, 1975; Morine-Dershimer & Kent, 1999). Prior beliefs about teaching arise from teachers' experiences as students and influence what teachers learn in their preservice education. Because they form the initial lens through which the teacher learns, these prior beliefs permeate all aspects of their learning and can be resistant to change through later PD (Grossman, 1990). Researchers in multiple content areas have expanded upon Shulman's model of PCK, and  have explored subject-specific PCK models in mathematics (Ball et al., 2008; Rowland & Turner, 2007), science (Gess-Newsome & Lederman, 1999; Magnusson et al., 1999), history (Harris & Bain, 2010; Monte-Sano, 2011), and teaching with technology (Mishra & Koehler, 2006), among others.

The construct of PCK, however, has encountered some criticism. One criticism is that the concept of *pedagogical content knowledge* is a structuralist perspective and that it is not universal; rather, it is inseparable from the teacher's context (Carlsen, 1999). Another criticism has been about whether the categories of pedagogical content knowledge are discrete or overlapping, and if a valid distinction can be made between content knowledge and pedagogical content knowledge. (Dapaepe et al., 2013).

In educational research, the pedagogical knowledge of mathematics teachers has received significant attention. Researchers in both the United States and worldwide have developed models of mathematical knowledge for teaching. I will now turn to a more thorough examination of this knowledge specific to mathematics teachers.

**Mathematical Knowledge for Teaching**

In mathematics education, researchers have examined the knowledge of mathematics teachers. A number of earlier researchers looked at teacher knowledge and mathematics subject matter knowledge (e.g. Clark & Lampert, 1986; Clark & Peterson, 1984; Leinhardt & Smith, 1984). Following Shulman's call to investigate PCK, researchers in mathematics education have examined not just teachers' mathematical knowledge but also how teachers use their mathematical knowledge in their practice. For instance, Ma (1999) described the teacher with a *profound understanding of fundamental mathematics* as "not only aware of the conceptual structure and basic attitudes of mathematics inherent in elementary mathematics, but is able to teach them to students" (p. xxiv). Fennema, Carpenter, and colleagues (Carpenter et al., 1989; Fennema et al., 1996) incorporated pedagogical content knowledge into their research by including examinations of teachers' knowledge of what children know and can do mathematically, moving beyond examinations of teachers' procedural knowledge.

Mathematics education researchers have developed several models of pedagogical content knowledge. Some of the models situate teacher knowledge within the teacher (e.g. Ball et al., 2008; Fennema & Franke, 1992; Shulman, 1987), while others situate knowledge within the teaching situation (Rowland & Turner, 2007; Venkat & Adler, 2014) There are, however, a number of commonalities across multiple models.

All models of mathematics teacher knowledge include attention to content knowledge in some form (Ball et al., 2008; Baumert et al., 2010; Fennema & Franke, 1992; Ma, 1999; Rowland & Turner, 2007; Shulman, 1987). It is critical for teachers of mathematics at all levels to have a solid conceptual understanding of mathematics both in the grade(s) or course(s) that they teach and in previous and subsequent grades or courses, as well as an understanding of the conceptual foundations of mathematics as a whole.

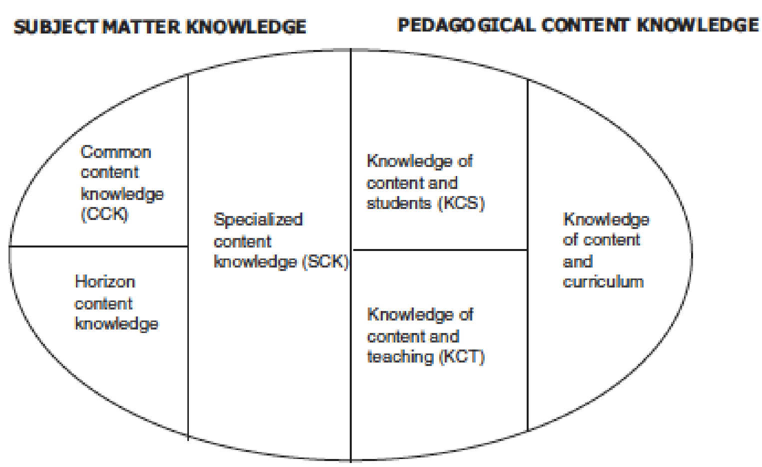
All models of mathematics teacher knowledge include a category of content knowledge that is specific to teachers and not used in other settings. Many models label this as *pedagogical content knowledge* (Ball et al., 2008; Baumert et al., 2010; Shulman, 1987), but this descriptor is not universal. This knowledge includes teachers' knowledge of mathematical representations and how they connect (Ball et al., 2008; Fennema & Franke, 1992; Ma, 1999) and ways to present mathematics so students can learn, including selection of mathematical tasks and teaching strategies (Ball et al., 2008; Baumert et al., 2010; Rowland et al., 2005).

Models of mathematics teacher knowledge include other types of knowledge as well, but none are as universal as the previous two. Several models provide a separate type of knowledge of students and how they learn, including how children learn, how students might approach a mathematical task, and what errors students might make (Ball et al., 2008; Fennema & Franke, 1992; Rowland et al., 2005; Shulman, 1987). Multiple models include other types of teacher knowledge: teachers' general knowledge of teaching and pedagogy (separate from mathematics teaching) (Fennema & Franke, 1992; Shulman, 1987); knowledge of curriculum, coherence, and long-term views of past and future topics within the study of mathematics (Ball et al., 2008; Ma, 1999; Rowland et al., 2005; Shulman, 1987); or knowledge of instructional design (Ball et al., 2008; Rowland et al., 2005).

In the United States, the predominant model for mathematical knowledge for teaching (MKT) was developed by Ball and colleagues (Ball, Thames, & Phelps, 2008; Hill, Rowan, & Ball, 2005; and others). Figure 1 shows the six domains of mathematical knowledge for teaching divided into two groups: *subject matter knowledge* and *pedagogical content knowledge*. Subject matter knowledge (SMK) refers to knowledge of mathematics, and pedagogical content knowledge refers to knowledge of mathematics as it is used in teaching.

**Figure 1**

*Mathematical Knowledge for Teaching (Ball et al., 2008, p. 403).*




Briefly, *common content knowledge* is knowledge that is known and used by a typical user or practitioner of mathematics (Ball et al., 2008), including everyday knowledge used in the real world (such as balancing a checkbook) as well as knowledge used in specialized settings such as business, science, and mathematics. *Specialized content knowledge* is mathematical knowledge specific to those who teach mathematics and includes a mathematics teacher's ability to evaluate student reasoning, break down mathematical processes and algorithms into methods that allow students to make sense of them, formulate goals for mathematical learning, and construct lessons and activities to help students move toward those goals. *Horizon content knowledge* is vertical knowledge of mathematics across multiple grades. *Knowledge of content and curriculum* is lateral knowledge of mathematics across a particular grade. *Knowledge of content and students* is knowledge that teachers have about students and how they learn. *Knowledge of content and teaching* requires teachers to understand sequencing of topics and tasks, as well as choosing appropriate examples and representations for the topics and tasks that are best suited to learning.

There is considerable overlap in these domains that makes measuring a single aspect of teacher knowledge problematic (Hill et al., 2005). Teachers' common content knowledge of mathematics is inextricably tied with their specialized mathematical knowledge and pedagogical knowledge (Carlsen, 1999; Krauss et al., 2008; P. H. Wilson et al., 2013). Efforts have been made to distinguish between the two but assessment of one without assessing the other has been difficult. Steele (2013) differentiated tasks intended to measure specialized mathematical knowledge and common mathematical knowledge of secondary geometry teachers, but noted that capturing the nuances of teacher knowledge required a significant time investment. Hill, Ball, and Schilling (2008) devised a measurement of teachers' knowledge of content and students, but found that it was difficult to distinguish knowledge of content and students from other domains of content knowledge.

An additional problem is that what is knowledge of content and students for one teacher can be specialized content knowledge for a different teacher, depending on the approach each takes and the amount of experience each teacher has (Ball et al., 2008). Ball and colleagues also acknowledge that the categories may be perceived as static, when in fact knowledge and use of knowledge is anything but static. They stress the importance of examining teacher thinking and rationales and the influence of these on the work of teaching and on the understanding of the work of teaching.

Some examination reveals that while other models of mathematical knowledge for teaching exist, many models are focused on specific domains of mathematics instruction. These include knowledge for algebra teaching (McCrory et al., 2012), knowledge of reasoning and proof (Rogers & Steele, 2016; Stylianides & Ball, 2008), content and pedagogical content knowledge for teaching middle-school mathematics (Saderholm et al., 2010), knowledge for teaching geometry (Mohr-Schroeder et al., 2017; Steele, 2013), and mathematical knowledge for teaching teachers (Castro Superfine & Li, 2014; Masingila et al., 2018). Additionally, some researchers have expanded upon the idea of *key developmental understandings* of mathematics, a construct that describes understandings that are necessary to students' developing understanding of mathematical concepts (such as *a fraction is itself a quantity*) (Silverman & Thompson, 2008; Simon, 2006). This framework demonstrates considerable overlap with specialized content knowledge, knowledge of content and students, and knowledge of content and teaching (Ball et al., 2008).

**Teacher Beliefs**

Researchers have examined teachers' beliefs and their impact on classroom practice and student learning; however, it has proven difficult to distinguish *belief* from *knowledge*. Some researchers provide distinctions (Philipp, 2007), whereas others hold them as indistinguishable (Beswick, 2012). Although there is no consensus on the definitions of *belief* and *knowledge*, in his review of the literature, Philipp drew upon a number of sources and constructed a working definition of *beliefs* as "psychologically held understandings, premises, or propositions about the world thought to be true" (p. 259) and *knowledge* as "beliefs held with certainty or justified to true belief" (p. 259). In other words, knowledge is a belief that one sees as true and has a rationale for determining that truth. Philipp pointed out that knowledge is often agreed-upon by a community, whereas beliefs are personal. Knowledge is generally interpreted as black-and-white—something either *is* or it *isn't*, whereas beliefs exist within shades of gray. However, given that nature of truth itself is debated among researchers and philosophers, knowledge for one person can be a belief for another, and vice versa (D. E. Gray, 2014).

Belief systems can be viewed as dynamic or static (A. G. Thompson, 1992). Thompson held the view that beliefs are dynamic and can be changed through experience. Additionally, beliefs depend on an individual's context, and an individual may hold beliefs that conflict with each other with no perception of cognitive dissonance (Philipp, 2007).

Teachers hold many beliefs about mathematics, teaching, learning, and students. These beliefs impact classroom practice and student learning by influencing the decisions teachers make about instruction (NCTM, 2014). Rather than using evaluative judgments such as *good* or *bad*, we can consider beliefs as *productive* or *unproductive* by examining their impact on teaching and learning. Unproductive beliefs hinder student access to mathematics by impeding the use of instructional practices known to be effective, whereas productive beliefs foster use of effective instructional practices and student access to mathematics.

The beliefs that teachers publicly profess can differ from the practices exhibited in their teaching. Beliefs impact the way teachers structure all aspects of their teaching, from classroom setup to lesson planning to implementation to assessment and all points in between (Cross, 2009). As such, teachers' beliefs have the potential to impact student learning and students' mathematical identities. Cohen (1990) said, "Students will not learn a new mathematics unless teachers know it and teach it" (p. 326). However, this must extend into beliefs as well: Students will not learn a new mathematics unless teachers believe it is valuable and teach in ways that communicate that student understanding of the mathematics is valuable.

Teachers hold multiple types of beliefs about teaching. I will constrain my focus to three overlapping categories: beliefs about mathematics, beliefs about teaching and learning, and beliefs about students. In the following sections, I will expand upon some of the beliefs that teachers hold in each of these categories. Despite considerable overlap in these three categories, when looking across different strands of research, the categories do not map well onto each other. There are enough differences to warrant separate examination.

***Beliefs about Mathematics and Teaching Mathematics***

Researchers have outlined frameworks to describe beliefs about mathematics as a discipline and mathematics as it is taught in schools. Some teachers hold a *traditional school-mathematics perspective*: a belief that mathematics is not connected to human experience and that students receive mathematical knowledge by listening to others talk about mathematics and watching others do mathematics (Simon et al., 2000). Mathematics is meant to be *absorbed*. Other teachers hold a *conception-based perspective*: a belief that mathematics is a part of human knowledge and knowing, that it is inseparable from their experiences, that people's current beliefs mediate what they learn and understand, and that mathematical learning is a transformative process. Mathematics is meant to be *experienced*. Still other teachers fall somewhere in between and hold a *perception-based perspective*: a belief that mathematics is an objective, interconnected body of work and that learning mathematics means experiencing mathematics and mathematical situations. Mathematics is meant to be *perceived*.

These views echo differing views of the nature of mathematics, with some teachers holding an *instrumentalist* view, where mathematics is a collection of facts, rules, and procedures; others holding a *Platonist* view, where mathematics is an unchanging body of knowledge awaiting discovery; and still others holding a *problem-solving* view, where mathematics is a dynamic process and a human invention situated within cultures and societies (Beswick, 2012; Ernest, 1989). Teachers can hold views about school mathematics that complement or contradict views about the discipline of mathematics. For instance, a teacher who believes that school mathematics is about having students master basic skills so mathematics for be enjoyed (outside of school) as a creative human activity holds an instrumentalist view of school mathematics but a problem-solving view of mathematics as a discipline. One consequence of these different belief structures about mathematics is that they lead different teachers to have different conceptions of what it means to be mathematically proficient. One teacher may view proficiency as being able to use mathematical skills and procedures in everyday life, where another may see proficiency as understanding the interconnectedness of mathematical concepts and procedures.

Another model of beliefs about mathematics concerns orientations toward mathematics. Teachers and students with *calculational* orientations view mathematics as a means to obtain a numerical result (A. G. Thompson et al., 1994). This orientation is not synonymous with the instrumentalist view described above; rather, teachers with a calculational orientation can hold a problem-solving view of mathematics and teaching but still emphasize the procedures and/or calculations used to obtain an answer. Teachers and students with a *conceptual* orientation shift focus away from the specific procedures toward mathematical relationships, representations, arguments, and other ways of thinking about mathematics as a system of ideas.

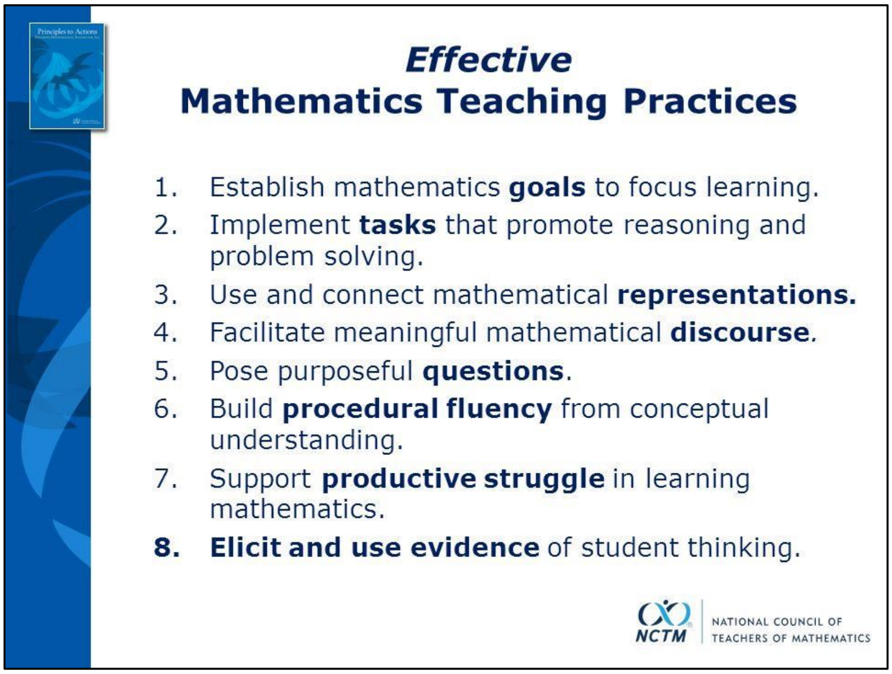
***Beliefs about Teaching Mathematics and How Students Learn***

One view of mathematics learning is that mathematics proficiency consists of five strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick et al., 2001). Rather than being a system of rules and procedures, this view portrays mathematics as a complex intermingling of these five strands, each inextricably connected with the others and each being necessary for the picture of mathematics as a whole. In this model, good mathematics teaching and learning attends to all five strands of mathematics proficiency and does not emphasize one or two over others.

*Principles to Actions*, a recent synthesis of research about mathematics instruction, identified eight effective teaching practices and categorized beliefs as *productive* or *unproductive* according to the degree to which the belief fosters or hinders student access to important mathematical ideas, development of student proficiency in the five strands described above, and teacher use of the eight effective teaching practices (see Figure 2) (NCTM, 2014). For instance, an unproductive belief would be that students must be fluent in basic skills and procedures before engaging in learning about mathematical concepts or solving real-world problems. A corresponding productive belief would be that students should develop conceptual understanding and engage in real-world modeling using mathematics as a means of developing procedural fluency.

**Figure 2**

*Eight Research-based Effective Mathematics Teaching Practices (NCTM, 2014, p. 10)*




***Beliefs about Students, Who Can Learn, and How They Learn***

Everyone has implicit biases about other people. Preconceptions about students' race, home language, gender, social class, and other identities impact teachers' perceptions about who is capable of learning mathematics. Perceptions of students from backgrounds different from the teachers' own have lasting impacts on all students and on students' access to high-quality learning experiences that allow them to reason about and make sense of mathematics in ways that engage all five strands of mathematics proficiency.

Beliefs about group identities are deeply rooted in American politics and cultural narratives (Gutiérrez, 2018; Valencia, 2010). Perceptions about students and learning can be—intentionally or unintentionally—framed using deficit narratives about students, their families, and their culture. These narratives—along with systemic factors such as segregation, school finance inequities, and lack of access to high-quality curriculum and highly-qualified teachers—

are harmful and remove opportunities for students to learn and understand mathematics deeply.

Because beliefs about students, who can learn, and how they learn are so deeply embedded in the thinking of the dominant culture, entire groups of children are sequestered into qualitatively different classes based on behavior and arbitrary readiness-to-learn qualities rather than on existing knowledge (Aguirre et al., 2013; NCTM, 2018). Beliefs that comply with the dominant culture as a measure of intellectual capability harm all children's opportunities to engage with mathematical ideas and discount the multiple assets students bring to the classroom with them.

Although the above paragraphs describe ways in which teachers' beliefs can harm students, there are also belief frameworks that can benefit students. For example, teachers who use culturally responsive methods believe students' cultures are important in learning and teaching; they find ways to leverage students' personal, cultural, and community assets to support the learning of all students (Hammond, 2015; Parker et al., 2017). Culturally responsive teachers believe it is necessary to be aware of their own beliefs and attitudes about students and learning, and these teachers try apply their knowledge of their students in ways that increase opportunities to learn.

In summary, teachers can have beliefs about mathematics (as a field) and mathematics (as a school subject) that are traditional, conception based, or problem-solving based. They can have conceptual or calculational views of the field of mathematics. Teachers can have productive views of mathematics teaching that foster students' opportunities to engage with important mathematical ideas and develop proficiency in the five strands by using effective teaching practices, or they can have unproductive beliefs that hinder student access and hamper use of effective practices. Last, teachers hold beliefs about students and have different attitudes toward the interrogation of those beliefs. Their beliefs about students impact the tasks teachers choose, the expectations teachers have for students, and the ways teachers have students engage with mathematics, potentially leading to significantly different learning outcomes for different groups of students. Understanding the relationship between knowledge and beliefs and the implications of both, I will turn to examining the importance attending to both in teacher learning.

**Why Teacher Knowledge and Beliefs Are Important**

Mathematical knowledge for teaching impacts what teachers do in the classroom and how they think about their practice. As such, MKT also correlates with student learning for urban and suburban students and students from high-poverty backgrounds. (Hill et al., 2005). Given that students from such backgrounds are less likely to have a highly-qualified, experienced teacher (Goldhaber et al., 2015; Papay et al., 2017), these results are encouraging. The implication is that pedagogical content knowledge is an important piece in determining how much and how well students learn mathematics.

Others contend that content knowledge is only one piece required for high-quality mathematics instruction and that teachers also must have knowledge of and use effective instructional practices. While MKT and quality of instruction are correlated, additional factors likely impact the quality of a teacher’s instruction, such as verbal ability and general pedagogical knowledge (Hill, Blunk, et al., 2008). Additionally, elementary students of teachers trained in specific instructional practices showed greater growth in achievement than students of teachers who did not use the practices studied, reinforcing the correlation between MKT, teaching practice, and student learning (Ottmar et al., 2015). Thus, while MKT is important in teaching, teachers must also know how to use their knowledge in ways that will successfully improve student learning.

In addition to teacher knowledge, teachers' beliefs also impact what they do in the classroom and how they think about their practice. Although there is not a clear research consensus, some researchers have found connections between teacher beliefs and classroom practices, that teachers' belief structures play an important role in the ways they teach mathematics and that the teachers' practices and beliefs mutually reinforce each other (Chapman, 2002; Stipek et al., 2001). However, this correlation is not absolute; some teachers share beliefs consistent with reform mathematics instruction but have practices that are more consistent with traditional mathematics instruction and do not reflect those beliefs (Cross, 2009; Polly et al., 2013). Nonetheless, beliefs about how students learn (transmission vs. constructivist) have been significantly linked with teaching practices (teacher- vs. student-centered). Consequently, teacher beliefs can have impacts on student learning and students' attitudes and beliefs about themselves as learners and doers of mathematics.

In considering the significance of teacher knowledge and beliefs, it is important to make connections from teacher learning experiences with student outcomes. This connection, while it may be intuitive, has been difficult to support with research. This may be a result of the multitude of mediating factors at play between teacher learning and the implementation of that learning by students in the classroom. In the next section, I will unpack several of these mediating factors.

**Linking Teachers' Professional Learning with Improvement in Student Outcomes**

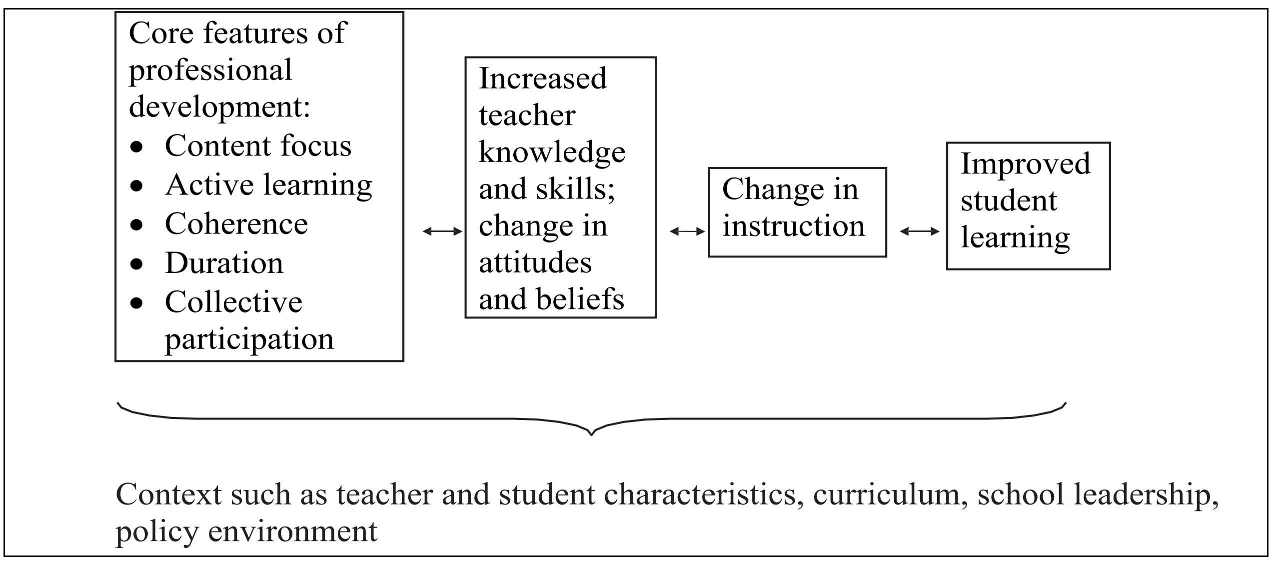
Establishing a link between teacher learning and student outcomes is complex. Studies that attempted to link PD with student outcomes directly have had mixed results (Jacob et al., 2017). Additionally, "different approaches to teacher development [may] have different effects on particular aspects of teachers' pedagogical content knowledge" (Ball et al., 2008, p. 405).

However, as demonstrated in a previous section, the domains of MKT are not discrete, and clarifying these domains may help teacher educators to better plan for mathematics teacher learning experiences.

Desimone (2009) proposed a theory of action for professional development and five core features of professional development that would result in the proposed changes (see Figure 3). PD using these core features would increase teacher knowledge, causing teachers to adapt instruction and leading to improved student outcomes.

**Figure 3**

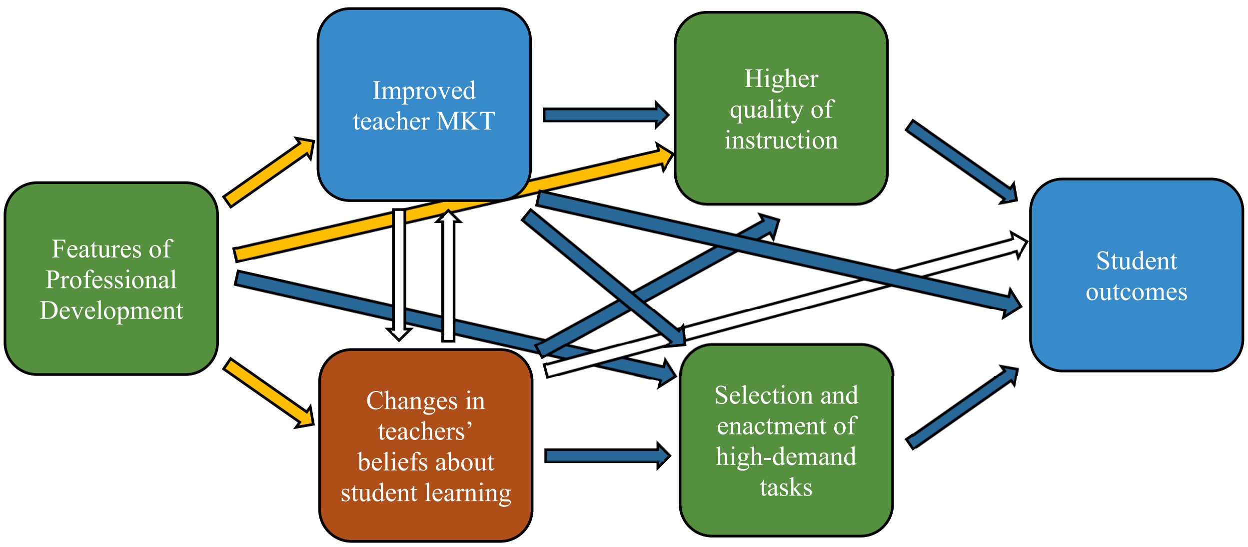
*Proposed Core Conceptual Framework for Studying the Effects of Professional Development on Teachers and Students (Desimone, 2009, p. 185)*




For my purposes, I will expand upon Desimone's model to provide more specific information about the changes in instruction that should take place in order to connect teacher learning through professional development with student outcomes. Connecting these two is not straightforward and involves multiple mediating factors: for instance, teacher knowledge, quality of instruction, MKT, and task selection (Figure 4). I will examine a subset of these incremental connections in the following sections. Note that these are not the only mediating factors or connections. This set of factors and connections was selected as being under the control of those involved in MMTP, related to the design features of practice-based professional development, and within the context of this locally-focused PD project.

**Figure 4**

*Incremental Factors Involved in Connecting Teacher Professional Development with Student Achievement.*




***Linking Cognitive Demand of Tasks with Student Outcomes***

In mathematics education, cognitive demand is a framework that "categoriz[es] mathematical tasks on the basis of the type(s) of thinking that the task requires of students" (Arbaugh & Brown, 2004, p. 28). Early researchers focused on the mathematical tasks students were asked to do in their mathematics classes and how the classroom work related to student learning (Doyle, 1988; Silver & Stein, 1996). This work led to the development of the five levels of cognitive demand (Stein & Lane, 1996). Cognitive demand describes "the kind and level of thinking required of students in order to successfully engage with and solve the [mathematical] task" (Stein et al., 2009, p. 1). Tasks with a high level of cognitive demand are classified in one of two categories: doing mathematics and procedures with connections to meaning. *Doing* *mathematics* tasks are not solvable using procedures or algorithms but require flexible thinking, offer multiple ways of thinking about the task, and may have multiple solutions that can be justified using reasoning (Stein & Smith, 1998). Tasks involving *procedures with connection to meaning* require students to think about underlying mathematical ideas when solving a problem, and they may require students to use a procedure or algorithm. However, the use of a procedure itself is not sufficient in the problem; students must make connections to the mathematical concepts by using different representations (graphs, equations, symbols, diagrams, and descriptions) or an understanding of the procedures and mathematical concepts being used.

Tasks with a low level of cognitive demand do not necessitate understanding of mathematical concepts. They can be solved through the use of procedures or algorithms alone or by memorization (Stein & Smith, 1998). Tasks involving *procedures without connections to meaning* are tasks that center on getting a correct answer rather than making sense of the mathematical concepts, where a required explanation is often a justification of the answer rather than a connection requiring deeper understanding. *Memorization* tasks are not solved with procedures or algorithms but by recall of facts or definitions with no requirement that students make connections to the mathematical concepts involved. The fifth level of cognitive demand, *unsystematic exploration*, is only visible during enactment of the task. It is characterized by a teachers' attempt to engage students with mathematical concepts but an ultimate failure in engaging students in gaining an understanding of those concepts.

Multiple levels of cognitive demand are useful in instruction. However, conceptual understanding of mathematics should be used as a basis for students' procedural fluency (NCTM, 2014). In order to build procedural fluency and flexibility of thinking about how and when to appropriately use procedures, students must have a solid grasp on the mathematical concepts underlying those procedures (Fuson et al., 2005). Since high-demand tasks support students' conceptual understanding, high-demand tasks must precede low-demand tasks in instruction.

Tasks pass through multiple phases from the beginning of planning to their enactment by students (Doyle, 1988; Stein et al., 1996). Tasks are presented in the learning materials, the teacher uses those materials to plan implementation of the task, the teacher presents the task to students, and the students interpret the task. At any transition between these phases, the cognitive demand of the task can change. A task as written in instructional materials can have the cognitive demand maintained, raised, or lowered during planning. The cognitive demand of a task can be maintained or lowered during enactment and, once lowered, demand does not rise again during instruction (Henningsen & Stein, 1997).

Selection and enactment of high demand tasks correlate with improved student outcomes (Boston & Smith, 2009; Henningsen & Stein, 1997; Stein & Lane, 1996). Tasks set up and implemented at high levels of cognitive demand produce stronger growth in students' mathematical knowledge than tasks set up at a high level of cognitive demand but implemented at a low level. Students who use tasks that were set up and implemented at low levels of cognitive demand grow the least.

### *Linking Professional Development and Teacher Knowledge with an Increase in the Cognitive Demand of Mathematical Tasks*

Professional development that focuses on teachers' selection and enactment of cognitively demanding tasks and reflections on the use of these tasks in the classroom leads to increased selection and maintenance of high cognitive demand tasks by secondary mathematics teachers (Boston, 2006, 2013; Boston & Smith, 2009, 2011). Additionally, the researchers followed up with some of the participating teachers two years after the PD and found that some of them were still selecting and enacting more cognitively demanding tasks than they had been prior to the PD.

Explicitly providing teachers experiences with high-demand tasks is important because, often, secondary mathematics textbooks do not provide sufficient cognitively demanding tasks (Jones & Tarr, 2007; Polikoff, 2015; Sears & Chávez, 2014). Additionally, even when they are provided, teachers may lower the level of demand during teaching (Candela, 2016; McDuffie et al., 2018; Otten & Soria, 2014). A cursory look at the 46 secondary textbook series reviewed by EdReports, a non-profit organization that examines alignment of textbooks with the Common Core State Standards, revealed that over half of the series do not fully provide learning experiences with enough depth for students to meet the expectations of the standards, including attention to conceptual understanding of mathematical ideas, building procedural fluency from conceptual understanding, and applications that allow students to engage in mathematical modeling (EdReports, 2021). When teachers do have a curriculum or text with high-demand tasks, the level of demand can change during enactment of the tasks (Henningsen & Stein, 1997; Remillard & Heck, 2014). Engaging in PD that includes a focus on selection and enactment of high-demand tasks can lead to maintenance of cognitive demand during instruction (Boston, 2006, 2013; Boston & Smith, 2009, 2011).

Teachers with higher MKT tend to select high cognitive demand mathematical tasks, spend more time having students engage with high-demand tasks, and maintain the cognitive demand of the selected tasks during instruction (Charalambous, 2010; Garrison, 2011; Wilhelm, 2014). Wilhelm found that teachers in the first quartile of MKT were significantly more likely than teachers in the second, third, or fourth quartiles to select low cognitive demand mathematical tasks. Wilhelm also found that teachers in the fourth quartile of MKT were significantly more likely than teachers in the other three quartiles to select high-cognitive-demand tasks and to maintain the cognitive demand during enactment of the task.

Teachers' MKT also influences their adaptation of mathematics tasks and curriculum. Teachers' decisions about enactment of curriculum are mediated (in part) by teachers' mathematical knowledge, beliefs about teaching mathematics, knowledge of instructional strategies, and knowledge of how mathematical understanding is built both within and across grades (Brown, 2009; Remillard, 2005; Remillard & Heck, 2014). Teachers with insufficient Knowledge of Content and Curriculum tend to plateau earlier in their implementation of *Standards*-based curriculum, reducing the investigative nature of complex tasks and undermining the intention of the authors (Banilower et al., 2006; Silver et al., 2009).

***Linking Teacher Beliefs with Selection and Enactment of High-Demand Tasks***

Teachers with a problem-solving view of mathematics tend to select tasks that are more cognitively demanding than teachers with more traditional views of mathematics (Beswick, 2012; Polly et al., 2013). Teachers with beliefs about the role of the teacher that are consistent with effective teaching practices are more likely to offer students more opportunities to learn mathematics more deeply than teachers who view the role of the teacher as a distributor of knowledge (Garrison, 2011). Likewise, teachers who do not hold productive beliefs about students' capabilities tend to select low-demand tasks, decrease the level of high-demand tasks during planning and/or enactment, or spend less time having students engage with a high-demand task (Garrison, 2011; Wilhelm et al., 2017). Even more troubling, the tasks that teachers give students do not always offer students opportunities to engage with grade-level content standards (TNTP, 2018).

Teachers who believe that some students have cultural deficits—that some students come from backgrounds that lack or discourage the necessary knowledge for success in mathematics—tend to choose tasks that are more skill-oriented for students from backgrounds with perceived deficits and choose richer tasks for students who they perceive not to have deficits (Anyon, 1981; Sztajn, 2003). These students are often students of color, students whose first language is not English, and students from low-socioeconomic backgrounds. However, there is the possibility that teacher practice and teacher beliefs about students are mutually reinforcing. When teachers see changes in student outcomes as a result of a change in practice, those outcomes can impact the teachers' beliefs about students and learning (Philipp, 2007).

### *Linking Teacher Knowledge with Quality of Instruction*

Teachers with stronger MKT demonstrate an overall higher quality of instruction and greater use of effective mathematics teaching practices (Copur-Gencturk, 2015; Hill, Blunk, et al., 2008). Teachers whose mathematical knowledge for teaching increased showed an associated increase in use of lessons that incorporated stronger support for students' conceptual understanding (including use of multiple representation), an increased emphasis on making sense of mathematical meaning, increased use of mathematical language, increased connections between mathematical concepts and the related mathematical procedures, and more appropriate teacher responses to students and student thinking. Additionally, teachers with more developed MKT tend to view student struggle as an essential element of the learning process (Charalambous, 2010).

### *Linking Quality of Instruction with Student Outcomes*

Researchers have linked the quality of mathematical instruction with improved student outcomes. For decades, NCTM has advocated for high-quality instructional practices as the foundation for student learning (NCTM, 1991, 2000, 2014). High-quality instructional practices are associated with gains in student achievement (Boaler & Staples, 2008; Hill et al., 2005; Kunter et al., 2013), and in NCTM's vision, "students are active learners, constructing their knowledge of mathematics through exploration, discussion, and reflection" (Boston et al., 2017). This vision requires teacher work before, during, and after instruction. Teachers must set goals that will focus learning (Hiebert et al., 2007; Wiggins & McTighe, 2005) and choose mathematical tasks that allow opportunities for students to explore mathematics and construct mathematical knowledge (Boaler & Staples, 2008; Stein et al., 1996, 2009). These tasks should allow students to construct mathematical meaning and build an understanding of mathematical concepts through the use of multiple representations (Bransford, Brown, & Cocking, 2000; Fuson et al., 2005; Kilpatrick et al., 2001; NGA & CCSSO, 2010). Teachers must plan for and facilitate meaningful discourse around these multiple representations using the work of students themselves (Smith & Stein, 2018). Teachers must be able to ask questions that advance student learning (Herbel-Eisenmann & Breyfogle, 2005), assess what students understand mathematically (Sherin & van Es, 2003), and know how to support students' struggles productively as they learn (Warshauer, 2015).

A consideration in linking quality of instruction to student learning is the method used to measure instructional quality. Researchers involved in the Measures of Effective Teaching Project note that "Teaching is a complex interaction among teachers, students, and content" (Archer et al., 2014, p. 1). Measurements of quality of instruction showed variation by teacher grade level, measurement instrument used, student perceptions of the teacher, and working conditions, among other factors (Kane et al., 2014). Additionally, the position of the observer—whether that person is a peer or administrator, whether the observer knows the teacher or does not know the teacher, whether the observer has pre-existing impressions of the teacher—impacted evaluations of teaching practice (Ho & Kane, 2013).

***Linking Teacher Knowledge with Student Outcomes***

Studies connecting teachers' MKT and elementary school students' outcomes have yielded positive results. Teachers with higher MKT produced larger student gains than teachers with lower MKT, especially for students of low socioeconomic status (Baumert et al., 2010; Campbell et al., 2014; Hill et al., 2005; Jacobs et al., 2007). Student outcomes were not significantly linked with either teachers' years of experience or with mathematics content courses or teaching methods courses that the teachers took as part of their preservice work.

A search for parallel studies of secondary teachers yielded few relevant results; most studies of secondary teachers connected teachers' mathematical knowledge with student learning gains without specific attention to teachers' pedagogical content knowledge (Krauss et al., 2008) or linked improved student learning with secondary math teacher certification and preservice content courses (Darling-Hammond, 2000; National Mathematics Advisory Panel, 2008). This dearth of research on mathematical knowledge for teaching for secondary mathematics teachers has been noted by others as well (Hill & Ball, 2009).

However, there are a few studies that have attempted to link secondary teachers' MKT with student outcomes. Some used student outcomes to measure effectiveness of teacher PD; a systematic review of the literature revealed two studies (of five that met the criteria for the review) that showed a significant increase in student learning that could be attributed to teacher learning (Gersten et al., 2014). A separate meta-analysis found two studies (out of 16 that met the criteria for inclusion)[1] involving mathematics teacher knowledge that included secondary teachers (Blank & de las Alas, 2009). Both studies, a dissertation and a report, were not peer-reviewed. These studies showed an effect size on secondary student achievement that was smaller than the effect size on elementary student achievement, but still statistically significant.

***Linking Teacher Beliefs with Quality of Instruction.***

Studies linking teacher beliefs with instructional practices have yielded mixed results. This may be due to the types of beliefs being measured or to the methods of ascertaining teacher beliefs. Beliefs cannot be directly observed; researchers must rely on other means of eliciting teacher beliefs about teaching, learning, and students. For instance, interviews and surveys are susceptible to social desirability bias (Maruyama & Ryan, 2014). Some researchers have found high degrees of consistency between teachers' beliefs and their classroom practices, with teachers having views of mathematics as conceptual tending to use more student-centered teaching practices than teachers who saw mathematics as procedural (Beswick, 2012; Chapman, 2002; Stipek et al., 2001). Other researchers have not seen these associations (Cross, 2009; Polly et al., 2013).

Inconsistencies between teachers' beliefs about the nature of mathematics and the nature of school mathematics have the potential to cause teachers to reveal possible inconsistencies in their practice (Beswick, 2012; Philipp, 2007), such as teachers focusing on skills or procedures more than their professed beliefs might lead one to expect. However, studies on this appear to be extremely limited and it is difficult to draw conclusions about the effects of such inconsistencies.

[1] The two studies identified by Blank and de las Alas are not the same studies found by Gersten, et al. due to differences in the search criteria.

***Linking Professional Development with Improvements in Teacher Knowledge, Changes in Instruction, and Changes in Teachers' Attitudes and Beliefs about Student Learning***

There are numerous studies of teacher professional development. Some consensus exists on the elements of professional development that contribute to improvements in teachers' MKT, changes in teaching practices, and impacts on teachers' beliefs. Given that teachers' professional learning is a key topic in this study, I will expand upon these characteristics and the impacts of these characteristics in the next section of this chapter.

## Teacher Learning

NCTM's Professionalism Principle offers a challenge to schools, districts, and teachers of mathematics:

> In an excellent mathematics program, educators hold themselves and their colleagues accountable for the mathematical success of every student and for personal and collective professional growth toward effective teaching and learning of mathematics (NCTM, 2014, p. 99).

Given the charge of engaging in professional growth, it makes sense to consider the aspects of teacher learning that are particularly effective in changing teachers' knowledge, beliefs, and practices and for increasing student success in mathematics.

Professional development is a standard expectation of every teacher. PD is built into schools' and districts' calendars and schedules. In some places, "PD" is a catch-all term for any group experience: periodic, short bursts of information in whole-staff and department meetings, times in which teachers sit together in a cafeteria and listen to a speaker reading PowerPoint slides, something inflicted upon teachers from above. It is synonymous with training, pouring knowledge into teachers' brains using methods teachers themselves are dissuaded from using. It is something to do on top of the other requirements of teaching. On the rare occasion a teacher can attend a conference or workshop, these are often done without the expectation that the local school or district will follow through with the teacher's learning.

Borko (2004) asserts that the millions of dollars spent nationally on professional development are "fragmented, intellectually superficial, and do not take into account what we know about how teachers learn" (p. 3). In a large-scale analysis of teacher learning opportunities, Garet et al. (2001) found that the majority of teacher professional learning opportunities do not take into consideration factors that are known to improve teacher knowledge and skills. For instance, most teachers experienced professional development activities which lasted four days or less. There appeared to be little coherence in the activities. Additionally, only half of the teachers reported that the work focused on specific content knowledge.

Given the importance of teacher knowledge on student learning gains (as demonstrated in the previous section) and the varied contexts and methods in which teachers learn, it becomes necessary to examine the ways in which teachers can be supported in their learning. It is important for all teachers to understand mathematics deeply, to understand how students learn mathematics, and to know how best to support student learning. It is important to listen to what children are saying about mathematics, recognize the strategies that students use, and use those strategies in instruction to build students' understanding (Sowder, 2007). These practices go hand-in-hand with teachers' personal conceptual knowledge of mathematics and their prior experiences with learning themselves; teachers will replicate how they themselves were taught in elementary and high school.

It is often more difficult to impact teachers' conceptual understandings of mathematics and their beliefs about teaching and learning than it is to change their individual use of a teaching practice (Desimone & Garet, 2015; Sowder, 2007). Nevertheless, Wilhelm (2014) showed that improvements in MKT through teacher learning can have an impact on teachers' choices of mathematical tasks used with students. Even if a teacher's mathematical knowledge does not change much through learning, teaching itself is a learning exercise and teachers can improve their own understandings through the use of high cognitive demand tasks (Desimone, 2009).

Day and Sachs (2004) outlined five phases that teachers pass through during their career. In the fourth phase, about fifteen years into a teaching career, teachers typically reach a professional plateau and follow one of two paths. One path leads to stagnation and disillusionment, while the other leads toward continuing learning and pursuing ways of increasing student learning. Day and Sachs stressed that, although teachers in the last ten to fifteen years of teaching are the most expert in the profession, they also become "skeptical about the virtues of change" (p. 11), and "may feel marginalized within the institution and embittered towards those whom they see as responsible for the condition of education, schooling and the declining standards of the students they must teach" (p. 12). Given the existence of this critical point in a teacher's career, it is imperative that, prior to this point, professional development providers find ways to engage teachers in learning that is relevant to the teachers' needs at each career phase and to improve teachers' knowledge in ways that conform to what we know about how they best learn.

**Determining the Effectiveness of Professional Development**

In the second half of this chapter, I will discuss professional development practices that researchers have established as effective. Examining the goals of professional development can provide a means to enter into evaluating the effectiveness of PD. Often, researchers have goals that emphasize improving multiple aspects of teacher knowledge; attention to both mathematical knowledge and pedagogical content knowledge is important (Doerr et al., 2010; Smith, 2001; Sowder, 2007). Another common goal is that teachers should be able to understand and respond to student thinking in ways that move students' mathematical understanding forward. Community is an important goal in teacher learning, as is consideration of teacher beliefs about themselves as teachers and about student learning.

Examining studies of professional development also provides insight as to how to measure the effectiveness of PD. Many researchers have viewed professional development as "effective" or "successful" if it produced sustainable changes in teachers' practices (Stein et al., 1999), such as increasing use of high cognitive demand tasks (Arbaugh & Brown, 2005; Boston & Smith, 2009; Smith, 2001) or changing discourse patterns or other class interactions (Copur-Gencturk & Papakonstantinou, 2016). Another method for measuring effectiveness has been to examine changes in teachers' mathematical knowledge for teaching (Bell et al., 2010; Hill & Ball, 2004), although most of these studies are with elementary teachers of mathematics. However, teacher knowledge can be difficult to change (Desimone & Garet, 2015).

The lack of a direct connection from teacher learning to student learning outcomes appears to be one weakness in the literature I examined. Ultimately, there should be a means of connecting teacher learning with student outcomes, but very few research studies make this connection explicit. As demonstrated in the previous section, the link appears to be mediated by many other factors. For instance, if there are studies linking specific teaching practices to student outcomes, then one could show that professional development which increases teacher use of those practices should improve student performance. This is an area for further investigation.

In the next section, I will explore the stages of teachers' careers as they relate to their professional learning, focusing on those who have already passed through the initial five to ten years.

**Phases of a Teacher's Career**

Teachers do not all pass through precise, well-defined phases as they move through their careers; their professional trajectories are not so clear-cut (Broad & Evans, 2006). Their needs can vary depending on their age and life stage (which may not correspond to where they are in their careers), personal history and context, present societal context and influences, and other factors on scales ranging from micro to macro, from internal to global (Dall'Alba & Sandberg, 2006).

Rather, teachers at a common place and time in their careers tend to exhibit some similar characteristics, although teachers can progress and regress through a continuum of characteristics; their skills and their understanding of practice both change at different rates and along different trajectories (Dall'Alba & Sandberg, 2006). While the characteristics of each stage of the continuum are not universal and not experienced by all at the same time, they offer an interesting framework upon which to examine the learning that occurs throughout a teacher's career and the motivations for that learning.

Teachers enter the profession while they are still learning (Huberman, 1995; Steffy & Wolfe, 2001). Beginning teachers are not unlike student teachers; they are still learning the mechanics of being a teacher: lesson planning, assessing, classroom management, discipline, communicating with parents, and so on. These first three years of learning are a time of tremendous growth for new teachers, although many are concerned with survival and getting through the next day (Hargreaves, 2000). The focus is on managing all the moving parts of teaching and less on evaluating their own work and improving student outcomes.

Around 20% of Wisconsin teachers will not continue past their first three years and will leave the profession (Wisconsin Department of Public Instruction, 2017, 2018). Nationally, between one-fifth and one-third of all new teachers do not continue past the first five years (L. Gray & Taie, 2015), with attrition being more pronounced for secondary teachers and teachers in schools with higher poverty rates (L. Gray & Taie, 2015). For those who do continue, the next two to three years are a period of exploration where the teacher settles into the day-to-day routine of their work and begins to interrogate their own practice, looking at different methods to improve student engagement, student learning, or another aspect of the work that the teacher finds troublesome (Broad & Evans, 2006; Huberman, 1995). This experimentation allows teachers to refine their practice and move beyond what they learned about in school.

Around five to ten years into teaching, as teachers discover what works for them, they settle into familiar routines that are more difficult to impact because the routines are tied to beliefs that lead from the teachers' experiences (Broad & Evans, 2006; Huberman, 1995). Teachers' identities become solidified through these experiences. Teachers can find the predictability of these routines comforting, especially if they teach the same grade or course from year to year. In this time of their careers, teachers face a wide range of choices about how to continue their professional learning. Teachers experience differing degrees of burnout (Garrett Holbert, 2015). They can become disillusioned with PD and feel as though "everything that goes around, comes around" and develop a sense that "this too shall pass" when they encounter PD that contains ideas they have seen before and that have not been followed through upon. The ideas presented are not distinct from those seen in past PD and some teachers do not see a need to expend the effort on new initiatives that they either feel are the same as older (abandoned) initiatives or are not going be followed through. However, no one enters the teaching profession thinking, "I never want to learn anything ever again."

Around 15 years into a teaching career, teachers can reach a professional plateau and follow one of two paths (Day, 1999; Day & Sachs, 2004; Huberman, 1995). One path leads to stagnation and disillusionment and the other leads toward continuing learning and pursuing ways of increasing student learning. Day and Sachs (2004) stressed that, although teachers in the last ten to fifteen years of teaching are the most expert in the profession, that they also become "skeptical about the virtues of change" (p. 11) and "may feel marginalized within the institution and embittered towards those whom they see as responsible for the condition of education, schooling and the declining standards of the students they must teach" (p. 12). Given the existence of this critical point in a teacher's career, it is imperative that professional development providers find ways to engage teachers in learning that is relevant to the teachers' needs at each teacher's career phase and to improve teachers' knowledge in ways that conform to what we know about how they best learn. I would also argue that this phase is also critical for students since students who have a teacher whose practice stagnates are missing out on crucial opportunities to learn.

When PD is presented as one-shot learning with little-to-no follow-through with individual teachers, they can become disenchanted with trying new methods (Broad & Evans, 2006; Tomlinson, 2018). These experiences demonstrate that the leaders may not necessarily be committed to changes and are themselves not using the best practices in their teacher learning sessions, checking with the teachers to solicit feedback, or helping teachers change beliefs thats led to their present practices. On the other hand, teachers whose professional learning experiences that are continuous over time; are assessed for impact on student learning and engagement; and are based in the teachers' own existing knowledge and experiences, professional learning needs, communities, classrooms, and contexts are more likely to see changes in beliefs, practices, and student learning (Baumert et al., 2010; Boston & Smith, 2011; Copur-Gencturk, 2015; Kunter et al., 2013).

The existing literature does not connect these teacher learning conditions to teachers' career stages. Anecdotally, the conditions listed in the previous paragraph should be particularly effective for teachers who are past the first five to seven years of survival and experimentation, already on a trajectory of pedagogical change and teacher leadership, and relish the idea of continuous learning (Maskit, 2011). These are teachers whose contextual factors, personal beliefs and attitudes toward learning, and ambitions predispose them toward leadership roles and enthusiasm for continued pedagogical change.

The above conditions should also be effective with teachers who are settled into their careers and classroom routines, helping them see benefits of exploring different practices on student learning and engagement. These are teachers who are comfortable in their careers, having developed a set of routines and practices that they feel work for them and their students. They feel as though they can teach on autopilot, using the same lesson plans and PowerPoint presentations from year to year with minimal changes. However, the above conditions may not be effective with teachers who are disillusioned with teaching and the state of education or who are suffering from some degree of burnout.

Next, I will turn to these elements of professional development that researchers have found to be particularly effective in impacting teacher knowledge and beliefs, classroom instructional practices, and student learning. I will emphasize the importance of centering the teacher and the work of teaching in professional learning and connect these elements to underlying theories of learning.

**Structuring Professional Development**

Many researchers have conducted studies of teachers' professional learning and found that some methods are more effective than others in impacting teacher knowledge, teachers' beliefs about teaching and learning, and classroom. In this section, I will examine elements of professional development found to be effective and outline a framework for effective professional development.

The teacher themself must be at the center of teacher learning. Learning experiences must support the work of teaching and take teachers' contexts into account (Loucks-Horsley et al., 2009; Stein et al., 1998, 1999). Honoring the knowledge and expertise experienced teachers bring with them and respecting the demands of their professional contexts makes learning pragmatic and can provide teachers with the motivation necessary for incorporating new knowledge into their practice (Wlodowski, 2008). Additionally, providing teachers with rationales for learning that are connected to their existing knowledge and practices can help them be more receptive to new learning (Knowles, 1989).

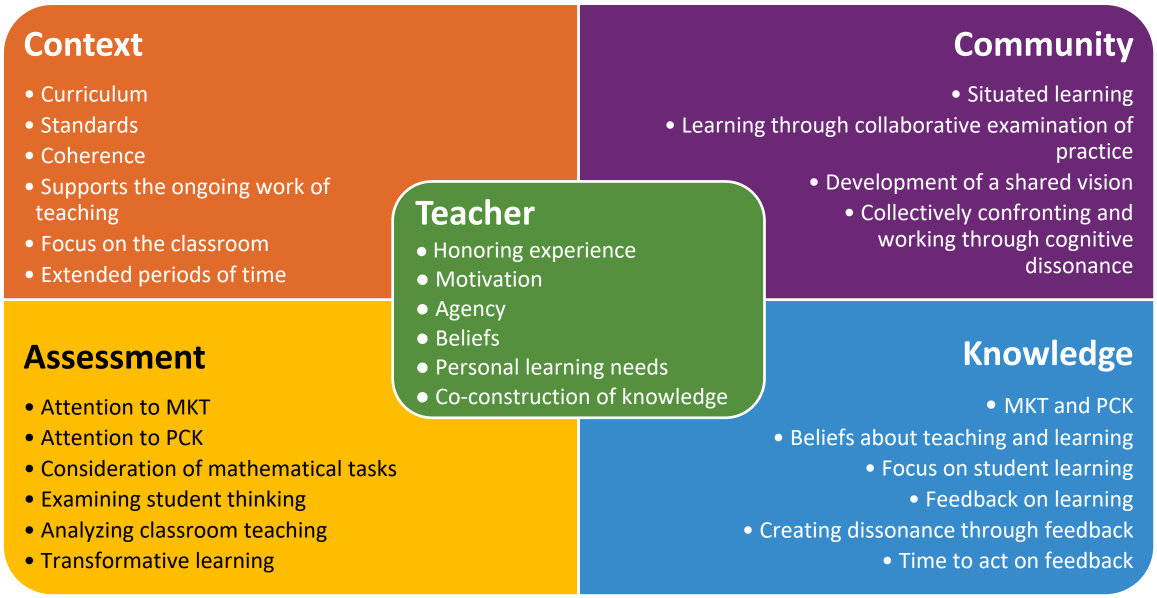
Researchers have offered frameworks for teacher learning. These frameworks have common elements, as there is some consensus about what makes professional development effective. In addition to centering teachers and the work of teaching, teachers need to engage with mathematics content as learners (Bransford et al., 2000; Loucks-Horsley & Matsumoto, 1999; Stein et al., 1998, 1999). Teacher learning should take place within a community of practice and incorporate collaboration, both within the school and with experts from outside the school community. Professional development needs to take teachers' contexts into consideration, including the culture of the school or district, existing policies and procedures, and other expectations at the local or state level.

Rather than trying to teach specific skills or training teachers in new techniques, PD leaders must take teachers' existing knowledge and beliefs into account (C. L. Thompson & Zeuli, 1999). Focusing on surface features (structure, cooperative learning, or an assortment of techniques) will not produce changes in teachers' beliefs or practices; rather, leaders must work to help teachers identify and interrogate their beliefs about teaching and learning in order to effect productive changes in practice. This type of learning requires that teachers receive assessment and feedback on the implementation of their learning (Bransford et al., 2000; Loucks-Horsley & Matsumoto, 1999). Additionally, teachers themselves must effectively assess the impact of their practices and changes in practice on student learning (Hawley & Valli, 1999).

Loucks-Horsley and Matsumoto (1999) and Bransford, Brown, and Cocking (2000) provide a framework for learning environments. In the framework, PD needs to be learner-centered; knowledge-centered, focusing on the content and pedagogy of the subject; assessment-centered, using regular feedback and measures of student progress to judge the effectiveness of the learning; and community-centered, using the community of teacher-learners to build collective knowledge. In alignment with these multiple components, I will use an adaptation of their framework to guide the sections that follow. I have placed the teacher at the heart of the framework and separated *community* and *context* into two different categories. I also use the word *oriented* rather than *centered* to keep the central focus of professional learning on the teachers themselves. In the following sections, I will expand upon each of the elements in this framework and explain why each is important in designing learning experiences for teachers.

**Figure 5**

*Components of Professional Learning*




### *Teacher-Centered Learning*

Teachers themselves must be the central consideration in professional learning (Loucks-Horsley et al., 2009; Smith, 2001; Stein et al., 1999). Less experienced teachers may be receptive to a top-down approach to teacher learning opportunities, but as teachers gain experience and their beliefs and practices stabilize, they become more skeptical to top-down approaches to learning. As they gain more experience, teachers' professional identities become linked to and impacted by their lived experiences and their existing knowledge, beliefs, and practices. As adults, their motivation to learn is often impacted by their perception of what and why they are being asked to learn and their own sense of agency surrounding the learning (Bandura, 2001; Knowles, 1989). If adults understand the reason for learning and the benefits, they will gain from what they are learning and they will be more receptive to the learning experience.

Productive PD is characterized by attention to teachers' motivation and agency. Several factors mediate teachers' motivation to learn: What (and why) are they being asked to learn?

What (and why) do they want to learn? Teachers are pragmatic learners (Wlodowski, 2008). They learn about things that they want to learn about, things that they need to learn about, things that they will be successful at, and things from which they derive enjoyment. It is important that learning be relevant in some way to the adult learner.

Motivation to learn is also mediated by teachers' agency, which allows learners to have voice and choice in their learning experiences. Internal motivation is a very powerful factor in adults' desire to pursue learning and knowledge (Ryan & Deci, 2000). It is important to adult learners that they have some degree of control over their own learning; adults will often resent learning that they find unimportant or learning that is forced upon them (Wlodowski, 2008). Extrinsic rewards, pressures, and threats can impact a person's perceived autonomy and can all negatively impact intrinsic motivation and cause teachers to become disillusioned with their professional learning opportunities.

Teachers themselves are individuals who have their own learning needs and goals. Leaders should be conscientious of teachers' existing learning goals and practices as indicators of knowledge and beliefs, and they use this knowledge as a basis for new learning (Putnam & Borko, 2000; Smith, 2001). Learning experiences must specifically and explicitly address teachers' beliefs about teaching and learning since individuals make sense of new learning within the context of what they already know (Farmer et al., 2003). Additionally, leaders must provide time and space for teachers to work through cognitive dissonance caused by contradictions between what they are learning and their existing beliefs (Mezirow, 1990).

Experiential learning opportunities allow teachers to construct knowledge and make meaning of their learning (Fenwick, 2001). Experience itself does not necessarily lead to learning, but experiences within the context of professional learning that provide time and space for reflection and processing can help teachers make sense of new knowledge, their experiences, and how they fit with their previous understandings and beliefs (Kolb, 1984; McLeod, 2013). Experiential learning is a cycle of having concrete experiences, reflective observation about those experiences, developing conclusions about the experience and integrating these as learning, formulating new plans to experiment with new understandings, and then returning to concrete experiences.

Additionally, teachers are adults (not children) and need to be treated as such. Expecting teachers to learn in the same way children do is unreasonable (Knowles, 1989). Although leaders want to (and should) model good pedagogy and practices, they must also use methods that are appropriate for adults and honor the knowledge adults bring with them to their learning.

Centering teacher learning also means centering teachers' contexts, community, knowledge as part of their learning, as well as assessment of and reflection on both their students' and their own growth and learning. I will turn to an examination of these elements in the next sections.

***Context-Oriented Learning***

Professional development should take teachers' contexts into account and be consistent with other work within their context: curriculum, content standards, other professional learning, school or district initiatives and priorities, standardized testing requirements, state mandates, and so on (Copur-Gencturk & Papakonstantinou, 2016; Doerr et al., 2010; Loucks-Horsley et al., 2009; Loucks-Horsley & Matsumoto, 1999; Smith, 2001; Stein et al., 1999). Supporting the ongoing work of teaching and attending to teachers' contexts makes the work personal for teachers. Grounding learning experiences within the work of the teachers themselves helps them connect the learning directly to their own classrooms (Putnam & Borko, 2000). Professional learning that is built upon previous teacher learning and that is aligned with standards and assessments used in the teachers' contexts can be effective in improving teacher knowledge.

Attending to context (including other professional learning, alignment with existing expectations, and collaboration among teachers) positively supports changes in teachers' practices, even after controlling for new learning (Garet et al., 2001). Learning is situated within the learner, the learning community, and the context of the learners (Lave & Wenger, 1991; Putnam & Borko, 2000), so learning for the classroom needs to take the classroom into consideration. This can be done by incorporating examination of student work, classroom observations, case studies, classroom data, or lesson planning into professional development (Copur-Gencturk & Papakonstantinou, 2016; Loucks-Horsley & Matsumoto, 1999; Smith, 2001; Stein et al., 1998; C. L. Thompson & Zeuli, 1999).

Coherence with other aspects of the school (e.g., assessments, other professional development, local initiatives, state expectations) allows teachers to evaluate the impacts of their learning within their context (Loucks-Horsley et al., 2009; Stein et al., 1999). Considering local needs of teachers by keeping the school and teacher goals in mind as well as including time for teachers to reflect on and plan for how they would integrate new learning into their classroom practice are all pieces that can contribute to changes in practice and new understandings (Koellner et al., 2011).

Connecting professional learning to the work of teaching provides teachers a space for experiential learning (Fenwick, 2001; Smith, 2001). Experiential learning starts with having a concrete experience and reflecting on those experiences; professional learning that is oriented to teachers' contexts provides teachers the opportunity to assess beliefs about their own students' capabilities and test out new understandings. The experiences teachers engage in have the potential to come into conflict with existing beliefs and understandings about students and learning, leading to cognitive dissonance (Hawley & Valli, 1999). Over time, with collaborative, deliberate reflection and processing of this dissonance, these experiences can lead to teachers forming new beliefs about what students know and can do (Mezirow, 1990; C. L. Thompson & Zeuli, 1999). Providing time and coherence with other work in the school or district, teachers can engage in multiple cycles of reflecting on dissonance and receiving feedback on their learning and practices (Arbaugh & Brown, 2005; Copur-Gencturk & Papakonstantinou, 2016; Doerr et al., 2010; Garet et al., 2001; Stein et al., 1998).

Another way to consider teachers' contexts in professional learning is to incorporate collaboration among members of the same school and content area (Loucks-Horsley & Matsumoto, 1999). I will next turn to a discussion of community and collaboration in professional learning.

***Community-Oriented Learning***

Collaboration among teachers situates learning within the teaching community of practice rather than within individual teachers (Lave & Wenger, 1991; Stein et al., 1998). A community of practice is a group of individuals engaged in "sustained pursuit of a shared enterprise" (Wenger, 1998, p. 45). Given that the community of practice is (by definition) a part of a teachers' context, learning within that community of practice offers consistency and coherence with professional learning and other work that is part of a group, department, school, or district.

Learning can occur through the observation and thoughtful examination of the practice of others (Bandura, 1971). Through learning, the community both impacts and is impacted by the learner. Legitimate peripheral participation is the process where newcomers (learners) in a community of practice participate in small ways at the beginning, and gradually increase the amount and responsibility of their participation as time passes (Lave & Wenger, 1991). Rather than being peripheral participants, mid-career teachers are full participants in the community of practice, although they may be peripheral in some aspects, such as when they are integrating new knowledge into their practice. However, for all teachers, working in collaborative learning communities correlates with greater improvements in knowledge and skills as a result of learning (Garet et al., 2001; Sowder, 2007).

A community of practice can encourage a collective vision for teaching and learning. That collective vision can be pre-existing—teachers can come together in a community of practice because they have a shared vision of good teaching and learning—or it can form as a consequence of working as a community of practice. It is important to note that the development of a teacher's or department's vision of mathematics teaching and learning is a process rather than a product (Sowder, 2007). The vision will likely change over time as it is shaped by new learning and experiences on the part of both individuals and the group as a whole. A shared vision is critical in improving student outcomes across a school (Association of Mathematics Teacher Educators, 2017; Sowder, 2007), and without a shared vision on the part of mathematics teachers, it would be difficult (if not impossible) for all students within a school to receive a fair and equitable mathematics experience (Steele & Huhn, 2018). Teachers and leaders must have a shared sense of what it means to teach and learn mathematics and who is capable of learning high-quality mathematics, and they must be capable of communicating that vision to others; pushback from individuals or groups who do not share this vision can have a detrimental effect on those advocating for equitable mathematics teaching and force those seeking change to revert to what has been considered the norm.

Communities of practice offer teachers a place to engage in the iterative process of experiential learning (Fenwick, 2001; Slavit & Nelson, 2010; Sowder, 2007). The community or individuals within the community have an experience and are able to come together in both formal and informal settings to reflect on the experience, learn from the experience, and plan for new experiences. This reflection may cause cognitive dissonance in one or more members of the community, but through engagement in a community of practice, teachers have the opportunity to collectively confront and work through cognitive dissonance. Working through dissonance (rather than avoiding it) is a mechanism for changing beliefs and practices and for transforming knowledge and practices (rather than adding onto existing beliefs and practices).

Knowledge is situated within the community and the context of learning. Given this, I will next examine the importance of orienting learning around different aspects of mathematical knowledge for teaching.

***Knowledge-Oriented Learning***

Good mathematics teaching is dependent upon teachers' knowledge and understanding of both mathematics content and pedagogy. As previously discussed, teacher MKT is linked with quality of instruction, beliefs about student learning, and student outcomes. Grounding the work in mathematical content and reflecting good pedagogy helps improve teachers' mathematical knowledge for teaching, attending to both their pedagogical content knowledge and their specialized content knowledge. (Hill et al., 2005); it also creates a type of apprenticeship through which teachers can learn and integrate parts of their learning before implementing their learning as a cohesive whole (Lave & Wenger, 1991). Loucks-Horsley and Matsumoto (1999) reiterate the importance of grounding professional learning within the content teachers teach. "Content knowledge is key to learning how to teach subject matter so that students understand it. Teachers cannot help students understand what they themselves do not understand" (p. 262). In using content matter, teachers improve their own content knowledge as well as improve their methods for interpreting student work and planning for teaching and student assistance.

High-quality professional development should focus on developing teachers' pedagogical content knowledge through a focus on the work of teaching, specifically how student learn, if students are learning, the mathematics they are teaching, and ways to teach (Copur-Gencturk & Papakonstantinou, 2016; Loucks-Horsley & Matsumoto, 1999). Teachers can engage with the work of teaching through active examination of mathematical tasks, case studies and other records of teaching, mathematical tasks, and student work (Doerr et al., 2010; Putnam & Borko, 2000; Smith, 2001). For instance, teachers should understand how to choose a mathematical task that aligns with learning goals, how to solve the task, the mathematical concepts behind the task, and how students may approach the task. Teachers can collectively analyze the cognitive demand of the mathematics tasks they are using and examine methods for increasing the cognitive demand of the tasks they use in their classrooms, thus changing the opportunities and ways students think mathematically.

Illuminations of student thinking are often student-written work but can also be in other forms, such as transcripts or recordings of interviews or student thought processes as they work (Loucks-Horsley & Matsumoto, 1999; Smith, 2001). When considering student work, teachers must shift their thinking to reflect the thinking of the student. This shift helps teachers uncover student thinking about the mathematical concepts and helps teachers understand both potential and actual understandings and misunderstandings that students can have about the underlying math concepts.

Students' work can demonstrate ways of thinking that may be different from the teacher's (Smith, 2001). By examining student work, teachers can gain a sense of students' knowledge and their familiarity with using mathematical concepts and procedures. Smith emphasizes that student work is best when done within the context of the teacher's own setting. In this instance, teachers would use a task with students and examine the work that the students produce as part of the teachers' own learning. Connecting the work to each teacher's practice makes the implications immediate and practical.

Records of teaching are often written or recorded instances of classroom teaching (Smith, 2001). These can be particularly valuable when a teacher is examining recordings of their own teaching. Teaching episodes allow teachers to analyze classroom practices, questions, decisions, and responses and see how these aspects impact students' opportunities for learning and mathematical thinking. Records of teaching have proven to be particularly useful in impacting teachers' beliefs about teaching (Loucks-Horsley & Matsumoto, 1999)

In order to produce changes in practice, professional learning needs to be transformative rather than additive (Smith, 2001; C. L. Thompson & Zeuli, 1999). In other words, rather than integrate new learning as additions onto existing practices, it is necessary for learning to change teachers' PCK and beliefs. Learning that is additive can feel to the teacher like they are being asked to do one more thing on top of everything else; learning that transforms PCK has the potential to change the way teachers approach planning and teaching on a daily basis so that they are approaching the work differently.

Learning that transforms knowledge involves a process of critical self-reflection and working through disorienting dilemmas, which are significant events in a person's life (Merriam & Bierema, 2014; Mezirow, 1990). Disorienting dilemmas can range from something as significant the death of a loved one or loss of a job to a thought-provoking discussion to contemplation of inequities in the world or workplace. These disorienting dilemmas can cause a person to reassess their own understandings, beliefs, and practices and can be a catalyst for learning at any point in a teacher's career (Day, 1999). Ultimately, transformative learning has the potential to lead to the learner shifting perspectives if they are able to work through the dilemma in a safe and supportive environment.

In education, this transformation can lead to the teacher not merely adopting an isolated activity or integrating a new teaching technique, but to changing how the teacher views the act of teaching itself and to changing classroom practices. Engaging in learning experiences that challenge teachers' existing knowledge and beliefs can create a sense of cognitive dissonance in teachers (Loucks-Horsley & Matsumoto, 1999; C. L. Thompson & Zeuli, 1999); working through this disequilibrium allows teachers to interrogate and transform their existing views about teaching and learning. Ball and Cohen state, "disequilibrium is required for such learning. It would not be sufficient simply to see what one already assumes about students, learning, and content; one would also need to see others' assumptions, differences in their content and effects, or unexpected effects of one's own ideas or practices" (1999, p. 14). Although it is uncomfortable, in order to change their practice, teachers must reevaluate their knowledge in light of what they learn and what they experience as part of their learning. Teachers must also be given support to think about and resolve the cognitive dissonance that their learning has created. This support should include time, a context through which to work through the dissonance, and resources which support the resolution of their internal conflict and ultimately the transformation of their thinking, which is necessary for achieving lasting change (Freire, 2000; Merriam & Bierema, 2014).

In order to determine the impact of learning on teachers' knowledge and beliefs, it becomes necessary to find ways to assess the impact of learning. Next, I will examine ways of assessing the impact of teacher learning.

### ***Assessment-Oriented Learning***

At its heart, PD is about improving student learning; centering students' learning keeps the ultimate focus on the students themselves and supports equitable teaching (NCTM, 2014; Smith, 2001). However, as previously demonstrated, the connection from teacher learning to student learning is mediated by multiple factors. Consequently, leaders may choose to assess and provide feedback on classroom practices, teachers' knowledge, the tasks teachers use in their classrooms, quality of instruction, or a host of other items.

Assessment does not need to always be a formal observation or test; it can take the form of informal discussions or observations. Likewise, feedback does not need to be formal—it can be as simple as teachers sharing what they notice and wonder about an episode of teaching or a discussion (Dobie & Anderson, 2021). What is important is that the assessment and feedback occur, not the formality. Assessment and feedback are both important contributors to teacher learning, and without some kind of feedback on teaching practice, teachers will not know if what they are doing is working. Assessment provides a means for making decisions about teaching.

Assessment can also lead to cognitive dissonance or disorienting dilemmas. Trying something new and seeing what students can do under the new circumstances can cause teachers to question their beliefs about teaching and learning. Continuously reflecting upon the impact of practice on learning can help resolve the dissonance and lead to more productive beliefs about teaching and learning that allow for greater student access to high-quality mathematics.

In addition to receiving feedback, teachers need time to act upon the feedback and be reassessed as needed. The action → assessment → feedback loop needs time to play out multiple times for optimal results, thus reinforcing the idea that professional learning needs to take place over extended periods of time. Likewise, they need time to work through their cognitive dissonance.

One way of structuring professional development that centers teachers and attends to their contexts, communities, knowledge, and assessment is to have them engage in classroom action research. Next, I will turn to a discussion of teacher action research and examine how it can be a catalyst for teacher learning and change in instruction.

**Teacher Action Research**

Teacher action research is a cyclic process of investigating teaching practice (Newton, 2006; Pine, 2009). The teacher asks a question of their practice, examines literature relevant to the question, develops and undertakes a plan of action designed to improve teaching and learning in their classroom, collects data, analyzes the data, and shares the results. The teacher then uses those results to revise their question and begins again with a new plan of action.

Centering teachers' professional learning on action research aligns the learning with many components identified in previous sections as being effective in changing teachers' beliefs, knowledge, and practices (Bransford et al., 2000). Given the nature of teacher action research, it provides an excellent learning opportunity for teachers. First, teacher action research is teacher-centered (Pine, 2009; Souto-Manning, 2012). It places the ongoing work of teaching at the center of the learning experience. It makes use of teachers' existing knowledge and expertise while seeing to move both forward. It provides teachers with motivation to learn because it focuses on learning about something that will help teachers in their own practice (Lopes, 2006). It can create a sense of cognitive dissonance when teachers encounter solutions that may run counter to their own beliefs about how students learn. Additionally, it provides teachers with time to wrestle with and possibly resolve the dissonance, leading to changes in beliefs about teaching and learning (Wallace, 2014). However, even though action research is an ongoing process and is tailored to a teacher's own context, teachers may need support to work through their disequilibrium and may not be able to resolve it by working alone.

Teacher action research relies on teachers' contexts and their own individual work of teaching (Lopes, 2006; Pine, 2009; Reason, 2006). Because it is cyclic, teacher action research can be sustained over long periods of time. It is, by design, connected to the work of each teacher's practice and so the implications are both immediate and practical (Pine, 2009). Teacher action research also allows for a great degree of teacher agency in their learning (Rust, 2009). Teachers choose their topics of study and make connections to their own classrooms. Rather than being recipients, teachers become the constructors of their own knowledge.

Ideally, action research should be done within a community of practice in a school or district, consistent with other work in the school, and supported at multiple levels within the school (other teachers, department leaders, and administrators) (Elliott, 2009; Wenger, 1998). Within the community of practice, teachers work together to investigate common problems of practice and possible solutions. They formulate questions, develop methods and interventions, analyze and make sense of results, and create new plans for moving forward (Capobianco & Feldman, 2006). Rather than informally investigating questions alone, action research provides a structure to professional learning that ensures all teachers can participate in inquiry and share the results of that inquiry with others. However, in order to be effective within the community, the teachers should have a common vision of good teaching and learning, take time to share their results with each other, provide and receive feedback, and revise or formulate new questions for investigation (Edwards & Hensien, 1999; Jaworski, 2006; Pine, 2009; Sowder, 2007).

Teacher action research can help teachers improve their mathematical knowledge for teaching because it focuses on improving teaching and learning (Pine, 2009). It allows the teacher to make different pedagogical decisions and observe the effects of those decisions within their own classroom, making the learning meaningful to their own context. Through the investigation of their own practice, teachers learn more about how students learn and about practices that support learning. By reviewing the literature, teachers expand their knowledge of research about teaching that helps students learn more effectively. Teachers can use the experience of action research to learn about their own practices and beliefs, thereby allowing them to examine the impacts of changes on those practices and potentially on their beliefs.

In addition to pedagogical knowledge, teachers can improve their own mathematical content knowledge by engaging in action research that has them teaching different mathematical concepts or by teaching familiar mathematical concepts in new ways. However, improving mathematical content knowledge could be a weakness of action research and leaders should therefore pay attention to ways in which mathematical concepts can be integrated into action research.

Action research relies on assessment of both student learning and teacher learning (Pine, 2009). Since teachers are changing a classroom practice and observing the impact, the teacher gathers data from students to assess the impact of those practices. These can be classroom assessments, surveys that take student voice into consideration, video recording of teaching, or other forms of data. Action research can employ qualitative methods, quantitative methods, or mixed methods depending on the question and the type of data available. It also allows the teacher to assess their own knowledge and growth as a teacher. Sharing the results of the action research with the community also gives the teacher opportunity to hear feedback and suggestions from others in the community (Jaworski, 2006). Likewise, hearing about other teachers' action research gives the teacher a chance to consider other questions and what the impact might be on their own classroom, potentially leading to new questions for the teacher to investigate.

**Micro-credentialing**

Digital Promise (2020a) defines micro-credentials as "digital certifications that verify an individual's competence in a specific skill or set of skills." As teachers learn to teach, they become certified by the state in which they live. These teaching credentials indicate the grade levels and subject(s) that the educator is broadly qualified to teach. Micro-credentials, on the other hand, certify that a teacher has demonstrated a specific competency (Center for Teaching Quality & Digital Promise, 2017). Through micro-credentials, teachers can demonstrate a wide range of competencies, from "creating a positive STEM learning environment" to "assessing student media" to "providing corrective feedback in a foreign language classroom" (Digital Promise, 2020b).

Teacher micro-credentials (MCs) are developed by individuals or groups (called "issuers") such as state agencies, school districts, university researchers, and nonprofit organizations. MCs are developed with four key design elements: they require a teacher to demonstrate competency in a specific skill; they are personalized, based on the needs and interests of the teacher, their students, school, and/or district and thus are centered around the teacher's own classroom and practice; they are available on demand, so a teacher can work on an MC on their own schedule and within their own time constraints; and they are digitally portable and shareable across multiple electronic platforms (Acree, 2016; Berry et al., 2016). Combined, MCs provide a personalized learning experience where the teacher is in charge of their own learning process, learning goals, learning trajectory, and evidence that demonstrates competence of a skill (Cator et al., 2014). Because of their design, MCs share a symbiotic link with teacher action research. MCs use teacher action research and are assessed based on what the teacher discovered in their own classroom and practice. Within the framework shown in Figure 5, MCs directly focus on teacher knowledge, context, and assessment.

Existing research on educator MC effectiveness in changing teaching is sparse, given that MCs are a recent development in teacher education. Badges have been used to recognize skills throughout history. Video games award badges for specific achievement. Digital badges as a way to recognize learning achievements and professional skills only date back to the mid-2000s (Ostashewski & Reid, 2015). Digital badges in education are even newer, dating back to the early 2010s, and the open electronic infrastructure that provides the basis for the portability of digital badges was developed in 2013 (Gibson et al., 2015). An unfortunate consequence of their relative newness is that MCs are not widely officially recognized by educational agencies (state licensing agencies, districts, universities) and so most teachers do not receive compensation or promotion when they earn MCs, as opposed to earning continuing education credits through conferences or university courses. The world of education is often slow to change, and new innovations like MCs outpace their official recognition. Time will tell if they become a recognized acknowledgement of teacher learning.

A note about terminology: At times, MMTP teachers and members of the MMTP facilitation team used the term “badge” as synonymous with “micro-credential.” These are not fully synonymous. The badge is the recognition a teacher earns for successful completion of a micro-credential, in the same way that a student earns a degree for successful completion of a course of study. Badges (like degrees) represent the accomplishment of successful completion, while the micro-credential represents the actual progression of learning (similar to a course of study). However, in the interest of authenticity, I do not change direct quotes these words are used interchangeably.

## Conclusion

Mathematics knowledge for teaching is the intersection of teachers' knowledge of mathematics and their knowledge of teaching. This knowledge is grounded in teachers' own lived experiences as learners, built upon through their experiences learning to teach, and strengthened by their experiences as classroom teachers. Their knowledge and beliefs about teaching and learning can be complex and teachers sometimes hold contradictory beliefs.

Teacher learning has the potential to impact student outcomes, but the link is not straightforward. It is, instead, mediated by many interrelated factors: design of the teachers' learning experiences, existing teacher knowledge, existing beliefs about teaching and learning, use of effective teaching practices, and quality of instruction are some of these factors.

Teacher learning that has the potential to impact teacher knowledge and beliefs should be centered on the teacher themself: their professional and lived experiences, agency, and learning needs must all be at the heart of their learning experiences. In considering the teacher, it is also necessary to consider the context in which they teach, the community of learning that they are part of, their existing knowledge and beliefs and how these can be transformed, and assessment and feedback that allow them to continue the cycle of inquiry and learning. Professional learning experiences (including micro-credentials) that include teacher action research takes into account all of these design considerations.

There is a gap in the literature at the intersection of effective professional learning and the consideration of the needs and experiences of teachers in the middle of their careers. Teachers have different learning needs after they have passed through their first few years of mere survival and after they have settled into a routine. These experienced teachers have great potential as leaders within their context, and yet their experience is often not considered. This is the gap where this study fits. I am interested in the application of the teacher learning framework shown in Figure 5 to a long-term locally based PD project with experienced secondary mathematics teachers.

# Chapter 3: Methodology

In this chapter, I will introduce the Midwest Master Teacher Partnership (MMTP) and discuss the parts of the design of this five-year-long professional development project that I used in my study. (A thorough description of the MMTP project as a whole can be found in the next chapter.) I will discuss case study research and why it is an appropriate method of investigation for my study. I will outline the study data sources (including observations, interviews, and document analyses) that I used to answer my research questions and the new data I collected. I will describe the coding methods I used. I will establish the trustworthiness of the study using multiple means, including examining my own position within the work of the project.

## Research Design

In this study, I employed qualitative methods to examine the changes in teachers' practices across time, both individually and collectively. I looked for specific episodes of teaching that indicated shifts (or lack thereof) in teachers' knowledge and beliefs and for changes that were sustained over time. I did not ignore the possibility that some changes may not have been sustained, and I use these episodes to describe teachers' practices over the five years of the project. In using qualitative methods, I chose to describe these changes narratively, using the teachers' own words to tell the story of their learning. As a participant in the project (in the role of facilitator), my use of qualitative methods allowed me to honor their contributions to our knowledge about how teachers learn and to give them feedback about how their teaching changed through the course of the project.

### Characteristics of Qualitative Research

Rather than relying on a single, universal truth, most qualitative research assumes that truth is not universal (Merriam & Tisdell, 2016). Qualitative researchers seek to explore the truth of the situation they are researching and to understand the meaning in that situation (Denzin & Lincoln, 2011; Patton, 2015). Patton (2015) states that “qualitative research inquires into, documents, and interprets the meaning-making process.” Denzin and Lincoln (2011) tell us that ”qualitative research is a situated activity that locates the observer in the world. Qualitative research consists of a set of interpretive, material practices that make the world visible.” The definition of qualitative research that resonates most with me is Creswell’s (2013):

> Qualitative research begins with the assumptions and the use of interpretive/theoretical frameworks that inform the study of research problems addressing the meaning individuals or groups ascribe to a social or human problem. To study this problem, qualitative researchers use an emerging qualitative approach to inquiry, the collection of data in a naturalistic setting sensitive to the people and places under study, and data analysis that is both inductive and deductive and establishes patterns or themes (in Creswell & Poth, 2018, p. 8)

For this study, qualitative research offers a means to examine current practices and thinking in a way not possible with quantitative research. Since I am attempting to identify current practices and discover what is happening in a few specific instances, a case study will allow for examining and explaining what is happening in a specific context (Hancock & Algozzine, 2017). In this case, a comparative case study offers the opportunity to look for changes in teachers’ practices over time and to compare practices both within and across cases. Because of the design of MMTP, these participants engaged in a common set of experiences, although they had agency in determining their paths through those experiences. Consequently, a comparative case study allowed me to examine the similarities and differences in the teachers’ learning.

**Type of Design**

This case study explored the professional learning pathways of secondary mid-career mathematics teachers at an urban district who participated in a five-year partnership project between the university and district. Interviews, classroom observations, and document analyses were used to analyze the changes in teachers' practices over time, the evolution of teachers' knowledge and beliefs, and to look for changes in their attitudes toward professional learning. Each teacher is an individual case.

A case study is an appropriate means of investigation for several reasons. This project extended over a five-year period, so we were afforded a long-term view of teachers' learning. Teacher learning experiences were designed with consideration given to teachers' contexts, the community of learners, teachers' knowledge, and assessment and feedback on learning. Teachers' learning was situated within their own contexts and teachers had a great deal of agency to direct their learning to the needs of their classrooms and students. We were able to record teachers' practices at multiple points in the project. Each teacher took different pathways in their shifts in knowledge and practice, with each of these shifts being influenced by a number of interrelated factors.

One challenge has been that I have a personal connection to the topic. My interest in this study stems from my experiences as a secondary mathematics teacher and department leader in Lakeside Public Schools, the district from which MMTP drew its participants. As a department leader, I tried to implement professional learning for the teachers I worked with, with varying degrees of success. In the work with MMTP, I needed to be conscious of my own experiences and tried to view the work of others through the lenses of both the leader and teacher learners. However, this challenge was balanced by the close relationships that I developed with the participants as one of the facilitators for this project. These relationships and the trust and openness that developed allowed me more insight into their thoughts, beliefs, and knowledge and greater access to their teaching than I would have had I been an outside researcher.

Another challenge has been my personal connection to the people involved in my study. Two participants were fellow department chairs in my previous position. Because of my position on the project, I developed both working and personal relationships with all four participants of my study. As a result, there were instances where I felt discomfort reporting on findings that could be viewed as critical of their practices, knowledge, or beliefs, although I attempted to be open and honest with my analyses. Likewise, the teachers may not have felt comfortable airing views that were critical of me or of the project. Again, this challenge was balanced by the access that I had to their classrooms. Over the course of the project, they each asked me for feedback on their teaching; at the time of the observations, I did not feel fully comfortable offering feedback. However, by looking back over the last several years, I was able to provide some of the constructive feedback that they asked about. As teachers, we all know that we have areas where we can grow, and feedback can allow us to identify and act on some of those areas.

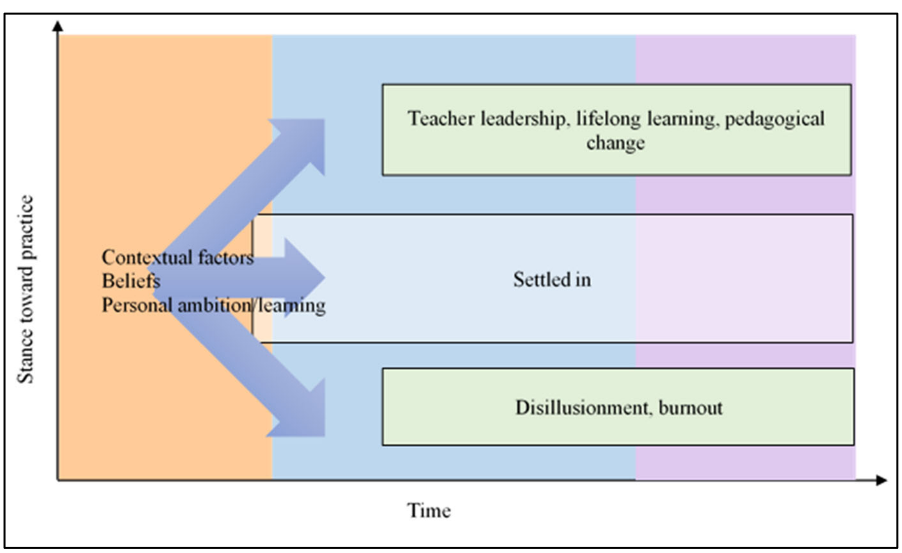
Case study research is not generalizable in the same way as quantitative research, and so this study does not precisely establish causal relationships. However, one goal is to describe what is happening in a unique place and time and provide insight into what may be occurring in other locations; we can compare what is happening in the case to what may be happening in other places (Corbin & Strauss, 2015; Creswell & Creswell, 2018). Case studies are helpful tools for building theory about social situations (such as professional learning) and improving teaching practice. Case studies are also useful for identifying areas needing further study. In addition, cases can be beneficial in learning for teachers and teacher educators. Smith and Friel state, “Cases also create opportunities for teachers to begin to develop new visions of mathematics teaching and learning and provide a common experience for teachers to discuss, analyze, and reference” (2008, p. 2). I would argue that this also extends to teacher educators: cases can create opportunities for teacher educators to begin to develop new visions of teaching mathematics teachers and provide a common experience for teacher educators to discuss, analyze, and reference.

## Study Context

I examined the professional learning of mid-career teachers within urban school districts. I wanted to examine mid-career teachers because these teachers reach a critical point in their careers where they are settling into their careers, and the pathways their learning takes can branch based on a number of complex and intertwined personal and professional factors (Day & Sachs, 2004; Huberman, 1995; Steffy & Wolfe, 2001). The interaction of these factors determines how a teacher proceeds with professional learning through the middle of their career. (See Figure 6.)

**Figure 6**

*Teachers' Stance toward Practice across Time.*



I focused on teachers in an urban school district. I am interested in teachers in urban districts for several reasons. First, urban districts offer teachers an array of professional learning opportunities, priorities, and delivery methods. Compared with smaller districts (suburban, smaller cities or towns, or rural districts), urban districts and schools service a wider range of students with different ethnicities, socioeconomic statuses, life experiences, and educational needs. Teachers of mathematics in urban districts have one of the highest turnover rates compared to other subjects and locations (Carver-Thomas & Darling-Hammond, 2017). For example, in Wisconsin, a 2011 state law that weakened the state's teacher unions have contributed to significant teacher attrition rates (Baron, 2018). Thus, mid-career teachers are foundational to the work within an urban district given that they have potential for leadership within departments and buildings that can promote effective teaching.

I also examined urban schools because of inequities in opportunities to learn and inequities in the teaching force. Students in urban areas are less likely to be taught by an experienced and licensed teacher than students in other locations, and students with more learning needs are more likely to have a new or unlicensed teacher (Adamson & Darling-Hammond, 2012; Peske & Haycock, 2006). Additionally, students in urban districts are more likely to encounter fewer high-quality opportunities to learn mathematics than students in other districts (Alfinio, 2007; Darling-Hammond, 1998; TNTP, 2018). These schools would benefit from opportunities for teachers to improve their MKT and examine teaching practices.

**Participants**

The teachers selected were all mid-career mathematics teachers with a variety of experience and placements in a variety of schools. When MMTP began, all four teachers worked in Lakeside Public Schools, a large urban school district in the upper Midwest; after the first year, one teacher moved to the South Lakeside School District, a first-ring suburban city. They ranged in experience from eight to nine years in the classroom at the start of MMTP. They all taught in schools that draw students from the entire city, with two teachers at International Baccalaureate magnet schools, both of which have a competitive application process. Each school's demographics more closely resembles the demographics of the neighborhood in which it is situated rather than the demographics of the city as a whole, likely due to persisting racial segregation within the city.

The teachers selected were all participants in a five-year partnership project, the Midwest Master Teacher Partnership, between Lakeside Public Schools (LPS) and Lakeside University, a local public university. MMTP was funded as a Robert Noyce Master Teaching Fellowship Program (Track 3) by the National Science Foundation from 2016 to 2021. Teachers initially applied for MMTP in the spring of 2016, following a series of informational meetings, with 12 secondary math teachers from LPS applying for MMTP. Eight were selected to participate based on the project leadership team's evaluations of their applications. Out of the eight mathematics teachers that initially began with MMTP, one left the project to pursue another advancement opportunity and two moved out of classroom teaching into leadership positions within the district. The participants in this study are four of the five teachers that remained in the classroom over the five years of MMTP. One of the classroom teachers was excluded from the analysis because she had significantly more experience than the other four at the beginning of MMTP (17 years) and no longer met my criteria of being a mid-career teacher. Table 1 contains some brief characteristics of each teacher. (See Chapter 4 for a thorough description of the MMTP project as a whole.)

**Table 1**

*Characteristics of the Teachers in This Study.*

| | School | Years of experience at start | Classes Taught |
|---|---|---|---|
| Nathan Inman | Arbor Vitae High School | 9 | Algebra 1<br>Geometry<br>IB[1] DP Calculus SL<br>IB DP Math Topics HL |
| Nolan Newman | Evergreen High School | 8 | Personalized Math<br>Geometry<br>IB DP Applications and Interpretations SL<br>IB DP Math Studies SL<br>IB DP Math Studies HL |
| Kim Nixon | River Willow High School | 8 | Algebra 1<br>Advanced Placement Statistics |
| Colleen Moore | Elm High School (Year 1)<br>Taylor High School (Years 2-5) | 8 | Algebra 1<br>Math Intervention<br>Algebra 2 |

The use of this convenience sample allowed me to examine the professional learning of four individuals within the same learning context over time. As such, I made conclusions about MMTP and its impact on the pathways their learning took and the teachers' attitudes toward learning. Given these teachers applied to be part of a five-year project and continued through to the end, this sample is not representative of the teaching population as a whole. These four provide an interesting perspective on continued learning through the middle of one's teaching career, the teachers who continue on the upward path shown in Figure 6.

[1] International Baccalaureate (IB) courses in the diploma program (DP) are classified as standard level (SL) or high-level (HL).

**Data Sources**

Data was collected through surveys, observations, interviews, and document analyses. A great deal of data was collected over the course of MMTP. I analyzed a subset of that data for my study. Teachers initially applied for MMTP by responding to a set of questions developed by the leadership team and submitting a video of what they considered to be a good episode of teaching (Appendix A). I conducted annual observations of classroom teaching, collected documents related to the lessons being observed, and interviewed teachers both before and after the observation (Appendix B). Given the unusual nature of teaching during the COVID-19 pandemic that interrupted the end of the 2019-2020 school year and disrupted the 2020-2021 school year, an additional observation of classroom teaching was conducted during the 2021-2022 school year that served as a final observation for MMTP. Teachers submitted evidence of their learning as required for the various project micro-credentials, which were assessed using rubrics by project facilitators. During the third year and all subsequent years, teachers completed an analysis of their own learning using an instrument designed by the research team, Chronicles of Learning and Development Episodes (CLADE), which was based on the model of Mathematical Knowledge for Teaching depicted in Figure 1 (Appendix D). Additionally, I conducted interviews with each of the five teachers in early 2022 about their experiences in MMTP and their professional learning (Appendix E). Table 2 contains a summary of the study questions and the data sources that are relevant to the question. (See Chapter 4 for a description of all data collected through MMTP.)

**Table 2**

*Alignment of Questions and Data Sources*

| Question | Data Source | When |
|---|---|---|
| 1) What trajectories did teachers' changes in practice take?<br>a. How did the nature of their participation in MMTP impact teachers' pedagogical practice? | Interviews | End of MMTP |
| | Micro-credential submissions | Throughout MMTP |
| 2) How did teachers' mathematical knowledge for teaching evolve over the course of MMTP? | Application materials (curated video, responses to questions) | Before MMTP |
| | Observations of teaching, pre- and post-observation interview, document analyses | End of each academic year, end of project |
| | Micro-credential submissions | Throughout MMTP |
| | CLADE | End of each academic year |
| 3) What pathways did teachers take in their professional learning with MMTP? | Interviews | End of project |
| a. What factors shaped their movement on the above trajectories? | Interviews | End of MMTP |
| b. How did the nature of their participation in MMTP impact teachers' attitudes toward professional development and their thoughts about future engagement in professional learning? | Application materials | Before MMTP |
| | Interviews | End of MMTP |

### *Interviews*

In case studies, interviews are key (Creswell & Poth, 2018). Interviews are a means to "[construct knowledge] in the interaction between the interviewer and the interviewee" (Brinkmann & Kvale, 2015, p. 4). In the case of this study, interviews provide a means to understand the experiences of the teachers in their classrooms and as they reflect on their learning with MMTP.

Throughout the course of MMTP, I conducted interviews with each teacher before and after annual observations of their teaching. The pre-observation interviews focused on the learning goals for the lesson and the planning process, and the post-observation interviews focused on the extent to which the goals were met, the evidence indicating the goals were or were not met, and aspects of their learning with MMTP that were evident in the teaching episode. The interviews were, as much as possible, conducted on the same day as the observations and within a few minutes of the start or end of class. All interviews were audio-recorded, with the exception of interviews conducted in May of 2021; due to the COVID-19 pandemic conditions, some participants responded to the pre-observation questions by email rather than verbally.

At the conclusion of the MMTP, I conducted interviews with each of the teachers about their learning with MMTP over the course of the five years (Appendix E). These semi-structured interviews were conducted in January and February 2022. In these interviews, I focused on the teachers' experiences with MMTP, perceptions of their changes in practices over the last five years, thoughts about their professional learning with MMTP, plans for future learning, and perceptions of professional learning as a whole. I used their initial application materials as part of these interviews using a stimulated recall interview approach (Calderhead, 1981; Clark & Peterson, 1976). I had the teachers discuss their current thoughts about their initial learning goals and conceptions of engaging teaching as evidenced by the teaching episodes they chose to submit as part of their application. All interviews were audio recorded.

***Observations***

Interviews provide one part of the picture, but they are not sufficient for drawing conclusions. In order to gain a wider understanding of the impact of the teachers' learning, as part of MMTP, I conducted observations of their classroom teaching at the end of each school year. Additionally, because of COVID-19, a final observation was conducted in the 2021-2022 school year, after the teachers returned to in-person instruction and after MMTP had ended. In the first and second years, the teachers were asked to schedule the observation on a typical day of teaching, and to exclude review or test days from consideration. In the third year, fourth year, and after the fifth year, the teachers were asked to schedule so that the lesson being observed in some way showed a connection to their learning with MMTP. The fifth year was disrupted by COVID-19; although observations were conducted, in all except one case, these were recorded over Google Meet with dates selected for convenience rather than explicit connections to prior learning. Along with the video and interviews before and after observations, artifacts were collected as part of the observation process, including lesson plans, other planning materials, student materials, and student work samples.

As a part of their application process, teachers were asked to share a video clip that showed students engaged in learning in one of their classes. Along with the annual classroom observations, these application videos were analyzed to provide a picture of changes in teachers' practices and conceptions of good teaching over the course of MMTP. This led to a total of seven classroom videos with artifacts collected over the course of seven different school years for most teachers.

I was not a staff member at any of the schools where the teachers worked; I conducted these observations as MMTP's graduate research assistant and as a member of the leadership team. Some participants felt intimidated by the academic accomplishments of those on the leadership team who had earned PhD or EdD degrees. Others were uncomfortable that the district math and science supervisors were part of the leadership team and felt that it would be unprofessional to discuss certain things with them. As a former teacher who had, at the time, very recently left the classroom and who was not yet a PhD, I was uniquely positioned as a conduit for communication between the teachers and the leadership team. This led to earning the participants' trust and becoming the teachers' "go-to" person for day-to-day matters dealing with MMTP.

***Document Analyses***

Along with observations and interviews, a number of documents were generated and collected over the course of the five years of MMTP. I used these documents in conjunction with the other data sources to gain a fuller understanding of teachers' classroom practices, to infer beliefs about teaching and learning, and to document their personal learning trajectories.

Three sources of documents were relevant to my research. The first source was the artifacts related to teaching. These included lesson plans, textbook pages, materials used for planning, presentation files (PowerPoint, Smart Notebook), handouts, student work samples, and contextual notes about the observation. These documents rounded out the picture of the teachers' classroom practices across multiple years. Along with the documents and artifacts collected with each observation, I analyzed the application materials the teachers submitted to be part of MMTP. These provided insight as to the teachers' initial practices and beliefs at the beginning of MMTP.

The second source of documents related to the teachers' learning. From the second year onward, as part of their MMTP obligations, each teacher completed a Chronicle of Learning and Development Episodes (CLADE), a document that asked teachers to reflect on their learning from each of the micro-credentials and the aspect of pedagogical content knowledge that the micro-credential focused on. The CLADE also asked teachers to provide examples of student learning that depicted transfer of knowledge from their learning through MMTP to their own classroom practice. Last, teachers were asked to reflect on their overall growth for each year, connect that growth to changes in their practice, and formulate goals for the next year.

The third source of documents are the narratives that the teachers wrote and documents they compiled and submitted to earn each of the micro-credentials. The micro-credential submissions are each composed of a narrative describing the overview and context of the micro-credential work, work examples and other artifacts, and a narrative reflection (see Appendix J through Appendix M for examples of micro-credentials and see Chapter 4 for a thorough description of the MMTP micro-credentials and micro-credentialing process). Each micro-credential was assessed using a rubric by a leadership team member. These rubrics assessed the degree to which the teacher demonstrated the key competency of the micro-credential. In some cases, teachers were asked to revise and resubmit their work. The initial submissions and all assessor comments were included as part of the micro-credential assessment. These documents are linked with specific instances of teacher learning and provide teacher-curated evidence of that learning.

**Data Analysis Methods**

Coding was done using NVivo. (See Appendix O for the full codebook.) During both stages of coding, I used a comparative case approach for analyzing the data (Creswell & Poth, 2018; Miles et al., 2014). I looked for themes in the teachers' words and actions (both individually and collectively) that allowed me to develop a description of the teachers' learning pathways and the evolution of their knowledge and beliefs over time. Throughout the coding process, I tried to be aware of possible blind spots and of the impact that my knowledge of later events had on my interpretation of earlier events.

I used values[1] coding during the first cycle (Saldaña, 2021). Given my interest in the evolution of the teachers' knowledge and beliefs throughout MMTP and the link between teachers' knowledge and beliefs and student learning, values coding seemed appropriate. Periodically, as I was coding, I paused to remind myself that I was coding for values and not for other constructs that may have proved interesting. I used three general categories of codes. The first was planned and described the eight effective mathematics teaching practices (National Council of Teachers of Mathematics, 2014). The second was also planned and used the five aspects of my framework for teacher learning, although I left myself open to sub-codes that would emerge through the teachers' work. The third was much more open and described the values that I elicited from the teachers' writings. These values were depicted using general terms. I tried to limit the number of new codes that I added and to refine my descriptions of existing codes as I progressed.

In the second-cycle coding, I shifted to looking at patterns in the first-cycle codes over time to discern the trajectories in teachers learning and changes in practices. In the second coding cycle, I used longitudinal coding (Saldaña, 2021). Longitudinal coding allowed me to examine and compare participants' values over time, both individually and collectively. I used two items to examine teachers' practices over time. First, I used NVivo to create visualizations of the frequency of the codes from the first-cycle coding. These visualizations—28 in all—each showed the relative frequency of the codes for one participant and one year (see Appendix P). Second, after the first cycle of coding was complete, I created heat maps of the teachers' scores on the observation rubrics for each year. (See Appendix F for the observation rubrics.) The heat

[1] "Values" here is meant as a catch-all term to reflect values, attitudes, beliefs, perspectives, and worldviews (Saldaña, 2021).

maps show each teacher's nine observation rubric scores for each year and are shaded from red (for a score of 0 or "not observed") to green (for a score of 4). The heat maps are included in Chapter 5. Using these visualizations, I looked specifically for correlations between changes in instructional practices and values and if (and/or how) the changes were maintained or adapted over the course of each teacher's time with MMTP. This was an iterative process, where I first examined school years and gradually increased the time span so I could gain an understanding of the long-term impacts of their participation in MMTP. This process provided a broad picture of changes in participant values, knowledge, and practices over time.

**Establishing Trustworthiness and Credibility**

*Validity* and *reliability* refer to assurances that the study measures what it purports to measure and that the results would be consistent if the study was replicated (Creswell & Creswell, 2018; Hancock & Algozzine, 2017). However, these ideas, while well-defined in quantitative research, are not as clear-cut in qualitative research. Most qualitative research rejects the positivist notion of a single reality for the notion that reality is dependent on the observer. In response, qualitative researchers have proposed the notions of *credibility*, *trustworthiness*, and *accuracy* as alternatives to validity and reliability (Creswell & Poth, 2018; Merriam & Tisdell, 2016) .

There is some consensus on strategies for establishing credibility and accuracy of qualitative studies. Creswell offers nine methods for establishing credibility, and stresses that qualitative researchers should engage in at least two of these strategies (Creswell & Creswell, 2018; Creswell & Poth, 2018). These methods are consistent with the suggestions of other researchers (Hancock & Algozzine, 2017; Miles et al., 2014; Patton, 2015; Yin, 2018). To establish credibility for this study, I used four of the strategies suggested by Creswell.

*Triangulation* is the corroboration of data and findings across multiple data sources (Creswell & Creswell, 2018; Creswell & Poth, 2018; Miles et al., 2014; Yin, 2018). I collected and analyzed purposeful data from several sources. Over the course of MMTP, there was ample data both collected from participants and submitted by the participants themselves. Additional data was collected to supplement the existing data. Observations of teaching were conducted annually every year of MMTP. Teachers were interviewed about the observation episodes both before and after the observation. Teachers submitted evidence of learning each year as part of the micro-credential requirements. Teachers were asked to reflect on their classroom practices and to synthesize their previous years' learning at the end of each academic year. In addition to the data collected through MMTP, I interviewed the teachers about their learning and practices overall as they had changed throughout the course of MMTP. This variety and number of data sources allowed me to corroborate teacher claims about their practices and learning and triangulate my claims of changes in their practices, knowledge, and beliefs.

Another method of establishing credibility is *prolonged engagement*. In addition to a study that extends for longer periods of time, this also involves working with participants and building close relationships (Creswell & Creswell, 2018; Creswell & Poth, 2018). As the main point-of-contact between the teachers and the university team, I developed close working relationships with all the participants; they trusted me and felt comfortable talking with me about MMTP, their progress, their successes, their setbacks, and their struggles. The length of MMTP (five years) also gave me a chance to observe the teachers at different points in time, so I had a basis on which to analyze changes in their practice and make inferences about corresponding changes in beliefs and knowledge.

*Reflexivity* in research is an introspective process of reflecting on and interrogating one's own beliefs with respect to the research being conducted (Creswell & Creswell, 2018; Creswell & Poth, 2018; Patton, 2015). As a researcher, what I observe and the inferences and conclusions I make are impacted by my own values, experiences, and biases. To establish credibility, in the next section, I address my background, experiences, and position within the study that can impact what I observed and my interpretations of those observations. This includes consideration of the context of the group meetings, observations, interviews, and other discussions with participants as well as my position as a member of the leadership team and research assistant for MMTP.

*Member checking* is the process of having findings and interpretations verified with the participants to ensure accuracy (Creswell & Creswell, 2018; Creswell & Poth, 2018). Given that I worked closely with the participants for five years, I wanted to make sure that I was able to correctly interpret their words and actions. Having the participants corroborate findings is a way to establish credibility of this study.

To incorporate member checking, I emailed a draft of each participant's narrative to the participant and asked for feedback. I asked each to read through the narrative at their own pace and to send me their thoughts, including what I may have gotten wrong or misinterpreted. No disagreements or discrepancies in the findings emerged, but some changes were suggested by the participants, and I incorporated the suggestions into each narrative. Kim mentioned in a personal communication that she was disappointed that her original narrative ended on a negative note and reminded me of her participation in the development of a Math for Social Justice course, so I restructured the end of her narrative to include this. This led to Kim's narrative concluding on a more positive note. Colleen corrected my description of some of the details of her original school, but otherwise agreed with the narrative. Nathan and Nolan both agreed that their narratives were accurate.

In addition to ensuring I correctly interpreted their words and actions and came to valid conclusions, member checking also allowed me to give something useful back to the participants. Over the course of the five years, they all asked me for feedback on their teaching. The process of member checking allowed for a reciprocal exchange of information, and the teachers found this process useful.

Along with the above four methods of establishing credibility, there are other methods I used as I analyzed the data and wrote about my findings: peer review (Creswell & Creswell, 2018; Creswell & Poth, 2018), using rich descriptions (Creswell & Creswell, 2018; Creswell & Poth, 2018; Miles et al., 2014; Wertz et al., 2011), and presenting discrepant information (Creswell & Creswell, 2018; Creswell & Poth, 2018; Patton, 2015; Yin, 2018). First, I have incorporated peer review of my work. I have been fortunate to work consistently with Dr. Steele on the MMTP leadership team over the entire project. I regularly sought his feedback on my interpretations of the data. His feedback was key in being able to point out potentially discrepant data since he was familiar with the data collected over the course of MMTP. He was able to offer insights into alternative explanations for changes in teachers' beliefs and practices (including whether those changes even existed).

One's epistemology and ideology are inherent in everything a qualitative researcher does, from the formulation of the original problem statement through the conclusion drawn from the data (Berger, 2015; Merriam & Tisdell, 2016; Patton, 2015). Because of the nature of qualitative research, it is incredibly important for the researcher to examine and acknowledge their own positionality, epistemology, ideology, and the impact each will have on the research process. I will first examine the notion of reflexivity and why it is important in qualitative research. I will then describe what I perceive as my own identity positions, my developing epistemology and ideologies, and my positions within the MMTP project. Last, I will discuss the implications of these positions on this study, the data, and my interpretations of the data.

**Reflexivity**

Berger (2013) tells us, "reflexivity is commonly viewed as the process of a continual internal dialogue and critical self-evaluation of a researcher's positionality as well as active acknowledgment and explicit recognition that his position may affect the research process and outcome" (p. 2). Probst (2015) defines *reflexive* as being "used to denote actions that direct attention back to the self and foster a circular relationship between subject and object" (p. 37).

Berger lists a number of positions that a researcher may hold, including "gender, race, affiliation, age, sexual orientation, immigration status, personal experiences, linguistic tradition, beliefs, biases, preferences, theoretical, political, and ideological stances, and emotional responses" (2015, p. 2). Although a researcher may not always see how their own position impacts a study, it is still important for the researcher to disclose those positions.

These positions can affect how willing participants will be to speak with the researcher, how much participants choose to reveal to the researcher, and how the researcher interprets the responses (Berger, 2015; Merriam & Tisdell, 2016). Reflexivity allows the researcher to examine the impact of these various positions on the interactions with participants and to take responsibility for them in the analysis. The researcher, in essence, attempts to control for the effect of their positions on the research process, outcomes, and analyses (Probst, 2015).

I am a white, native English speaking, middle-class, cisgender, straight woman in my early 50s, and I recognize that I hold many privileges associated with those groups. I am a former high school mathematics teacher, with over 20 years of experience teaching in both private and public urban high schools. I served as a department leader in my last school and attempted (with mixed success) to bring the school's curriculum into alignment with the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and the teaching practices outlined in Principles to Actions (NCTM, 2014). For six and a half years, I was the research assistant for the MMTP project. In that position, I was the main point-of-contact between the MMTP leadership team and the participants, I observed and recorded each participant annually, and I was involved in the planning, implementation, and assessment of several micro-credentials developed by the MMTP leadership team. I also work as the secondary mathematics methods and seminar instructor and as the field supervisor for the secondary mathematics preservice teachers at the university.

I am a strong believer in feminism and anti-racism, although I am not as active in those communities as I would like. I recognize when positions benefit patriarchy. I recognize racism in some of my own beliefs and work actively to change them as they are recognized. I try to recognize institutional racism as it occurs in educational settings, although I am not as astute in my recognition since I have benefitted from these systems and have not been explicitly aware of their impact until more recent years. Ideologically, I identify politically as a progressive liberal with socialist leanings. I believe in the responsibility of society to take care of individuals. I see some groups as having an inherent advantage over others just by virtue of their identity and position in society. In our current US society, this means, for instance, male, white, middle- and upper-class individuals.

I recognize in my epistemology the remnants of positivistic views from both my past and from society (Merriam & Tisdell, 2016). In our larger society, there seems to be pressure to adopt a stance in which experimental design is optimal, more value is placed on research from such designs, and that we can determine “The Truth” if we just use the right methods and eliminate sources of error. I see remnants of positivism in my questioning of the validity and reliability of qualitative research and in my desire to find explanations for phenomena I do not fully understand.

However, I also see this view as problematic because I have come to believe that there is not one Truth (capital-T, absolute Truth) but that there are many truths (lower-case) (Merriam & Tisdell, 2016). Truth can be relative; people and groups construct their own truths, and different people have different truths. Different cultures and communities (both large and small scale) have different truths. Their truths are influenced by values, power, and contexts of the people and communities (Lave & Wenger, 1991). (By “communities,” I am referring to both large and small groups of which a person is a member. These could be very large communities—such as identifying with or belonging to a particular gender, socioeconomic status, language, sexual orientation, race, nationality, religion, or any number of other communities that may define one’s identity—or smaller communities—such as a social group, a school, or a learning community within a school.) In this sense, I lean toward interpretive and critical epistemologies. I recognize that I currently associate more with a constructivist/interpretive stance.

Additionally, although I value critical inquiry (as described in Merriam & Tisdell, 2016), I also recognize that I have not yet completely internalized the ability to question power relations and privilege. I believe that doing so is important as a researcher and that I must examine truth (lower-case) in order to see who benefits from that truth, but it is not yet something that comes automatically to me. I occasionally need to remind myself to think about the power relations inherent in interactions within and between communities or individuals and each person's position with respect to that power and to each other. Sometimes I am more conscientious about examining power relationships than others (especially regarding gender and, to a lesser extent, with regard to race), but I value this interrogation and I am progressing.

Within the context of this study, there are several areas where I have needed to attend to my identity, epistemology, ideology, and position within MMTP. As a former teacher, I had more access to the participants, some of whom were intimidated by the educational credentials and positions of the other leadership team members (four professors and two district leaders), Most of the participants viewed me as a peer rather than as a superior and consequently were often forthcoming in my discussions with them. Prior to leaving the classroom, two participants were fellow department leaders. We knew each other and had worked together, although in different capacities. The other two participants were not known to me. Throughout the five years of MMTP, I built closer personal relationships with all the participating mathematics teachers through travel to conferences, collaboration on presentations, classroom visits, and hosting of student teachers. In terms of MMTP, I would consider myself a full participant, although in a different capacity than the teacher participants.

The two men and two women in this study are white, native English speakers, and do not identify as Latinx. When MMTP began, each had at least eight years of teaching experience and had earned master's degrees. Two participants are second-career teachers, two began teaching immediately after finishing their education. This lack of racial, cultural, linguistic, and socioeconomic diversity is not reflective of the district as a whole. While the district teaching force remains overwhelmingly female (approximately 75%) and white, just over 30% of the teaching force do not identify as white (Wisconsin Department of Public Instruction, 2021). Within MMTP, there was an effort to recruit teachers with different backgrounds. 11 mathematics teachers applied to be part of MMTP. One Asian-American applicant withdrew from consideration. A second Asian-American applicant did not complete the full application. A third white applicant did not meet the criteria for selection. Of the eight mathematics teachers who were selected to participate, one Latinx participant left MMTP after the first year to pursue a different career pathway, one Latinx participant was promoted to administrator after the second year and left the classroom, and one white participant left the classroom in the fourth year to become a district math coach. One participant was excluded from this study because she had been teaching for seventeen years at the beginning of MMTP, a length of time that put her past the "mid-career" aspect of this study. The remaining four participants are all white. Because of the lack of diversity in the teachers in my study, the data collected cannot be considered representative of the teaching force of the district. However, because their race, ethnicity, and backgrounds more closely match my own, I was able to relate to them in ways that may have been different had they not. For instance, I sometimes had difficulty working with one Latinx participant, in part because our perceived positions (administrator vs. research assistant, man vs. woman, native Spanish speaker vs. native English speaker) caused some miscommunications between us.

Because of my experience leading a department and attempting to implement professional learning with a group of teachers at my former school, I began MMTP with a somewhat jaded sense of experienced teachers' receptiveness to new learning and willingness to change classroom practices. Although I am a naturally optimistic person, this pessimism fueled my initial inquiries into teacher learning. However, my own participation expanded my understanding of what it means for teachers to learn, how teachers learn, and how learning is demonstrated. Realizing that I held a belief that the teachers did learn and change practices throughout their participation, I tried to guard against the possibility that I would ignore or downplay evidence of a lack of change in beliefs, knowledge, or practices.

Since I have personal relationships with each of the participants, I was aware that I could find myself less critical in my analysis of their beliefs, knowledge, and practices. I tried to be aware of times I the analysis process where I felt I might hold back in my reporting of less-productive teaching practices. By using member-checking as part of my validation of the work, there was an increased chance that I would be hesitant to make statements that could be perceived as critical; however, having the participants read my work was a crucial part of my analysis process. One way I tried to guard against bias was to openly have discussions with teachers about how statements that may seem critical to them should be considered part of the process. They were getting my honest analyses of their practices. Overall, they were receptive to this approach; none were defensive when discussing teaching or when I visited their classes. Another way I tried to guard against possible bias was to use pseudonyms and to mask all participant identities. By using pseudonyms, I have taken precautions to guard against possible negative consequences to each of the participants. To the extent possible, I have used methods that will not allow readers to deduce the identities of any participant.

**Limitations and Delimitations**

One limitation of this study is that I did not analyze data as the five years of MMTP progressed. In some cases, I analyzed data that was up to six years old. I may not have an accurate memory or interpretation of what happened in those moments from several years ago. Since more recent episodes are clearer in my memory, there may have been a tendency for me to emphasize these episodes as more important or more significant than episodes that occurred further in the past.

Because the participants are all white, the results are not representative of the district's teaching force. The lack of educational, racial, cultural, or linguistic diversity and the relative similarities in years of teaching experience have led to conclusions that are representative of only teachers with similar characteristics.

Another limitation includes the nature of qualitative research itself, which is interpretive by design (Creswell & Poth, 2018). Because of my positioning, the meaning that I have constructed from the data is not necessarily the same as the meaning that another researcher would find in the same data. However, by disclosing my positions and revealing as much as possible about my research process and data, I hope to mitigate this limitation.

This study does not directly examine student learning outcomes. Although the ultimate goal of any teacher learning is to improve student learning, such an examination is beyond the scope of this study.

## Conclusion

As a whole, MMTP provided a robust, long-term opportunity to engage experienced teachers in professional learning. The participants had agency over their learning and conducted classroom action research to examine the impact of their learning on their students. This study used qualitative case study analysis to examine changes in teachers' practices and uncover possible changes in their beliefs about teaching and learning. This work adds to the field by examining the impact of PD designed specifically for mid-career teachers and demonstrating the merit of designing teacher learning that takes career stage into account. In the next chapter, I will provide an overview of the MMTP project, including parts that are not being used in my study.

# Chapter 4: The Midwest Master Teacher Partnership

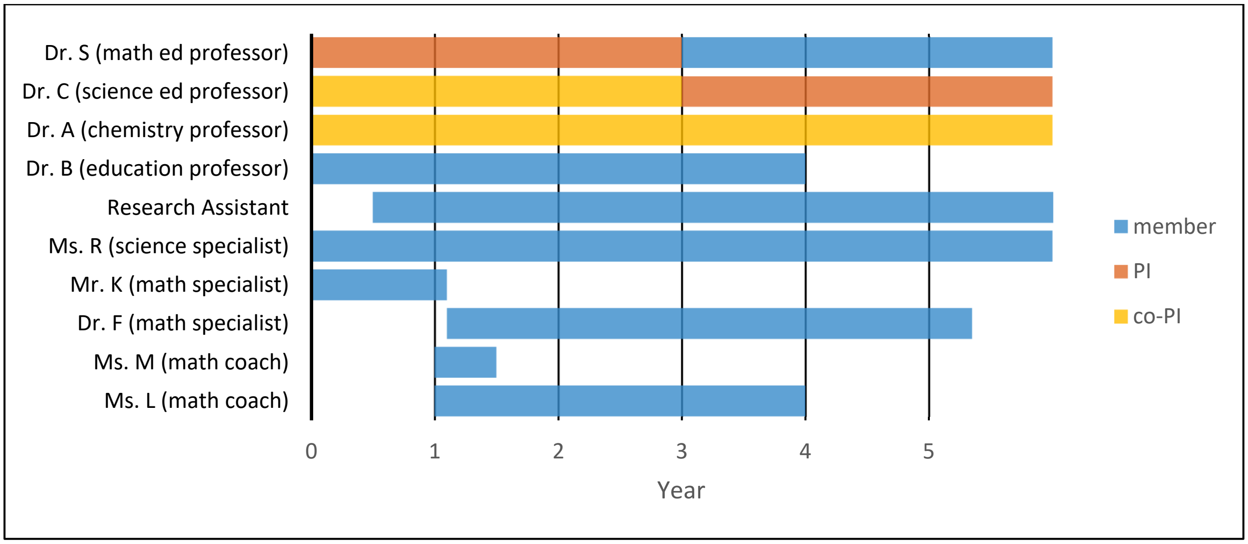
The Midwest Master Teacher Partnership (MMTP) was a five-year partnership between Lakeside University (LU) and Lakeside Public Schools (LPS). It was funded by the National Science Foundation (NSF) as an NSF Robert Noyce Master Teacher Fellowship. MMTP was active from the fall semester of 2016 to the summer of 2021, with planning occurring in the 2015-2016 academic year and recruitment in the spring of 2016. MMTP targeted teams of secondary mathematics and science teachers from multiple LPS schools. The goals of MMTP were (1) to improve teaching practice by building teachers' pedagogical content knowledge through classroom action research and (2) to develop teacher leaders in secondary mathematics and science.

## The Leadership Team

The initial MMTP leadership team consisted of four faculty members from LU, a graduate research assistant from LU, and a handful of district leaders from LPS. Although the leadership team experienced some changes in membership over the course of the five years, the team at the end was very similar to the team when MMTP was in its planning stages. Figure 7 shows the timeline of leadership team membership over the course of the planning year and the five years of MMTP.

**Figure 7**

*Timeline of Leadership Team Participation from the Beginning of the Planning year (Year 0) through the End of MMTP (Year 5).*




The members of the leadership team were:

- Dr. S, a professor of mathematics education in the School of Education at LU, who was the principal investigator (PI) for MMTP from the beginning of the planning year through the end of the second year.
- Dr. C, a professor of science education in the School of Education at LU, who was the co-PI for MMTP from the beginning of the planning year through the end of the second year and who took over as PI at the beginning of the third year.
- Dr. A, an associate professor of chemistry at LU whose research has focused on science teacher education, who was the co-PI for MMTP from the beginning of the planning year through the end of MMTP.
- Dr. B, an associate professor in the School of Education at LU and an expert in teacher leadership and qualitative research. Dr. B was unable to continue with MMTP after the third year.

- The author of this study, who served as the graduate research assistant from the middle of the planning year through the end of MMTP.
- Ms. R, the science curriculum specialist at LPS.
- Mr. K, the mathematics curriculum specialist for LPS from the planning year through the beginning of Year 1, when he left LPS.
- Dr. F, the mathematics curriculum specialist for LPS from the beginning of Year 1 to the middle of Year 5. During Year 5, Dr. F accepted a different position within the district; consequently, for the second half of Year 5, the LPS mathematics department was not represented on the team.
- Ms. L and Ms. M, district mathematics coaches with LPS. Ms. M left LPS shortly after MMTP began to pursue a different career opportunity. Ms. L continued to support the mathematics teachers in MMTP until the district decided that her participation would no longer be supported.

In addition, the leadership team contracted with several outside specialists when additional expertise was needed.

- Ms. Z was contracted in Year 2 to help develop the Environmental Education and Education for Sustainability micro-credential that was offered in Year 3.
- Dr. L, an employee of LPS, former professor, and an expert in diversity training, was hired to help write and implement the Culturally Responsive Pedagogy micro-credential developed in Year 4.
- Mr. E, an LPS teacher, helped facilitate small-group meetings for the Culturally Responsive Pedagogy micro-credential with Dr. L.

- Ms. G, a consultant and expert in antiracist teaching, was hired in Year 5 to lead teachers through a series of sessions where teachers examined their beliefs and their teaching practices using an antiracist lens.

**The Recruitment and Application Process**

In the spring of 2016, the leadership team held a series of focus group meetings at several high schools around the city and at times intended to accommodate most schedules. All eligible LPS teachers were invited to attend these focus groups. (See Appendix G.) These meetings were held for the dual purposes of (1) disseminating information about MMTP and recruiting participants and (2) gathering information about the professional development needs and interests for teachers in LPS. (See Appendix H.) Teachers were paid $50 for their participation in the focus groups, regardless of their intent to apply.

Prior to the third focus group meeting, the MMTP application was finalized and posted to MMTP's website and all eligible teachers in LPS were invited to apply to be part of MMTP. The application asked for teams of teachers at individual schools to apply, with the intention of forming teams of three-to-five teachers from five-to-seven high schools; however, given that about half of the high schools in LPS are smaller schools with less than 400 students, the leadership team anticipated that individual teachers from these small schools would also be interested, and created an application for those teachers who would be the only applicant from a particular school. (See Appendix A.) The intention was that these individual teachers would, themselves, form a team.

Teachers were eligible to apply if they taught mathematics or science and had a master's degree or other advanced professional degree. Noyce Master Teacher Fellowships also require teachers to have at least five years of teaching experience, although the leadership team was flexible with years of experience so long as the teacher would meet the requirement within the five years of the grant. Some administrators were interested in participating; however, the application was only open to those who held teaching positions at the start of MMTP. A final requirement of the fellowship was that teachers needed to be employed in a high-need district. This was automatically met as all applicants were employed by LPS.

Teams of applicants were asked to complete both individual and team portions of the application. (See Appendix A.) The team portion asked the principal to commit to supporting the teachers' work with MMTP. The individual portion asked teachers to acknowledge the five-year commitment and to compose a personal statement describing their daily work of teaching, their areas of interest, their anticipated learning from MMTP, and ways they had provided or were interested in providing educational leadership. Leadership team members scored the applications using a rubric. (See Appendix A.) In total, 30 teachers from 11 different schools completed the first stage of the application.

All applicants were then asked to complete the second stage of the application, which consisted of three parts. For the first part, teachers were asked to provide a ten-minute video showing an episode of student engagement and a narrative where the teacher had to describe their practices and challenges around student engagement. For the second part, teachers were asked to provide possible action research questions they would be interested in investigating. For the third part, teachers were asked to submit a lesson, task, or lab that they used this year but would change when teaching it the next time and to discuss the rationale behind the changes. As with the first stage of the application, leadership team members scored the second stage applications using a rubric. In total, 28 of the 30 first-stage applicants completed the second-stage application; the two who did not complete the second-stage application decided not to continue with the application and voluntarily withdrew. Additionally, one teacher withdrew their application after the second stage when he left the district for a teaching position in a neighboring district. The final 25 MMTP members were chosen by consensus of the leadership team, with attention first to those with the highest rubric scores for both stages and considerable discussion around the remaining applicants.

## The Teacher Participants

Of the initial 25 MMTP participants, 16 were teaching science, eight were teaching math, and one was teaching computer science. Although the leadership team had not initially considered computer science, in his application, the teacher (who was also certified in math) made a persuasive case for considering him as a computer science teacher. Additionally, many participants held multiple licenses, including administrator licenses, bilingual education licenses, and alternative education licenses. Table 3 shows the teaching licenses held by each of the participating teachers.

**Table 3**

*Teaching Licenses Held by MMTP Participants.*

| | | Content Areas | | |
|---|---|---|---|---|
| | | Computer Science | Math | Science |
| | | 1 | 8 | 16 |
| Teaching License(s) Held | Administrator | | 1 | 2 |
| | Alternative Education | | | 2 |
| | Bilingual | | 2 | |
| | Mathematics | 1 | 8 | |
| | Computer Science | 1 | | |
| | Biology | | | 16 |
| | Broadfield science | | | 10 |
| | Chemistry | | | 7 |
| | Earth & Space Science | | | 2 |
| | Environmental Science | | | 6 |
| | Physics | | | 1 |

The 25 MMTP participants were initially distributed across eight different LPS high schools and two LPS K-12 schools; by the end of MMTP, this distribution had changed due to teachers transferring within the district or taking positions in other districts. Initially, three teachers were the only participant from their school; all other teachers had at least one colleague on their school's team, with the largest school team having five participants. Table 4 shows the initial distribution of participants across schools by subject taught, as well as a short description of each school. Table 5 shows the final distribution of participants across schools by subject taught.

**Table 4**

*Initial Breakdown of Number of Participants by School.*

| | | Computer Science | Math | Science | Type of school |
|---|---|---|---|---|---|
| School | Arbor Vitae High School | 1 | 1 | 2[1] | Large comprehensive IB magnet school |
| | Birch High School | | | 1[2] | Small specialized magnet school |
| | Cedar High School | | 2[3, 4] | | Large comprehensive neighborhood school |
| | Elm High School | | 1[5] | | Large comprehensive neighborhood school |
| | Evergreen High School | | 1 | 2[6] | Large comprehensive IB magnet school |
| | Hickory High School | | 1 | 2 | Large comprehensive AP magnet school |
| | Maple School (K-12) | | | 2[7] | Small K-12 Montessori magnet school |
| | Pine School (K-12) | | | 1[1] | Small specialized K-12 magnet school |
| | River Willow High School | | 2[8] | 3 | Large comprehensive neighborhood school |
| | Sycamore High School | | | 3[9] | Small neighborhood school |

[1] One teacher accepted a position as a middle school teacher beginning in Year 5.
[2] Teacher transferred to a different LPS school beginning in Year 3.
[3] One teacher left MMTP to pursue a different career opportunity within LPS.
[4] One teacher accepted a position as an administrator in LPS in Year 3.
[5] Teacher accepted a position at a suburban high school beginning in Year 2.
[6] One teacher accepted an administrator position at a public charter school beginning in Year 3.
[7] One teacher left MMTP for medical reasons.
[8] One teacher accepted a position as an at-large math coach for LPS in Year 4.
[9] One teacher left MMTP at the beginning of Year 4.

**Table 5**

*Final Breakdown of Number of Participants by School.*

| | | Computer Science | Math | Science | Type of school |
|---|---|---|---|---|---|
| School | Arbor Vitae High School | 1 | 1 | 2 | Large comprehensive IB magnet school |
| | Arthur High School | | | 1 | Small charter school |
| | Ash High School | | | 1 | Large arts magnet school |
| | Carter Middle | | | 1 | Suburban middle school |
| | Evergreen High School | | 1 | 1 | Large comprehensive IB magnet school |
| | Hickory High School | | 1 | 2 | Large comprehensive AP magnet school |
| | Maple School (K-12) | | | 1 | Small K-12 Montessori magnet school |
| | River Willow High School | | 1 | 3 | Large comprehensive neighborhood school |
| | Sycamore High School | | | 2 | Small neighborhood school |
| | Taylor High School | | 1 | | Suburban high school |
| | LPS at-large subject-matter specialists | | 2 | | |
| | Departed MMTP | | 1 | 2 | |

As a Noyce project, participants received a $10,000 fellowship annually, paid in quarterly installments of $2,500 for the entire five years of MMTP. Participants who voluntarily left or who were asked to leave as a result of not meeting the expectations of MMTP were expected to repay up to half of the funds paid out prior to their departure. For the first three years, participants received the quarterly fellowship payments automatically. At the end of the third year, the leadership team evaluated the efficacy of the fellowship payments and concluded that some participants would not complete the expected work if payments were not contingent on successful completion of micro-credentials. (The MMTP micro-credentials and micro-credentialling process will be discussed in detail in the next sections.) From the beginning of the fourth year through the end of the fifth year, participants received fellowship payments if they were in good standing with MMTP and not delinquent on micro-credential submissions or other project expectations. Participants who fell behind in their action research or micro-credential submissions had their fellowship payments withheld until they had made satisfactory progress. This change in payment structure caused one teacher to leave MMTP; all other participants accepted the change. By the end, 15 of the final 22 participants completed all the expected work and received the full $50,000 fellowship.

In addition to the fellowship, participants also received one master's credit through Lakeside University for each micro-credential completed, for a total of 20 credits over the course of the five years. Participants also received support to attend state and national conferences, with approximately half of the teachers presenting their action research project results at national conferences. 17 chose to attend or present at a national conference at least once over the five years, with some participants choosing to present multiple times. Participants were also able to request supplies and classroom equipment through MMTP. In the first year, each participant received an iPad to facilitate some of the work they were expected to complete with MMTP, including videorecording of lessons. Most participants also received books as part of their micro-credential materials (such as the *5 Practices* books for mathematics and science (Cartier et al., 2013; Smith & Stein, 2018)) or for summer book study groups (such as *Drive* (Pink, 2011)).

In total, of the 25 participants who began in the first year, only three participants left the program: one math teacher at the end of the first year due to a career change, one science teacher due to a change in payment structure, and one science teacher due to an emergent medical condition.

## Project Design

The goals of MMTP were (1) to improve teaching practice by building participants' pedagogical content knowledge through classroom action research and (2) to develop teacher leaders in secondary mathematics and science. As outlined in the original grant application, teacher learning experiences were designed as micro-credentials (MCs). Earlier MCs supported the goals of MMTP by being small, focused, teacher-designed action-research projects that supported participants' learning about both content and pedagogy. Later MCs supported the goals of developing teacher leaders by focusing on different aspects of leadership. The MMTP proposal outlined three levels for each MC, roughly corresponding to the stages of leadership as outlined in the PRIME Leadership Framework, leadership of self, leadership of others, and leadership in the extended community (NCSM, 2008). For a *Level I* MC, participants would engage in learning and conduct their action research within their own classroom. For a *Level II* MC, participants would expand past their own classroom and conduct professional development (PD) and action research with a small group of teachers from their building or department. For a *Level III* MC, participants would conduct a larger-scale PD on the MC topic at the district level and investigate the impact of their PD on the knowledge of participating teachers.

**Micro-credentials**

Individuals or small groups of leadership team members initially developed each MC. Once the first draft was produced, the individual or small group would then seek input from the entire leadership team. After reaching consensus, the team would then send the final draft to our external partner (and hosting platform) Digital Promise for editing and finalizing. In the first year, these edits were completed by Dr. S and our partner organization's micro-credential program manager. The editing duties and communications with Digital Promise were taken over by the graduate research assistant (myself) in the second year.

All MCs were developed using the same general template developed by Digital Promise. (See Appendix I.) The template required that each MC have identified one competency and a key method of achieving and demonstrating the competency. Digital Promise required that we support both the competency and key method with research from the literature. Each MC also required each participant to respond to overview questions that provided context, submit artifacts that served as evidence of the competency. Artifacts submitted over the course of MMTP included written responses, data analysis, research posters, lesson plans, videos, audio recordings, presentations, and supporting documents. Some MCs also required a separate reflection. As part of the MC template, Digital Promise required assessment rubrics describing artifacts that completely met the requirements, partially met the requirements, or did not meet the requirements. Assessment of MCs was divided among the MMTP facilitation team, with those who facilitated particular MCs or groups of teachers being responsible for assessing the MC. Examples of MCs are included in Appendix J, Appendix K, Appendix L, and Appendix M.

While the template provided by Digital Promise was not always ideal for our purposes, it served to keep the MC design focused on a number of key components including teacher action research and the importance of student voice as part of participants' data collection and analysis. One adaptation we had to make almost immediately was that the submission guidelines on the template (Part 1, Part 2, Part 3) did not always align with the different parts of our method components. Although minor, the submission guidelines were not always chronologically aligned with the experiences outlines in the MC methods section. A second limitation that we noticed was that artifacts could only be submitted under Part 2 of the submission. Several participants who wanted to include artifacts for other parts had to include those in Part 2 with an explanation for where they belonged. Although we were constrained by the existing template, as we gained experience, we became more adept at fitting the needs of our program and our participants into the template. The reminders to consistently include research-based methods and competencies and to include student voice kept both the MC authors and the participants focused on the ultimate goal of improving student learning.

Throughout MMTP, 39 MCs were developed with all but two falling into three broad categories: content, pedagogy, and leadership. Two of the first three MCs were foundational, giving participants the opportunity to learn about the process of conducting classroom action research. Of the remaining MCs, five focused on math or science content, 20 focused on pedagogy, and 12 focused on leadership. The MC titles, a short description of each, the number of participants that engaged in each MC, and the years each MC had participants are included in Appendix N.

**Data Collection**

Over the course of MMTP, we collected a great deal of both quantitative and qualitative data. Data sources include videos, surveys, documents, MC submissions, and evaluations of teaching. Much of the data collection was repeated annually, allowing for comparisons of teacher practices over time, with the first data point being teachers' applications in 2016 and the last being the final observation in the fall of 2021[1]. Figure 8 and Table 6 contain a comprehensive timeline and description of the data collected throughout the lifetime of MMTP. Not all of these data sources are used as part of my study but are part of the collection of MMTP as a whole. In addition, a number of secondary data sources were consulted in compiling this history of MMTP, including emails among team members and/or participants, leadership team meeting notes and agendas, MMTP whole-group meeting PowerPoints.

[1] Given that most participants were still teaching virtually during the Spring 2021 observation and data collection period due to COVID-19, we reached out to the participants in the Fall of 2021 to get a more accurate picture of their classroom teaching after the official conclusion of MMTP.

**Figure 8**

*Timeline of Data Collection from the Beginning of the Planning Year (Year 0) through the End of MMTP (Year 5).*

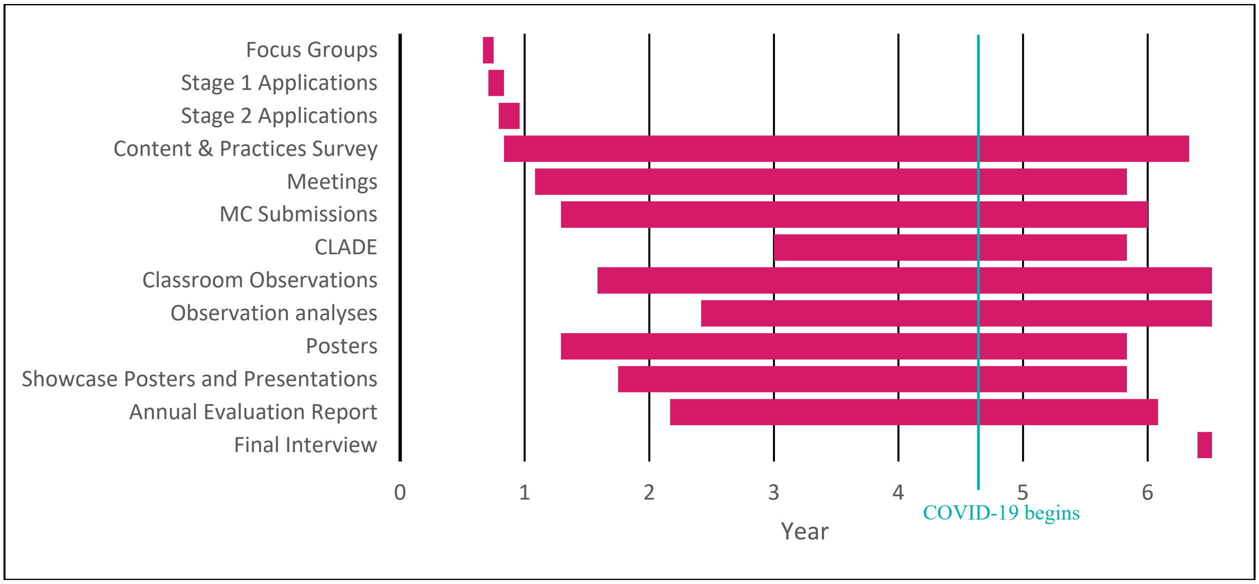



**Table 6**

*Summary of MMTP Data Sources.*

| *Date(s)* | *Data source* | *Format* | *Description* |
|---|---|---|---|
| *6-23 April, 2016* | Focus groups | Written notes, audio | Leadership team presented information about MMTP and asked teachers for their input on their questions about the project, possible math/science content to be included, possible pedagogical topics, possible obstacles, and their questions about MCs. |
| *Stage 1: 21 April – 9 May 2016*<br><br>*Stage 2: 12 May – 17 June 2016* | Applications | Written responses, video | Teachers submitted applications including a personal statement, a video of engaging teaching and corresponding analysis, possible action research questions of interest, and an example of a lesson that the teacher felt needed to be changed for the next time it's taught. |
| *9 May 2016 – 11 July 2016* | Application scoring rubrics | Rubric | Evaluation of each applicant's application materials on a five-point rubric |
| *September 2016 – May 2021* | Whole-group meetings | Video | Video recordings of all whole-group MMTP meetings. In-person from September 2016 to February 2020, virtual from March 2020 to June 2021. |

| *Date(s)* | *Data source* | *Format* | *Description* |
|---|---|---|---|
| *Quarterly, November 2016 – July 2021* | MC submissions and artifacts | Video, audio, written responses, student work, lesson plans, spreadsheets, data analysis, slides, research posters, facilitator assessment rubrics | All artifacts related to participants' MC submissions. Multiple formats of artifacts were expected and accepted. Includes the assessor's rubric scores and comments. |
| *August 2018 – May 2021* | CLADE | Written responses | Chronicles of Learning and Development Episodes: Participants reflected on their learning, the domain of PCK, and connections to practice. |
| *Spring semesters 2017-2021, Fall 2021* | Classroom observations[1] | Audio, video, documents, and photos | Pre- and post-lesson interviews, video of lesson, text pages, lesson plan, student work samples, materials, and other documents associated with the lesson. |
| *January 2018 – (ongoing)* | Analysis of classroom observations | Rubric | Evaluation of classroom teaching on eight rubrics based on the eight teaching practices. |
| *November 2017 – May 2021* | Posters | Research Posters | Research posters sharing background, methods, data, results, and conclusions from selected action research projects. |
| *December 2021(?)* | Final interview | Audio | Final interview of selected mathematics teachers. |
| *October 2017 – August 2021* | Annual Evaluation Report | Report | Annual interviews of participants conducted and compiled by our external evaluator. Contained no individually identifying information. |
| *May 2017 – May 2019* | Showcase posters | Research posters | Research poster highlighting each participant's action research projects through the year. |
| *May 2020* | Showcase presentation | FlipGrid video | Individual videos highlighting each participant's action research projects through the year. |
| *May 2021* | Final Showcase | Video | Groups of participants shared their work with MMTP publicly via Zoom. |
| | Video showcase interviews | Video | Videos recorded for the STEM for All Video Showcase |
| *May 2016 – November 2021* | Content and practices survey | Survey results | Survey of teaching practices and content taught over each academic year. |

[1] In Year 1 and Year 2, teachers scheduled observations on a typical teaching day. In Years 3 and 4, the teachers were asked to schedule so that the lesson being observed showed some connection to their learning with MMTP. Year 5 was disrupted by COVID-19. All but one class was recorded over Google Meet. Given the limited time the district gave after approving the observations, observations were scheduled for convenience.

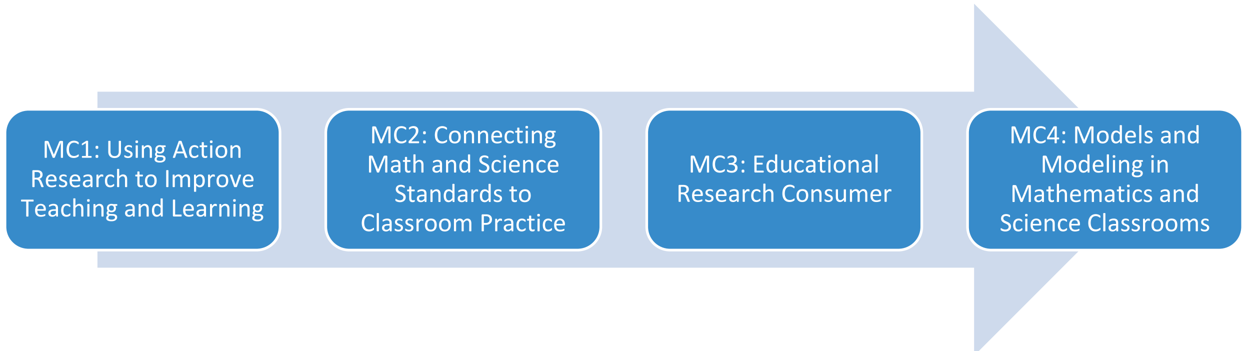
**Year 1**

13 whole-group meetings were held in Year 1. The meetings were held at multiple sites around the city, using spaces at each of the participating LPS schools and at LU; however, at the end of the year, most participants asked for consistent meeting places and times for the following years. Meetings were held approximately every two to four weeks. Six meetings were held on Saturdays from 9 a.m. until 3 p.m. (from September to December) or 1 p.m. (from January to May), six meetings were held on weekday evenings from 4:30-7:30 p.m., and one meeting took place on a district-designated professional development day. The final meeting of the year was intended to be a showcase of participants' work throughout the year. Participants' principals, assistant principals, department chairs, and colleagues were invited, along with school board members, university faculty and administrators, and local, state, and federal elected officials. Participants were able to share one of their action research projects and their learning over the course of the year with these outside parties.

The MCs for the year were designed with the intention of laying the groundwork for participants to conduct classroom action research and understanding the role of the Common Core State Standard for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and the Next Generation Science Standards (NGSS Lead States, 2013) in classroom instruction. The initial plan was that first MC would teach participants about the principles of classroom action research, the second would have participants engage with their content standards, the third would teach participants about critical analysis of academic research, and the fourth would teach participants about modeling in their content areas. Figure 9 shows the timeline of MCs as it was initially planned at the beginning of the year.

**Figure 9**

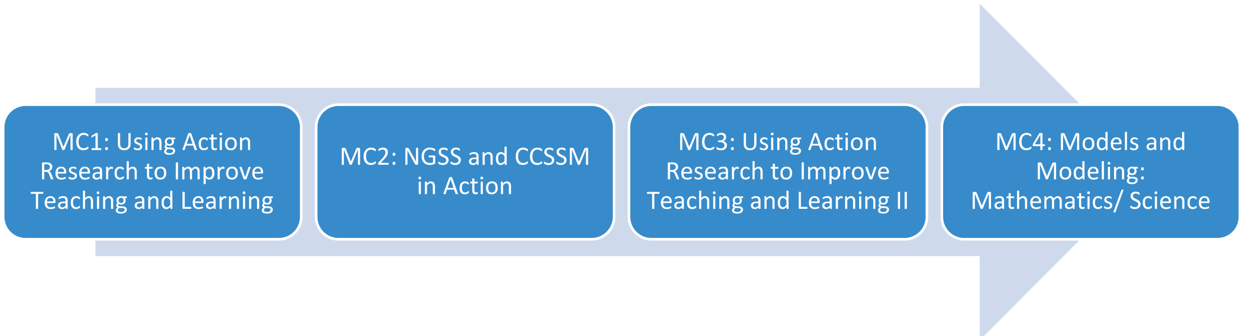
*Year 1 Initial Plan.*




As the work on the first MC commenced with the participants, it became clear that they would need more time to implement their first action research projects to answer their questions and so the timeline for the year was altered from the initial plan (see Figure 10). The initial ction Research MC was split into two MCs to allow time for planning, implementation, and analysis to be conducted. The first MC had participants craft action research questions, conduct a review of the literature, and plan their study. The second MC had participants conduct the study, collect and analyze data, and share results. Two of the remaining three MCs planned for the first year were implemented as intended. For the second MC, NGSS and CCSSM in Action, participants were tasked with unpacking the content knowledge required to show progress toward meeting a math or science standard (or a connected set of standards), design an assessment to measure student progress toward those standards, analyze the data from the assessment, and reflect upon student performance. The final MC for the first year, Models and Modeling, had participants learning about and using modeling in their classrooms. The mathematics group made extensive use of the recently-released GAIMME report (Consortium for Mathematics and Its Applications & Society for Industrial and Applied Mathematics, 2016). The science group focused on scientific modeling and different types of scientific models.

**Figure 10**

*Year 1 Actual Micro-credential Implementation.*




The original MMTP proposal included work during the summer, with the examples of having participants partner with university faculty to engage in research, develop curriculum for the school or district, or partner with K-8 teachers to mutually improve understanding of content across multiple grade levels. Although the proposal did not explicitly mention the first summer, during the summer between Years 1 and 2, we organized several activities for participants to build community and continue the learning. First, the leadership team considered having a summer book club. One of the participants suggested the book *Drive* as a possibility. Two book-club-style discussions were held in late June and early July to discuss the book. Second, we coordinated and held a picnic for participants and their families in late July as a social gathering.

**Year 2**

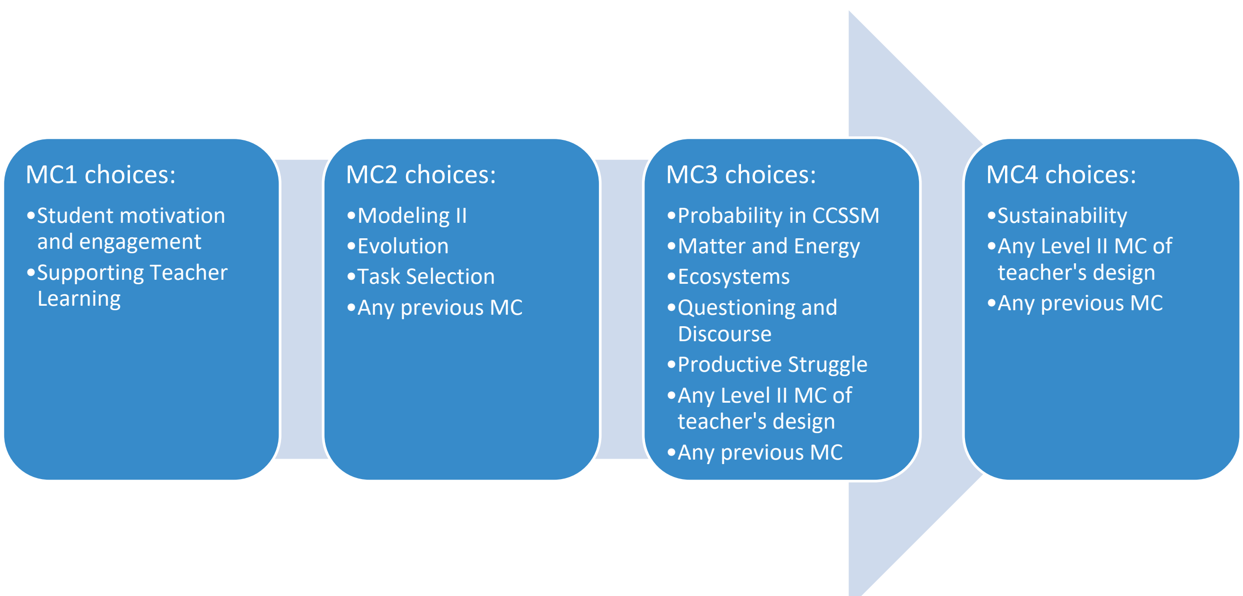
For Year 2, the meetings were streamlined to six and held approximately every six to nine weeks. Rather than meet more frequently as a large group, much of the collaborative work was done within small groups of those working toward each MC and facilitated by one of the MMTP leaders. Those meeting times and places were set by the groups themselves. The intention was to have each MC roughly correspond to each academic quarter (ending mid-October, mid-January, mid-April, and mid-June), but the meeting dates were not well-aligned.

All Year 2 whole-group meetings were held at LU. As with the first year, the final meeting was a showcase designed for the participants to share their work with others. Additionally, we held a social outing in January of Year 2 for participants and their families.

In order to determine the MCs for Year 2, at the end of Year 1, the leadership team surveyed the participants about possible topics of interest. The participants were asked about specific topics in mathematics or science content, instructional practices, and leadership, with space given for participants to suggest other topics of interest. The leadership team narrowed down the Year 2 choices so that two to five new MCs would be developed and deployed each academic quarter. The broader theme of the MCs over the second year was individualization and meeting participants' existing needs. Figure 11 shows the initial plan for MC offerings as intended at the beginning of Year 2.

**Figure 11**

*Year 2 Initial Plan.*



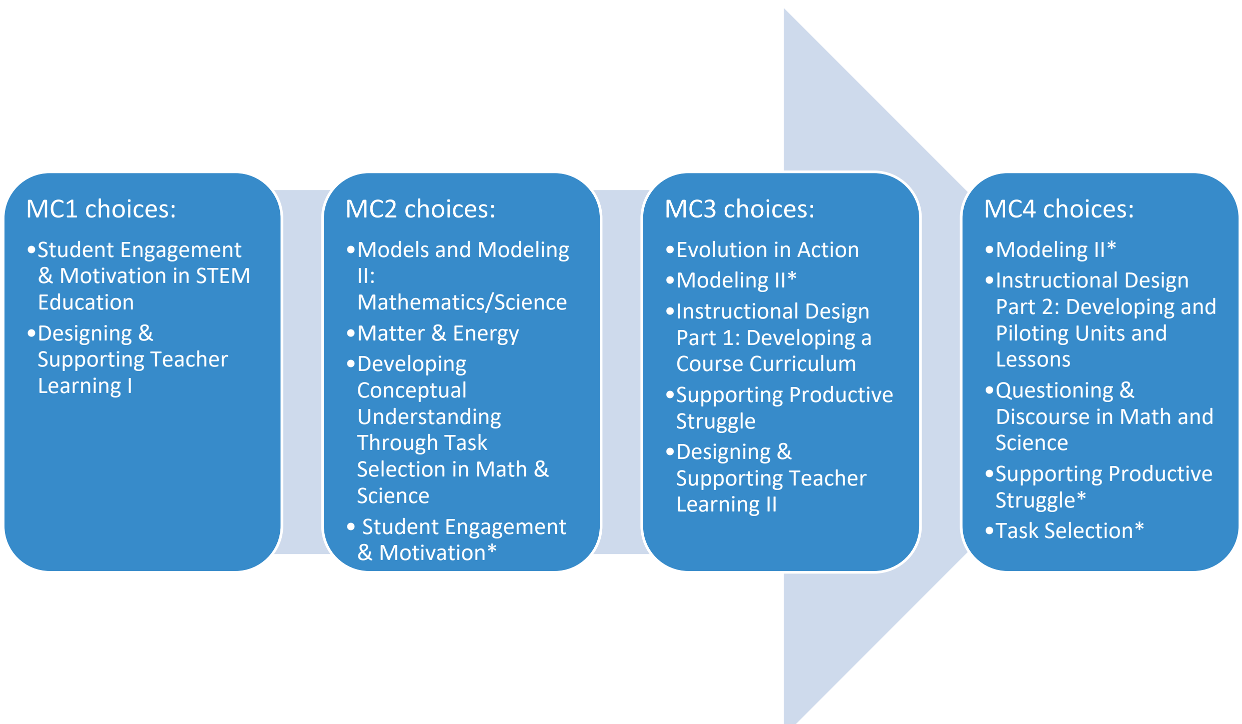

In Year 2, participants could pursue their own pathway through any four MC offerings. We intended to have a few new offerings each academic quarter, but participants were free to choose their MCs. Participants would work with others pursuing the MC and with a facilitator. As the year progressed, it became apparent that the leadership team would need to structure the offerings so that each MC group had at least two participants, given the expectations that teachers would collaborate as a part of their learning. It also became apparent that it would be difficult to offer more MCs than there were facilitators for any quarter; each member of the leadership team took on facilitation duties for small groups of participants each quarter and, in a few instances, one facilitator had to lead multiple groups in the third and fourth quarters.

It was evident that the plans for the MCs would have to shift yet again. The concepts of *Level II* and *Level III* MCs were revised here. In addition to scaling up learning and teaching of each topic from individual to school to district levels, the definitions were expanded to include subsequent MCs of the same name providing further development of teacher knowledge and further engagement with that topic. For instance, the learning from Models and Modeling I from Year 1 was extended into Models and Modeling II, which included the use of mathematical and scientific modeling to address student misconceptions about key topics. This allowed participants to extend their learning on some topics. Other multi-level MCs continued to follow the intended level progression. For instance, in Designing and Supporting Teacher Learning I, participants learned about the principles of teacher learning; for Designing and Supporting Teacher Learning II, participants implemented and examined outcomes of a teacher leadership project.

The majority of the 12 MCs developed in Year 2 were designed around pedagogical practices. Two MCs developed in Year 2 provided a launch into teacher leadership and two MCs allowed science teachers to deepen their content knowledge. One of the most popular MCs offered was Student Engagement and Motivation in STEM Education. Participants learned about motivation in learning, and designed, taught, and reflected on a lesson intended to promote high student engagement. Nearly every participant earned the Engagement and Motivation MC in the second year. Another popular pedagogy MC, earned by just over half of the participants, was Developing Conceptual Understanding through Task Selection in Math and Science, in which participants learned about the levels of cognitive demand in math or science and analyzed the cognitive demand of the tasks they used in their classrooms. Figure 12 shows the sequence of MCs offered in Year 2. The descriptions of the individual MCs offered in Year 2 can be found in Appendix N.

**Figure 12**

*Year 2 actual Micro-credential Implementation (MCs marked with * were repeats of previously-developed MCs.)*




A shift in district calendars meant most of the teachers would be beginning school in Year 3 approximately four weeks earlier than previously, which limited the time for summer activities. Despite this shift and the significantly shorter summer break, all teachers engaged in work during the summer. These experiences ranged from job shadowing instructors at a local university, conducting research with local university and medical college researchers, mentoring incoming Teach for America members, and investigating and working to address issues of concern at their local school site. It was initially noted that some teachers might be able to apply their experiences toward an MC the following school year, but these MCs were not created.

**Year 3**

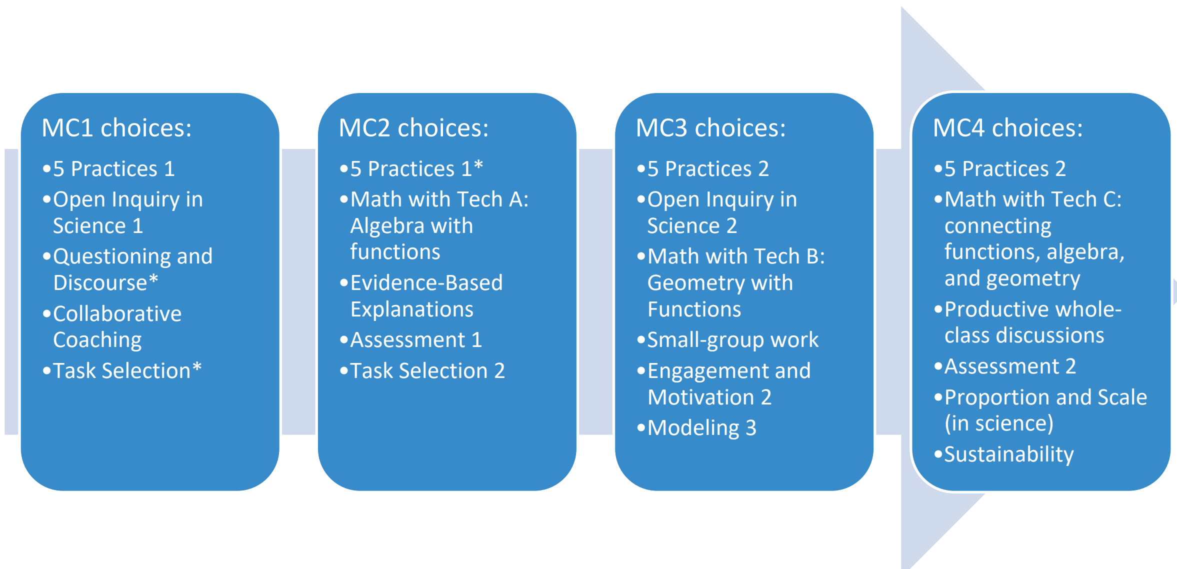
Year 3 had six scheduled whole-group meetings, which (at the request of the participants) coincided with the beginnings and ends of each academic quarter for LPS. Meetings were subsequently scheduled in this way through the end of MMTP. All whole-group meetings were scheduled at LU and held on Saturdays from 9 a.m. to 1 p.m., except for the final showcase meeting.

Early in the summer between Years 2 and 3, the leadership team coordinated three focus group meetings with the participants—one each for science, mathematics, and teacher leadership—to determine the MC offerings for Year 3. The result of these focus groups was the selection of several pre-existing MCs offered on Digital Promise from other organizations and a list of MC topics for Year 3.

Year 3 began with an ambitious plan. As a result of the conversations in the focus groups, the leadership team planned to offer MCs for math, science, and cross-disciplinary pedagogy, using technology in mathematics, and teacher leadership. Mathematics teachers seemed particularly interested in learning more about incorporating technology tools to help their students learn. Science teachers seemed particularly interested in planning and implementing open-inquiry investigations. Across disciplines, teachers were interested in revisiting task selection from the perspective of revising and extending tasks, extending their knowledge and use of modeling in the classroom, using the five practices for orchestrating productive discussions (Cartier et al., 2013; Smith & Stein, 2018), and improving summative assessments. Other topics were planned for as well; Figure 13 shows the initial plan for MCs for the third year.

**Figure 13**

*Year 3 Initial Plan (MCs marked with * were repeats of previously-developed MCs.)*

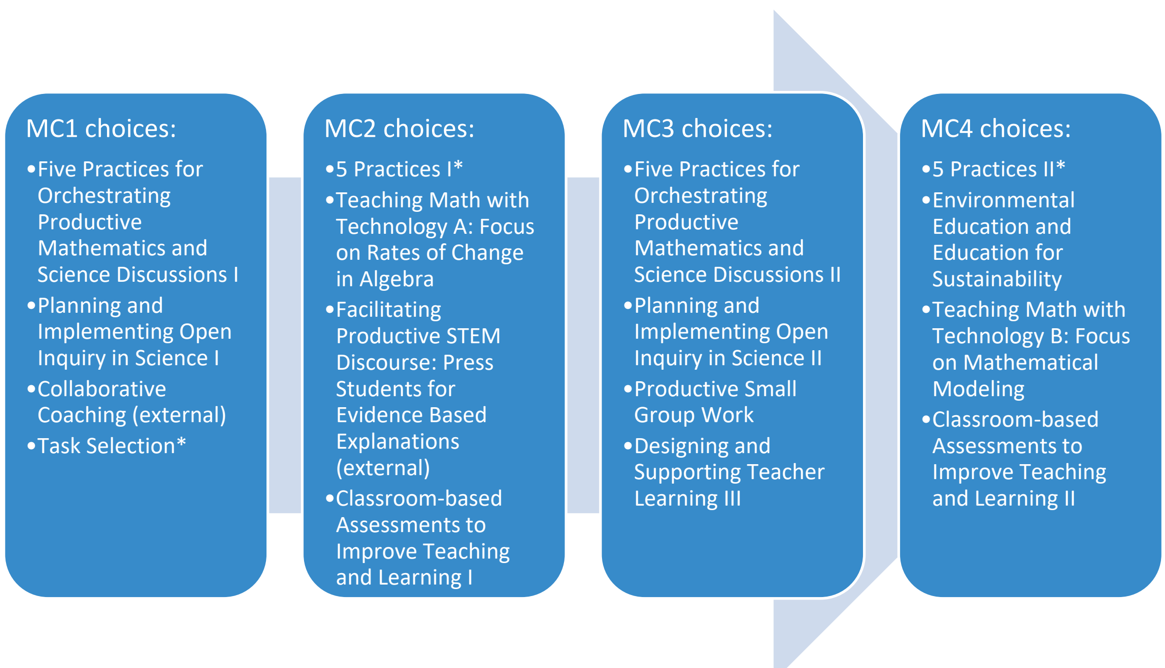



In mathematics, we initially planned to offer MCs on teaching math with technology that incorporated the essential concepts for algebra and geometry from a function perspective, as outlined in the recently-released publication *Catalyzing Change in High School Mathematics* (NCTM, 2018). The three planned Teaching Math with Technology MCs would have teachers explore rates of change in algebra and congruence and similarity in geometry separately, then connect the two using functions as a lens. As the year progressed, as in previous years, participants' needs and priorities solidified, and these were condensed to two MCs: One for using technology to investigate rates of change in algebra from a functions perspective and a second for using technology to engage with mathematical modeling tasks.

Overall, as the year progressed, the MC offerings became much more focused. Nearly every participant completed the two Five Practices MCs, and most math teachers completed the two Teaching Mathematics with Technology MCs. Additionally, the structure of the MCs shifted and became less prescriptive, broadening the ways in which participants could apply their learning and plan and conduct action research. As the leadership team became more proficient at writing MCs, we also became more proficient at broadening the ways teachers could show competency for each MC. The MCs offered for Year 3 are shown in Figure 14 and the descriptions of the MCs can be found in Appendix N.

**Figure 14**

*Year 3 Actual Micro-credential Implementation (MCs marked with * were repeats of previously-developed MCs.)*




The broadening of the MCs was in part due to a desire to increase the cohesion of the work participants were doing across MCs and across years. In the beginning of the year, we introduced a new tool, the Chronicles of Learning and Development Episodes (CLADE), that teachers would use to reflect on their content knowledge and pedagogical content knowledge, look for connections across MCs, and plan for cohesive experiences. (See Appendix D.) At the beginning of Year 3, teachers summarized their learning, identified the domain(s) of PCK targeted, reflected on their overall growth during the previous year, and crafted goals for the current year. Participants returned to their CLADE each subsequent academic quarter in Year 3 to reflect on their learning and at the end of the academic year to look back at the year and look ahead to the next year.

In part, the CLADE was driven by a perceived lack of participant interest in engaging in deeper learning about mathematics or science content. The leadership team wanted participants to reflect more broadly on their content knowledge for teaching (including common content knowledge and specialized content knowledge), rather than having a narrow focus on pedagogical knowledge and learning about pedagogy.

In planning for summer activities, it became apparent that the policies, practices, and structure of LPS (as a large district with a large bureaucracy) limited our ability to have participants engage in curriculum development (as initially planned). Proposals for new courses needed to be completed early in the spring semester, curriculum planning work was scheduled by the district to occur every several years, and that schedule did not coincide with our needs, and collaborations with teachers outside of MMTP required administrative approval that proved difficult to obtain. Ultimately, the team made the decision to redirect the summer learning experiences.

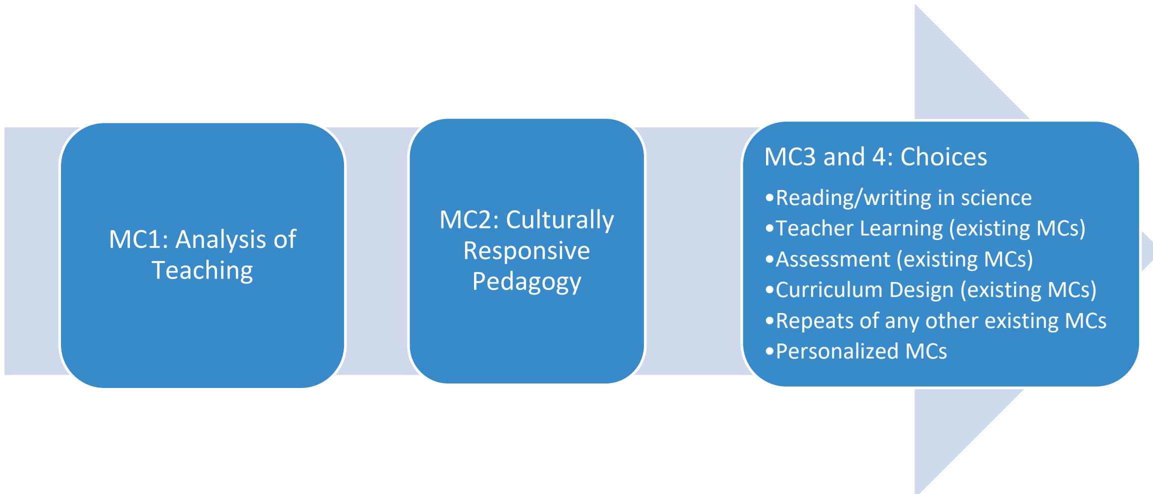
During the summer between Year 3 and Year 4, the leadership team revisited book studies since the first book study had been successful. Rather than have all participants read the same book, we divided into four smaller book study groups to discuss different books about math, science, leadership, and learning. Both participants and leaders suggested books, and participants were able to select which book (or books) they wished to read over the summer. The four books we chose were *For White Folks Who Teach in the Hood… and the Rest of Y'all Too: Reality Pedagogy and Urban Education* (Emden, 2016), *Medical Apartheid: The Dark History of Medical Experimentation on Black Americans from Colonial Times to the Present* (Washington, 2006), *The Invention of Science: A New History of the Scientific Revolution* (Wootton, 2015), and *Everything You Need for Mathematics Coaching: Tools, Plans, and a Process That Works for Any Instructional Leader, Grades K-12* (McGatha et al., 2018). Each book study group met twice in July to discuss their books.

**Year 4**

Year 4 initially started with the intention of having two common MCs that all participants would engage with, Analysis of Teaching and Culturally Responsive Pedagogy. From there, participants could choose from among the existing MCs or propose their own MCs. (See Figure 15.) This was done in order to streamline the MC choices, add coherence, and build toward leadership of others. Continuing the course from the previous year, the participants had much more flexibility in their choice of how to fulfill each MC. The Year 4 MCs were designed so that a participant could identify a relevant problem of practice in their own setting and use the tools of the MC to examine that problem. The MCs also more explicitly allowed for flexibility in format of submissions, including video narratives (rather than written) and research posters (rather than written narratives).

**Figure 15**

*Year 4 Initial Plan.*



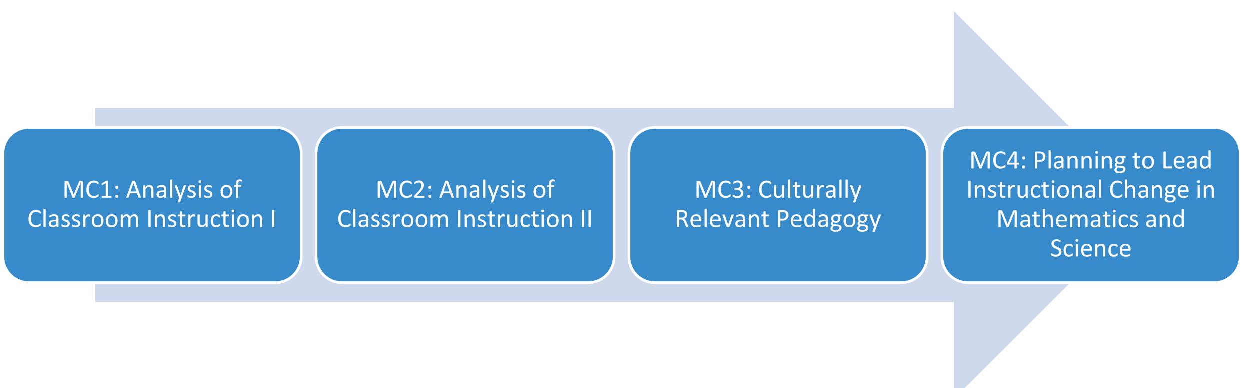

Analysis of Teaching would introduce participants to the SeeMeTeach® tool developed by Dr. Craig Berg (Berg, 2019). Along with learning to use SeeMeTeach®, teachers would analyze their actions both quantitatively and qualitatively, reflect on their actions, and use the analysis to find ways to increase student engagement in the classroom. After learning how to use SeeMeTeach®, the participants would then have access to it as an observation tool to use for both analyzing their teaching and providing feedback to others.

The Culturally Responsive Pedagogy MC was developed at this time for several reasons. First, we had been noticing deficit thinking being communicated by some of the participants, and we wanted to confront that head-on. Second, the group had been together long enough that the leaders thought that there was enough trust among the members of the group that we could have difficult conversations. We contracted with Dr. L, a district employee of LPS, former professor, and an expert in diversity training, to help create the MC and facilitate the MC introduction and check-in meetings since the leadership team did not want to make inadvertent errors in leading participants through this work.

As the first academic quarter progressed, it became clear that the leadership team was not ready to implement the Culturally Relevant Pedagogy MC in a way that we felt comfortable, and the facilitation team made the decision to delay the MC until later in the school year. We wanted to make sure that we would not be doing harm by rushing the preparatory work. An additional Analysis of Instruction MC was added in which participants would collaborate with another MMTP member or colleague to analyze instruction using a lens of equity and inclusion. By the end of Year 4, the team had streamlined the MC choices and each participant completed the same four. (See Figure 16 and Appendix N.) However, as noted before, both the individual goals and products of the MCs varied by participant, although the overall goal was to have participants purposefully reflect on their practices.

**Figure 16**

*Year 4 Actual Micro-credential Implementation.*




Year 4 closed with an MC intended to lead teachers into a year-long leadership project that would be implemented in Year 5. Teachers planned projects that involved mentoring beginning teachers (including preservice teachers); mentoring another teacher in elementary, middle, or high school; developing and implementing new curriculum, including developing new courses; or developing and implementing professional development to strengthen research-based instructional practices. Teachers had a great deal of flexibility in designing their projects, with most falling under the umbrellas of social justice and equity, mentoring, and curriculum development.

It should be noted that the two Analysis of Teaching MCs and the Leading Instructional Change MC (along with the MCs in Year 5) were all created to build teachers' leadership capacity but were quite different in format than the earlier leadership MCs. The leadership MCs in the second and third years were primarily developed by Dr. B. They were explicitly intended to teach the participants to lead teacher PD or engage in curriculum development. Participants were able to choose the Designing and Supporting Teacher Learning MCs and/or Assessment MCs as they desired, and these four MCs were narrow in scope.

In contrast, the leadership MCs in Year 4 and Year 5 differed in several ways. First, all participants completed these later MCs. Second, these later leadership MCs were developed by Dr. C and Dr. S with considerable input from the larger facilitation team. Third, the later leadership MCs were much broader in scope than the earlier leadership MCs. While the earlier leadership MCs were written specifically using a combination of theory and application and were intended to teach participants how to plan and lead teacher PD, the later leadership MCs focused solely on application; they were written to allow for participants to investigate any aspect of leadership in which they were interested. (See Appendix M and Appendix N for examples of both types of leadership MCs.)

Ultimately, Year 4 was disrupted by COVID-19, with the third meeting in January being the last time all participants gathered in-person. All schools in the state were closed in mid-March 2020. Although the fourth meeting occurred before this official closure, LU had restricted all gatherings and the fourth meeting was quickly reworked and moved to Zoom. LPS schools did not return to instruction until the beginning of the 2020-2021 academic year, although other schools in the region developed and implemented plans for online instruction as it became clear that returning to in-person instruction would not be possible.

During the summer between Year 4 and Year 5, given the changing conditions and the expectation that schools would not be opening in-person instruction for 2020-2021, the facilitators organized a series of optional online hour-long workshops for teachers to learn about conducting engaging instruction online. Three of the four drew upon the competencies that teachers had built in their previous MC work: Engagement and Motivation in Online Learning Spaces, Using the 5 Practices in Online Learning Spaces, and Practicing Authentic Science in Online Learning Spaces. The fourth, Using Desmos in Science Classrooms, introduced the science teachers to Desmos, an online tool already used by the math teachers. The overall goal of these workshops was to increase students' access to authentic learning experiences and meaningful discourse while classes were conducted in online spaces.

**Year 5**

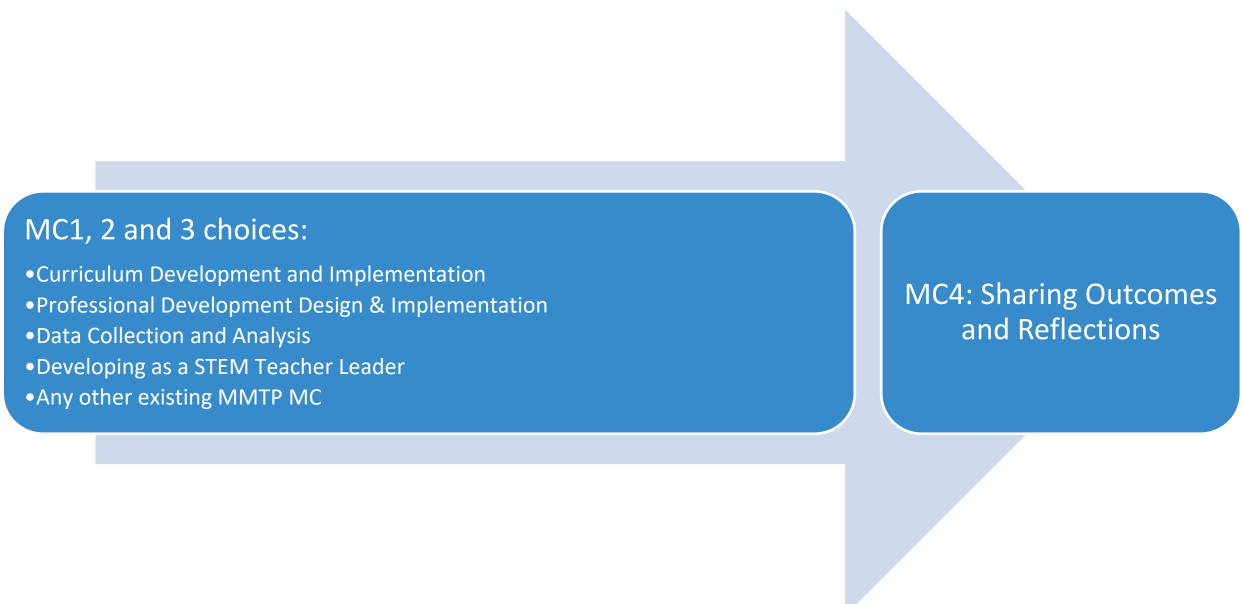
Year 5 was structured differently than the previous four years for multiple reasons. First, it included the previously planned year-long leadership project for all participants to design, implement, and analyze. Second, instruction in LPS was conducted online for the majority of the year because of COVID-19. Third, all meetings for Year 5 were virtual because LU facilities were closed due to COVID-19.

The Year 5 MCs were designed for maximum flexibility. (See Figure 17 and Appendix N for descriptions.) Some teachers needed to adjust their plans from the previous year because of COVID-19, but the projects still mostly fell into the categories of curriculum development, PD development, mentoring, and social justice. The Curriculum Development and Implementation MC was designed to guide participants through the process of developing units using

Understanding by Design (Wiggins & McTighe, 2005), a process where instructional units are developed first by identifying desired goals and results, then determining the evidence that would show that students had met those expectations, and then designing the instructional experiences. The PD Design MC was developed with the same process in mind. Participants were also expected to collect data and analyze the results of their leadership projects and could reflect on their own growth and development as a teacher leader. The final MC, Sharing Outcomes and Reflections, was designed for participants to bring the work of the whole year together and reflect on their learning, growth as a teacher, and development as a teacher leader over the course of the five years of MMTP.

**Figure 17**

*Year 5 Initial Plan and Actual Micro-credential Implementation.*




An additional component of Year 5 was the integration of work intended to help participants understand the context of their students using culturally relevant teaching, precipitated by the events of the spring and summer of 2020 that led to national protests and conversations about racial justice. The leadership team invited a guest speaker (Ms. G) who led everyone (both participants and leadership team members) through a series of sessions designed to help participants interrogate beliefs and learn about antiracist teaching.

## Conclusion

In this chapter, I have presented a historical narrative of MMTP. Overall, MMTP provided a long-term opportunity to engage teachers in professional learning in ways that honored their experiences as mid-career teachers. They planned, executed, and shared action research in their own classrooms and were able to see the impacts of their learning on their teaching over the course of several years. The group became a tight-knit learning community, and some participants have chosen to engage in work as school and district leaders that will extend beyond the boundaries of MMTP. Two participants are now in positions as coaches, one is a principal, and one is a district-level administrator. Three participants wrote a proposal for and piloted a new third/fourth-year course that integrates mathematics and science topics. One participant is gaining prominence as an expert in using restorative circles in teaching and is hoping to write a book sharing what she has learned and experienced.

# Chapter 5: Findings

The examinations of five and a half years of teachers' work elicited many themes. The themes for each person coalesced into two major categories for each: the evolution of their teaching and the evolution of the teachers as leaders. The second of these was unexpected for me. I had not anticipated that themes of leadership would be as prominent as they were for all of these four teachers.

I focused on examining teachers' changes in practice, looking for evidence of changes in their knowledge and beliefs, in an effort to answer my research questions and sub-questions: How have teachers' practices changed through their participation in a practice-based professional development project?

1) What trajectories did teachers' changes in practice take?
    a) How did the nature of their participation in MMTP impact teachers' pedagogical practice?
2) How did teachers' mathematical knowledge for teaching and beliefs about teaching mathematics evolve over the course of MMTP?
3) What pathways did teachers take in their professional learning with MMTP?
    a) What factors shaped their movement on the pathways?
    b) How did the nature of their participation in MMTP impact teachers' attitudes toward professional development and their thoughts about future engagement in professional learning?

In the next sections, I will share narratives that will illustrate the evolution of each teacher's classroom practices and leadership over their five years with MMTP in order to answer my second sub-question. I will tie the changes to their learning to the structure of learning within

MMTP in order to answer the first sub-questions. I will then link these changes with aspects of the design of MMTP that were influential in their learning.

I have structured the narratives to include the teachers' own words. In each narrative, I will introduce the teacher and share their timeline of work with MMTP. I will then expand upon the themes that I elicited surrounding the evolution of their teaching practice and the evolution of their leadership. I will link each teacher's learning outcomes to the design of MMTP as a learning experience. I will close each narrative by summarizing their learning pathway, including themes of changes in teaching practice, leadership, and the structure of MMTP, and tie these to my framework for teacher learning (Figure 5).

These narratives are not shared in any particular order. Each presents the teacher as an individual case. When quotes are used, they are direct quotes and unedited except where shown with ellipses or bracketing. Unless otherwise noted, all spelling, grammar, and wording are as they appear in the teachers' original works. All quoted words are the teachers' own.

### Nolan Newman

> *I now have the knowledge and skills to actually feel worthy of being a coach for another math teacher. Prior to the MMTP program there is no way I could have done this work with any sense of credibility. (Newman, narrative for Planning to Lead Instructional Change MC, Y4)*

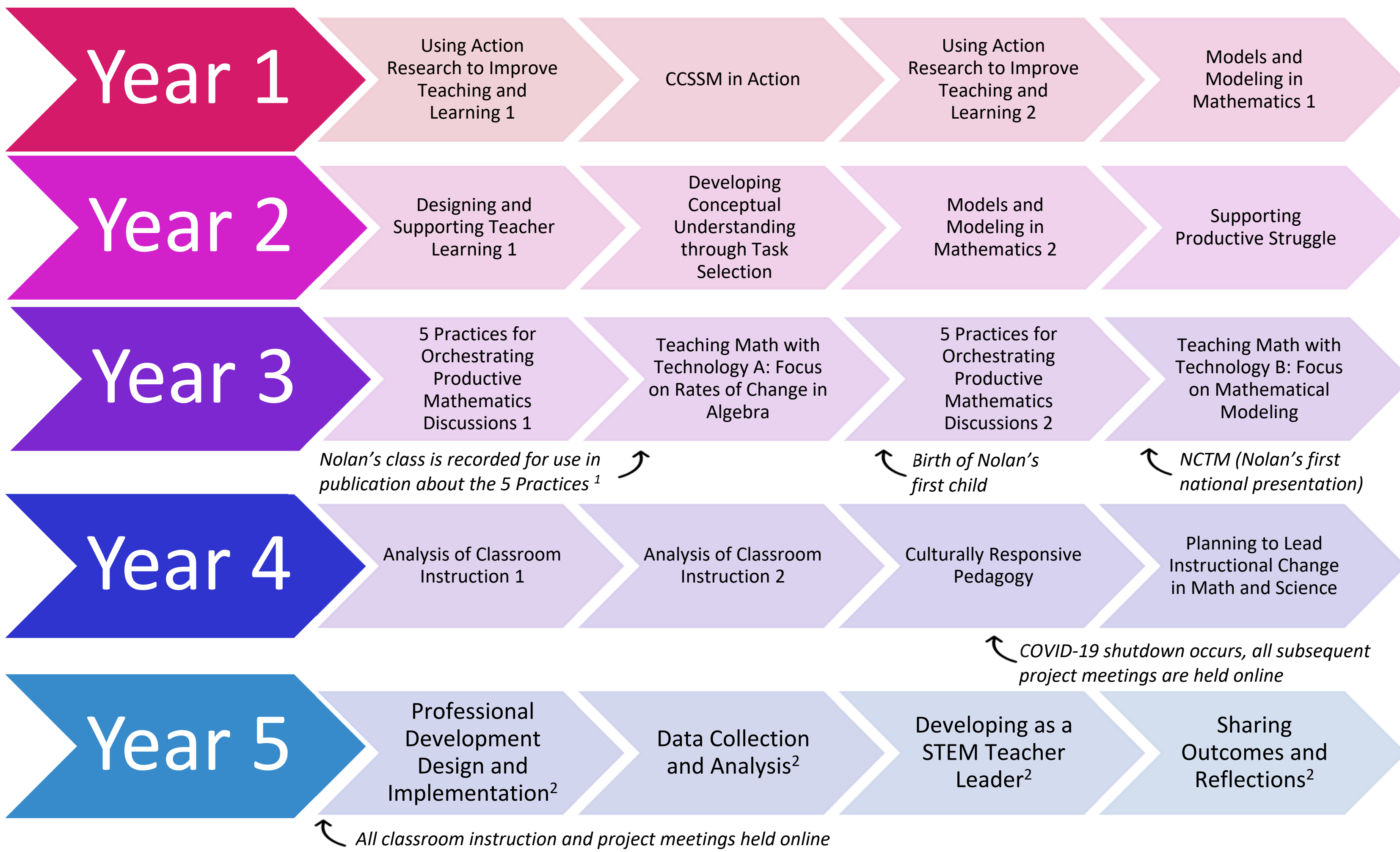
Nolan had been teaching for eight years when MMTP started. He is the chair of the math department at Evergreen high school, an International Baccalaureate (IB) magnet school. His classes included Geometry and a variety of eleventh- and twelfth-grade level IB math courses, as well as a math class designed as intervention for ninth and tenth grade students who struggled with their mathematics classes.

In his work with MMTP, Nolan completed only 16 of the 20 micro-credentials that he was expected to complete. For reasons that were both personal (Nolan’s first child was born in January of 2019) and related to the COVID-19 shutdown in the spring of 2020, Nolan did not complete the written requirements or submit work to earn the Year 5 micro-credentials, and consequently was not paid for his participation in Year 5, although he continued to be an active participant in the MMTP meetings. Nolan’s timeline with MMTP is shown in Figure 18.

Over the course of MMTP, Nolan experienced changes in both his teaching and in his leadership. Although he began as a confident teacher who had a history of choosing high-demand tasks, he was not necessarily maintaining the demand of the tasks through the lesson. Nolan acknowledged that he had a tendency to talk too much in his teaching rather than having students talk. As a leader, Nolan was a department chair but did not engage in the larger math teacher community and did not lead teacher learning at his school. Nolan’s artifacts for his micro-credentials, his videorecorded lessons, and his interviews provide evidence of the changes that Nolan experienced in his teaching practice and leadership as he came to view himself as a credible authority. In the sections that follow, I will expand on these changes and share evidence of their existence in order to answer my second sub-question.

**Figure 18**

*Nolan Newman's Timeline of Work with MMTP.*




[1] The name of the publication is redacted for blinding purposes.
[2] Intended but not completed.

**Evolution of Nolan's Teaching Practice: Changes to Nolan's Notion of "Success"**

Nolan's initial application and classroom observation in the first year indicated that he was planning for use high-cognitive-demand mathematical tasks, although not necessarily maintaining the demand during the lesson. (Table 7 contains a summary of Nolan's rubric scores using the MMTP Classroom Observation Tool (see Appendix F).) Nolan's lessons were typical of a teacher-led classroom, where he was sharing knowledge with students and students were practicing. In several places in his application, Nolan noted a desire to learn about formative assessment and the extent to which students understood what was being asked of them. This indicates a desire for Nolan to control the pace and flow of the lesson and that student success meant, for him, that students would produce correct answers. In the observation in the first year, Nolan began with a high-demand task, but the demand of the task was lowered during class because the connections between the procedures and the mathematical conceptual ideas were entirely made by the teacher and told to the students, rather than being made by the students themselves; additionally, there was not a clear expectation that the students' conjectures be supported by mathematical reasoning.

**Table 7**

*Heatmap Visualization of Nolan Newman's Classroom Observation Rubric Scores over Time.*

| | App | Y1 | Y2 | Y3 | Y4[1] | Y5[2] | Post-Y5[3] |
|---|---|---|---|---|---|---|---|
| *Goals* | 2 | 2 | 4 | 4 | | 4 | |
| *Tasks* | 3 | 2 | 3 | 4 | | 3 | |
| *Representations* | 3 | 3 | 3 | 4 | | 3 | |
| *Teacher Discourse* | 2 | 3 | 3 | 3.5 | | 2 | |
| *Student Discourse* | 2 | 2 | 3 | 3.5 | | 2 | |
| *Questions* | 3 | 2 | 3 | 3 | | 3 | |
| *Fluency from understanding* | Not obs | 3 | Not obs | 4 | | 3 | |
| *Struggle* | 4 | Not obs | 2.5 | 2 | | 3.5 | |
| *Evidence* | 1 | 2 | 3 | 3 | | 3 | |

[1] Year 4 observation was scheduled for a date after March 13, 2020, when schools closed due to COVID-19.
[2] Year 5 classes and observation were conducted entirely online and may not be indicative of typical teaching.
[3] Despite MMTP facilitators attempting to schedule an observation, Nolan's final observation was not completed.

In addition to selecting high-demand tasks, Nolan's application and first classroom observation in the spring of Year 1 showed use of multiple mathematical representations (graphs, tables, formulas, and numeric work), although connections between the representations were inconsistent and more connections were made by the teacher than by the students. The scaffolding present in the task in the first year removed opportunities for students to productively struggle. His questioning reflected this; Nolan either prompted students with low-level questions or responded to his own questions.

Overall, Nolan appeared to focus on ensuring that students were using formulas correctly and obtaining a correct numerical solution for the task, showing concern for students being able to complete the procedure, although he hints that he wants students to use different representations and that he wants them to connect the different representations (such as using a graph to find a solution for an equation).

> The math, like I kept saying at the end, will come back. I know now thanks to the exit slip, I don't really need to focus on if given everything [in the compound interest formula], find a future value. They seem pretty competent with that there at the end of class. But now I know that I probably need to focus on if the exponent is missing a piece, if we're missing [the number of compounding periods in a year] or [the number years] in that exponent, or if we're missing the interest rate. They don't learn about logarithms in [IB] Math Studies…we primarily only focus on solving exponentials through graphing. (Newman, post-classroom observation interview, Y1)

In this first classroom observation, Nolan used student participation as a measure of success. When asked if he met his goals for the lesson, Nolan responded:

> I felt like the kids were really engaged, which is always goal number one. I maybe had one or two kids that were a little off topic, but just the level of discussion I felt was really great. The questions that they were asking, the things they were sharing, that for me is always like indicator #1 if the lesson was just enjoyable, right? If they if they were engaged in the learning and I felt a high level of engagement today, so success for sure on the engagement front. (Newman, post-classroom observation interview, Y1)

This measure of success was consistent with Nolan's micro-credential work in the first year. Nolan initially judged success of lessons based on student engagement, whereby if most students were engaged in doing mathematical work during the whole lesson, answering his questions, and staying on-task, he felt the lesson was successful.

> Often times I will have a lesson that by all indicators seems to have been successful. High student participation, solid discourse, high quality in class work, and even success on exit slip questions. (Newman, narrative for Action Research 2 MC, Y1)

One of Nolan's first lessons using mathematical modeling used the task in Figure 19 and asked students the question, "How many people would the amphitheater hold when filled to capacity?"

**Figure 19**

*Task Used by Nathan in Models and Modeling 1 MC, Y1*

Archeologists and mathematicians work hand in hand often to analyze artifacts to help better understand an ancient people and their civilization. Below is a picture taken by an archeologist sent to you for some mathematical interpretations. It is a picture of an amphitheater in Turkey.

Using math, what information could you possibly inform your friend about regarding the ancient amphitheater.

This task had the potential to be a good, high-demand *Doing Mathematics* task, but Nolan's expectations for students were that they be engaged with the task, which potentially lowered the demand.

> I was mainly just looking for solid student engagement. My biggest priority was to have everyone contributing to the work on a problem. I was definitely not concerned with the correctness of the work. (Newman, narrative for Models and Modeling MC, Y1)

In the second year, Nolan continued to use high-cognitive-demand tasks in his teaching, although the implementation of the tasks shifted. Nolan prompted students for justification and explanations that moved beyond the mechanics of the calculations and connected to their understanding. Nolan also began to use factors beyond student engagement and include his thoughts about student thinking and perseverance. Although he continued to emphasize student participation as a means of success, inclusion of these indicators marked a small shift in his thinking about what it meant for a lesson to be successful and in his conceptions of the meaning of student engagement. These shifts were evident in his writing and his responses to questions about the goals of the lesson.

> Justifying that your answer is correct and being able to show how you know it is, is a main component to a doing mathematics task. It is also slightly unnerving to students who just want to be told that they are doing the work the right way and rest comfortably in that type of success. Engaging students in tasks that are examples of doing mathematics requires work in changing the mindset of students about what we are seeking when we do mathematics, to develop more questions along the way rather than just an answer. (Newman, narrative for Task Selection MC, Y2)
>
> I saw a lot of kids really struggling, at first, to get going. But then they did…They were just sitting there, staring, a lot of them. Maybe highlighted the two days of data they wanted to look at, but that was about all they had done, and minutes were passing and that's all they had done…Having them work through that process of, let's think about things that we know how to do, think about things that are similar, and everybody got going. Like I said, I that was the biggest part to me that I was happy with. (Newman, post-classroom observation interview, Y2)

These shifts in implantation of the tasks and what it meant for students to be successful correlated with a shift in Nolan's stated goals. In the first year, Nolan's lesson goals for were performance goals (Smith et al., 2017) and tied mostly to mathematics content with little opportunity for students to engage in the Standards for Mathematical Practice.

> Today we're learning about compound interest and I hope by the end of the class they can find the future value of an investment using the compound interest formula and also identify an unknown exponent, either the number of compound periods or the years needed in an interest formula given the future value. (Newman, pre-classroom observation interview, Y1)

In contrast, his goals for the second year (and beyond) were learning goals, and shifted away from what students would do toward what students would understand.

> Today I want them to just look at a data table 'cause they're about to be collecting a lot of data. So I'm going to give them a sample set of data and have them kind of practice. Like how would I want to represent this? What are different ways to talk about it? Have those discussions…Hopefully they see that there's different ways to represent data, which ways work best for different types of datasets, and also that there's different ways to talk about data in terms of averages. The difference between mean, median, mode, that kind of stuff, and that it leads to different discussions. (Newman, pre-classroom observation interview, Y2)

In the third year, Nolan also had the opportunity to be featured in a then-upcoming publication on using the Five Practices for Orchestrating Productive Mathematics Discourse[1]. This involved extensive planning in collaboration with experts on the Five Practices and with district coaches, multiple revisions to his initial plans based on feedback, videotaping of his classroom, and interviews both before and after about the lesson and his views on teaching practices that lead to successful use of the Five Practices. This experience of working with

[1] The name of the publication is redacted for blinding purposes.

experts in such a personalized way seems to show a marked shift in Nolan's planning practices and he noted this as a high point of his participation in MMTP.

> I obviously really enjoyed all the work that I got to do with [the two authors] around questioning and discourse, the Five Practices. That was a highlight of my career probably getting to do work with [the author] and her team and then be part of the book…The knowledge of the Five Practices and the level of comfortability that I got with them through doing that work was amazing, especially since that extra layer of them coming and taping and interviewing really forced me to, I had to read that material several times over and…I really had to familiarize myself with those Five Practices. (Newman, final interview, post-Y5)

Nolan continued refining his mathematical goals for lessons, attended to maintaining the cognitive demand of the tasks he used, and increased his attention to student understanding as a precursor to procedural fluency.

> Students are learning to understand the difference between experimental and theoretical probability and be able to use simulations to model real events. (Newman, lesson plan for Math with Technology: Focus on Modeling MC, Y3)

> Today, we are going to be applying properties of quadrilaterals to know that we've proved that we've constructed a quadrilateral in the coordinate plane. My goals are for kids to be able to justify how they know that they've created the quadrilateral by expressing properties of that quadrilateral. I hope that they'll learn how to use properties in order to know that they've constructed something properly in the coordinate plane. (Newman, pre-classroom observation interview, Y3)

Nolan was mentioning participation and engagement less as a way of assessing the success of a lesson. He began referring to and using his mathematical goals as a way of measuring a lesson's success.

> I got every anticipated solution that I thought I would see. I think I got a really firm expression to them of the idea of justification, what's going to be expected of them on their upcoming assessment. I think that that was clear. I wish obviously that the exit ticket would have gone a little bit better than 79% correct. I wasn't expecting 100, but the fact that 20% of them still couldn't decide where a fourth [vertex] went to complete a rhombus, a little bit alarming. (Newman, post-classroom observation interview, Y3)

This correlates with an increased specificity in Nolan's goals and his use of learning goals as opposed to performance goals (as described in Smith et al. (2017)).

> [Students will] understand that (1) creating mathematical models of geometric sequences is helpful in identifying key features that can be used to make mathematical arguments; (2) similar triangles are related in two ways: their corresponding angles are congruent, and the lengths of their corresponding sides are related by a common scale factor; and (3) Justifying that two triangles are similar means making arguments about the ways in which corresponding angles are congruent, and corresponding sides are scaled using ideas such as corresponding parts of triangles and scale factor. (Newman, lesson plan for Five Practices publication, Y3, used with permission of the author)

By the third year, Nolan also recognized his tendencies to dominate the classroom discourse and began encouraging students to participate more in whole-class discussions. As he became aware of the impact of the teacher's voice in classroom discussions, he also became concerned with increasing student voice in discussions. There appeared to be a sense of cognitive dissonance that had existed prior that was beginning to resolve as he reconciled his previous conceptions of "success" (students being on-task and producing correct answers) with his new thoughts on what it means for students to be successful in mathematics (increasing conceptual understanding).

> I think every single teacher on the face of the earth struggles with not telling, right? Saying to myself, "Be careful with your leading," and feeling sure I will fall into the pit of saying too much as I always do. You want to point things out, you want to put fingers on students' papers. I do my absolute best to never take a pencil from somebody, [and] draw on their drawing, but it's always tempting. It's super tempting to say, "Oh, let me just add a little line to your picture here. Now do you see the triangle? Of course you do, because I drew it there!" [Try] to be conscious of it as much as possible. If you try to make a point of it every day, it becomes routine. (Newman, interview for Five Practices publication, Y3, used with permission of the author)

In the fourth year, there was no opportunity to observe Nolan's classroom. An observation was scheduled, but the closing of schools on March 13, 2020, necessitated its cancellation. Even with this setback, it is possible to infer some information about Nolan's teaching based on his micro-credentials from that year. In the Analysis of Teaching 1 MC, teachers investigated the actions of themselves and their students. In his reflection, where he analyzed used self-recorded seven-minute video from an unspecified date in Year 4, Nolan noticed that:

> The most common question I ask is asking a short answer question. I think that this is largely because I am guiding. I have an end destination in mind for me and the students and sequence a series of short answer questions to help lead to the conclusion. I also

asked questions that required speculation by the student on 5 occasions throughout the video clip. These questions that require speculation are looking for the student to try and make connections…There is only one time that I used a student answer to pose something to the group. I am glad that this happened the one time but am disappointed that it was only once. The use of a student's response to further the conversation makes the dialogue more of a group discussion than just me and the students going back and forth. This is a practice I would like to keep in mind moving forward to place an emphasis on improving. (Newman, narrative for Analysis of Teaching 1 MC, Y4)

This connects with Nolan's remarks in Year 3 that Nolan made about "not telling" and provides evidence that he continued to be concerned increasing student voice in both small- and large-group discussions.

Nolan did not specifically address the success of the lesson, but he was encouraged by the number of questions that students asked him. It indicates that Nolan is also thinking about engagement differently than he had in the past.

More importantly than the students answering my questions is the 8 times that the students made a comment to me and the 5 times that the students asked me questions. A student asking me questions is the most desired part of teaching. Students asking questions show that they are engaged and actively thinking about the topic. It demonstrates that the wheels are turning and they are trying to make sense of something. I think that the number of questions that they asked throughout the 7 minutes of video demonstrates a good level of engagement. (Newman, narrative for Analysis of Teaching 1 MC, Y4)

Whereas in Year 1, Nolan saw *engagement* as participation, this shows that he is considering engagement to have an intellectual component and students engaged in reasoning about and making sense of mathematics.

Nolan continued to refine his learning goals. The specificity of his learning goals led Nolan to move away from telling (as he was concerned with in Year 3) and to plan for and ask questions that allowed him to bring student thinking to the forefront and use that thinking to move their understanding forward.

> Using the practice of anticipating student solutions did allow me to increase the quality of the questions and also be successful in anticipating student approaches and to use pre-planned questions in the live setting. Being able to successfully plan questioning is showing the results that it promises. That by anticipating the ways students may attempt to solve a problem and to design instructional supports for those different approaches that I am far more comfortable and efficient in helping them with their work. (Newman, narrative for Analysis of Teaching 2 MC, Y4)

Building students' conceptual understanding became more explicit for Nolan. In a senior-level class, Nolan had students exploring the parameters of exponential functions in the form $y = a^x + c$ and examining the impact of those parameters on the limit of an exponential function.

> The lesson plan involved having student use an excellent online graphing calculator at Desmos.com in order to graph different exponential functions with only small differences between equations in order to investigate the effect that element of the function has on the graph and overall behavior of the function. (Newman, narrative for Culturally Responsive Pedagogy MC, Y4)

As part of the lesson, Nolan questioned the students about the relationship between the limit of the function and the equation of the function, as he attempted to have students discover how the limit was represented in the equation. Initially students were unsure about how the value of *c* impacted the graph of $y = a^x + c$:

Student 1: So, we just had a question on this one. Because I was just playing, and I was like, it doesn't. But what effect does changing *c* have on the shape of the graph? And that's just the *y*-intercept. But it doesn't really change anything does it? Because if you move it farther on the graph, what doesn't change is that. And that's just the, that's the starting [point].

Student 2: And what I thought was that if you add *c*, then it makes the graph grow faster. And if you subtract *c*, then it makes it grow slower. And it makes it more curved outward.

Through his questioning, Nolan's students came to understand what it meant for a function to have a limit. The understanding of *limit* helped students realize that the value of the constant *c* was related to the horizontal asymptote of the exponential function, which led them to the understanding that *c* was also related to the limit (in one direction) of an exponential function and that the *c* value did not impact the shape of the exponential.

Nolan: These do have a limit, right?

Both students: Yes.

Nolan: What is the limit? Can we describe the limiting we're seeing? What's limited?

Student 1: That's not the vertical asymptote, is it?

Nolan: If the limit were to exist, what does that mean?

Student 1: It can't go any further.

Nolan: So each of those graphs has a limit. Like, what is the limit of $y = 2^x - 2$?

Student 2: Wouldn't the limit be −2?

Nolan: What if I keep putting bigger numbers in for *x*?

Student 2: It'll keep going up.

Nolan: What if I keep putting negative more and negative more numbers in for x?

Student 2: It'll keep going down until negative two.

Nolan: So, if *x* keeps getting more and more and more negative, what never happens?

Student 1: It never reaches −2.

⋮

Student 2: So, it doesn't necessarily change the shape of the graph, it changes just where the asymptote is. (Newman, video for Culturally Responsive Pedagogy MC, Y4)

The fifth (and final) year took place during the 2020-21 school year and Nolan was teaching entirely online. Despite this challenge, it was clear that Nolan valued student understanding and student struggle with mathematical concepts. He continued to use high-demand tasks (and maintain the demand, although not to the degree he had been able to during in-person instruction). He continued to value student discourse in whole-class discussions, although students seemed reluctant to engage in discussions online. Despite lower-than-typical engagement from his students (which he told me in a personal conversation was the norm during online instruction that year), the platform Nolan used allowed him to monitor his students, who were able to ask questions and get feedback about their learning through written communication.

> It was nice that some [students] actually participated…I used wait time well. With all of these things now [during Covid], it seems like it takes a long time, but a lot of those questions that were being asked today also were ones that took some contemplation and so it was nice. It felt like I got to ask some good questions to go a little deeper with some

> of the stuff that was showing up in the chat. It's amazing what can be done when kids give us even just a little bit to kind of start prying at and asking some follow-up questions. (Newman, post-classroom observation interview, Y5)

Unfortunately, due to the COVID-19 pandemic and Nolan's own life circumstances, there is little other work from Nolan from that year. He continued to engage actively with the other MMTP participants and facilitators and was extremely interested in the social justice discussions that were held with the larger group. In his final interview, Nolan noted:

> It's been interesting with all of the Covid protocols we have in place in the classroom. Kids can't really work in groups anymore. They have to be seated in individual desks three feet apart. It's really iffy of people coming up to the front of the room and presenting and sharing, and like touching common material. Everything just sucks right now, it's just, every ounce of joy, fun that was part of math that I've learned through all of these processes, it's like now 9000 barriers have been put in place. And so, thank goodness for some of the other stuff…I feel super comfortable with Desmos and TI and Geogebra. And I use those things on a daily basis now with the way that we're being forced to teach, that I can't have kids sit at a table and work collaboratively on a poster project to come bring up and present at the front of the room. I still write some lessons with the Five Practices. With Desmos you can select student work and share it. And that was a large part of the Five Practices was selecting students work and then sequencing it. And I'll still put elements of that into my lesson plan with Desmos, look for certain answers in Desmos to select and sequence the sharing of it then. And so I mean, Desmos really supports the Five Practices so well in a virtual sense. But there's always something kind of lost with the virtual. (Newman, final interview, post-Y5)

Reflecting on his experience with MMTP, Nolan credited MMTP with changing his beliefs about teaching and learning and what students were capable of doing in the classroom.

> I feel like I've taken so much of that scaffolding [from the textbook] away. I mean, when people talk about taking scaffolding away, they're always kind of worried that then the kids aren't going to go anywhere. And I feel like with the work that I did with the MMTP, I've kind of gotten through that barrier where I'm not worried that it's not going to go anywhere. I can still get them moving and get them asking those questions. And so, just taking the scaffolding away, I think I used to do a lot of leading, like taking a pencil away from a kid and being, like, oh, here you go. Let me show you. Oh, you want to put a dot here on the graph paper, and you want to put it out here. I wouldn't dream really of doing that anymore. Like, so rarely do I do that anymore. And so, I mean it, it fundamentally changed what I viewed as the point of my classes and then how I teach them. (Newman, final interview, post-Y5)

**Evolution of Nolan's Leadership: Establishing Credibility**

In addition to changes in his teaching, Nolan's time with MMTP impacted him as a leader and how he views himself as a leader of other teachers. In the fourth year of MMTP, in his first Analysis of Teaching narrative, Nolan began mentioning being a leader of others.

> Not only is [analyzing teaching using video] a best practice for me personally to engage in but will also serve as a concept for working with other certified and pre-service teachers. (Newman, narrative for Analysis of Teaching 1 MC, Y4)

Nolan cited the opportunity (in the third year) to be featured in a publication on using the Five Practices for Orchestrating Productive Mathematics Discourse as a point where his thinking about teaching, learning, and leading others shifted, marking a pivot from Leadership of Self to Leadership of Others (NCSM, 2008).

> I have learned so much in regards to the practices of anticipating student responses, planning questions, selecting student work to share, and sequencing their ideas. I think that I am in a good position to work with other math teachers who would like to improve their abilities with questioning and discourse and am excited to teach them and help them with implementing the 5 practices in their own planning and lessons. (Newman, narrative for Planning to Lead Instructional Change MC, Y4)

During Year 4, Nolan began planning for ways to share his learning with the other teachers in his department. He appeared to be concerned with his credibility for teaching other teachers.

> If I am going to work with, and coach, other math teachers regarding [questioning and discourse] I need to be as credible as possible. The more information and personal experience I have with these pedagogical shifts in practice the more I will be able to confidently lead others in adopting the same practices. (Newman, narrative for Analysis of Teaching 2 MC, Y4)

Nolan also became an active member of his school's equity team in the fourth year, noting that things he had learned during his time with MMTP positioned him to advocate for equity practices in the school.

> We [the equity team] are working on addressing many of the issues of CRP addresses in this part of the [Wisconsin Model to Inform Culturally Relevant Practices] model. We are looking to establish a set of common used language regarding race and equity in our building, implementing restorative practices in a meaningful way on a school level, and

supporting curriculum designs around social justice and cultural diversity. (Newman, narrative for Culturally Responsive Teaching MC, Y4)

I feel like doing that culturally responsive work has put me in a strength of leadership on that team where a lot of people don't have a lot of knowledge about things like restorative practices. And I'm coming to it with all of this knowledge that I got from the MMTP because we did that badge. So, I mean, that has had real trickle over into our building where by doing that badge with me, I've then been able to go be a pretty strong voice on our school's equity team. (Newman, final interview, post-Y5)

Subsequent to this point, Nolan exhibited more confidence in his knowledge of teaching and, by the end of the project, felt as though he had both the knowledge and credibility to teach others.

I now have the knowledge and skills to actually feel worthy of being a coach for another math teacher. Prior to the MMTP program there is no way I could have done this work with any sense of credibility. (Newman, narrative for Planning to Lead Instructional Change MC, Y4)

I got so much out of working with people at different schools. Faye [a math teacher who had moved into a district coaching position], Leon [a math teacher who had moved into a district specialist position], making those relationships, and now as they move into different roles, having those relationships with people that are in different positions. I loved our trip to San Diego [to present at the NCTM conference]…I thought that those were really not just fun but that they lent a lot of credibility to what you were doing beyond just, this is nice for me. And I felt like it made me feel like more of a

> professional and more of a master of what I was doing. (Newman, final interview, post-Y5)

Unfortunately, when Nolan found himself in a position to support the learning of other teachers in his department, the state of the world shifted rather dramatically.

> I felt like that was one of the strongest places for me with the math coaching work that I had set up [in early 2020] and was almost ready to get going, and had done some self-assessment surveys. And I had some people that wanted to work on questioning and discourse. I felt like I was really close to having a group of three or four people that I could really get on board with the Five Practices and then the world shut down. (Newman, final interview, post-Y5)

Regardless of this shift in how school was conducted for the 2020-2021 school year, Nolan felt optimistic that he would be able to be the leader he envisioned once the health emergency ended and education returned to a more normal state.

> The last badges with the, I developed that math coaching model which had been, I mean the MMTP ended in the world's weirdest, unforeseen way of the MMTP ever…It's what Covid has done to everyone around the world. But I still have a lot of that stuff in the can ready to hopefully unleash. I mean, [the 2020-2021 schoolyear] was completely virtual and so I didn't, I still feel like a lot of people, myself included, are still scrambling so far away from any sense of normalcy that it's been really hard to enact any of those initiatives in a meaningful way. But I've got them. I mean, I've got the learning, I've got the materials that I set together. And so, it's all there just kind of waiting for the world to kind of get back to a place where it seems appropriate. (Newman, final interview, post-Y5)

**Linking Nolan's Learning Outcomes to the Design of MMTP**

The design of MMTP supported Nolan's learning in several ways. I will outline these supports in his learning using my framework for teacher learning (Figure 5). Specifically, Nolan's learning was impacted by the teacher-centered-ness of the experiences and how his individual needs were attended to by the MMTP community that was built over the years (community), by the use of his classroom as a focus for his learning (context and knowledge), by the length of time and cohesiveness of the learning experiences over time (context and knowledge), and by the feedback from both the facilitation team and the other MMTP teachers (assessment).

In his final interview, Nolan noted that there is a dearth of high-quality professional learning opportunities for experienced teachers.

> By far and away the most professional learning that I've ever heard of anybody doing that I work with. I mean, I feel like the people that are in my department clamor for the type of professional learning that I got through the MMTP, cause what else is out there? Not a lot really…The current professional development opportunities that have been conducted often lack connections to math instruction. (Newman, final interview, post-Y5)

Nolan noted that having agency in his learning was extremely important and contributed to his motivation in learning.

> I loved being able to kind of pick what I was interested in. (Newman, final interview, post-Y5)

> I really enjoyed, appreciated, and was kind of pleasantly gifted with the direction it then turned into with the different topics that we had to pick from and essentially areas of

learning and the materials that were then provided to learn and collaborate around all the different badges with technology, with questioning and discourse…It was like getting to pick from a course catalog of what I wanted to strengthen with my teaching. (Newman, final interview, post-Y5)

Nolan also described the recognition of his accomplishments as being a component of his continuous participation in MMTP.

> They lent a lot of credibility to what you were doing beyond just, this is nice for me. And I felt like it made me feel like more of a professional and more of a master of what I was doing beyond just like nobody caring in my building. (Newman, final interview, post-Y5)

Nolan cited the community and the length of time as major factors that impacted his learning and his teaching. From the beginning, Nolan seemed to crave collaboration with other teachers.

> If there is truly one thing I am looking forward to, it is the opportunity to work collaboratively with other teachers to identify and approach ideas as a team. Hopefully through forming a strong connection of healthy professional learning and development with our cohort, we can then become leaders of future collaborative ventures. (Newman, narrative for MMTP application, pre-Y1)

When MMTP wrapped up, Nolan confirmed that the community and length of time both contributed to viewing his learning with MMTP as successful.

> This would probably be the best professional development that I've had for teaching in general. For math teaching in general. Just because it was so cohesive and supportive and ongoing. (Newman, final interview, post-Y5)

> The collaborative nature of it, I got so much out of working with people at different schools, [names two other participants], and making those relationships. And now as they move into different roles, having those relationships with people that are in different positions, I mean there's so much out of the collaborative nature of it. (Newman, final interview, post-Y5)

In addition, Nolan had many opportunities to get feedback from peers and mentors alike. Nolan appreciated the opportunity to get more frequent feedback and noted that he sometimes felt de-motivated when the opportunities for feedback were not available.

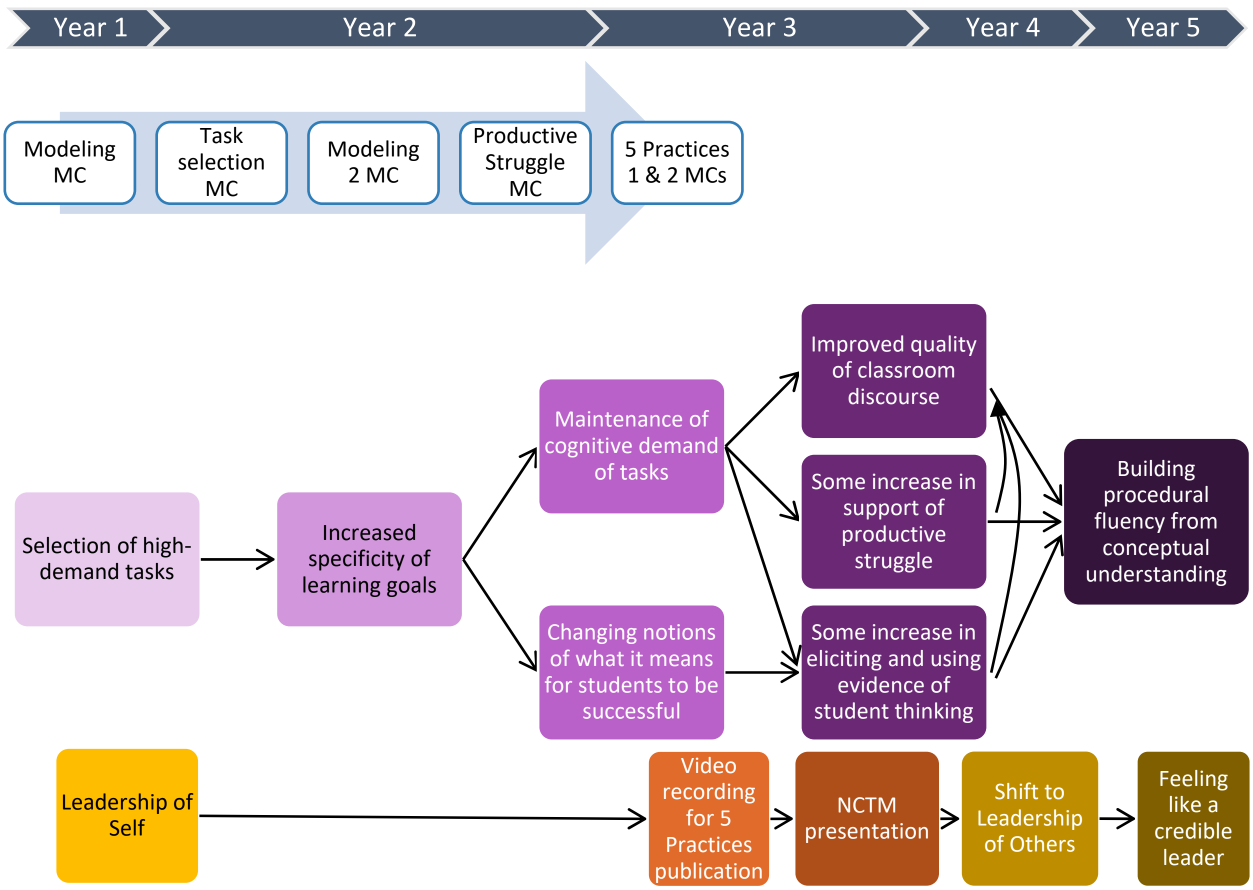
> Dr. C did a wonderful job with…offering those in-between drop-in sessions. Like, hey, looking for some help with [the Analysis of Teaching MC], I've got drop-in nights available this night and this night. I know I loved having those and I took advantage of those because given two months, it's very easy to procrastinate but also it's very easy to sit there and feel in a spot where you're having a hard time getting going or taking the next step and then it would kind of deflate me and I would step away from it until we were about to have our next meeting. I feel like some more little drop-ins or support sessions in between major meetings was a good addition there at the end. (Newman, final interview, post-Y5)

**Summarizing Nolan's Learning Pathway**

Considering Nolan's learning from the perspective of my research questions, how did Nolan's teaching change through his participation in MMTP? I will summarize the answers to sub-questions one and three below. A summary of Nolan's overall trajectory with MMTP is shown in Figure 20.

**Figure 20**

*Trajectory of the Changes in Nolan's Teaching Practices and Leadership, Including Notable Micro-credentials and Events.*




Nolan's learning pathway began with the same micro-credentials as the other teachers. From the start, he had the agency to choose the direction of his teacher action research (teacher-centered). In the beginning, despite all participants working on the same MCs, Nolan was able to identify areas of interest that were relevant to his classroom (context): the impact of student choice on homework completion, developing students' conceptual understanding of different types of data, and developing student understanding of trigonometry and how it applies to the world.

Nolan selected high cognitive demand tasks from the start, although he did not necessarily maintain the cognitive demand of the tasks during instruction. By engaging in the two modeling MCs and the task selection MC (knowledge, coherence), Nolan began increasing the specificity of his learning goals. The specificity of his goals correlated with Nolan maintaining the cognitive demand of tasks during instruction and, simultaneously, Nolan considering his beliefs about the meaning of student success to be more about student understanding rather than getting correct answers or merely participating.

The sequence of the productive struggle MC, the two 5 Practices MCs, and having his class recorded for a publication on the 5 Practices appears to have been a catalyst for further changes in Nolan's teaching (knowledge, teacher-centered, context, assessment: feedback). Following these, Nolan showed changes in the amount of using evidence of student thinking in his classroom, consistent with the 5 Practices. He changed how he approached student struggle, using more questions so students could make sense of the mathematical concepts themselves and using less telling students about the mathematical concepts.

Alongside the maintenance of cognitive demand, the support of productive struggle, and using evidence of student thinking, and based on feedback he was getting through MMTP from facilitators and colleagues (community, assessment), the classroom discourse changed in Nolan's classes as he became more proficient with using the 5 Practices and allowed students to speak more, although the change was difficult for Nolan to maintain during online instruction. Together with his changing notion of student success, Nolan shifted his emphasis from using procedures to developing conceptual understanding as a precursor to building fluency with procedures.

Alongside the changes in his teaching practice, Nolan was becoming more confident as a leader. His participation in the 5 Practices publication gave Nolan the feedback that he was succeeding with his teaching practices (assessment, teacher-centered: recognition of accomplishments). Nolan also presented at an NCTM conference, further allowing him to share knowledge with the larger teaching community (community). This was followed by shifts in how Nolan viewed himself as a leader and gave him a feeling of credibility that led to him being included on the school's equity team and feeling confident enough to begin plans to coach his department on their teaching practices.

**Kim Nixon**

> *I am humbled by the idea of good teaching. This is an on-going process to continue improving as a teacher. The analogy that comes to mind is golf. Initially, it's exciting to make dramatic improvements and feel a sense of getting better. However, there's always more to learn and improve upon. There's not a point where you can feel done. There's always some aspect to work at improving. (Nixon, narrative for Analysis of Teaching I MC, Y4)*

When MMTP began, Kim had been teaching for eight years. Kim is a second-career teacher, having spent several decades working in industry. She entered teaching through an alternate certification program. She teaches at River Willow High School, a large, comprehensive high school and one of the largest high schools in the entire district. In the five years of MMTP, she taught Algebra 1 and AP Statistics each year.

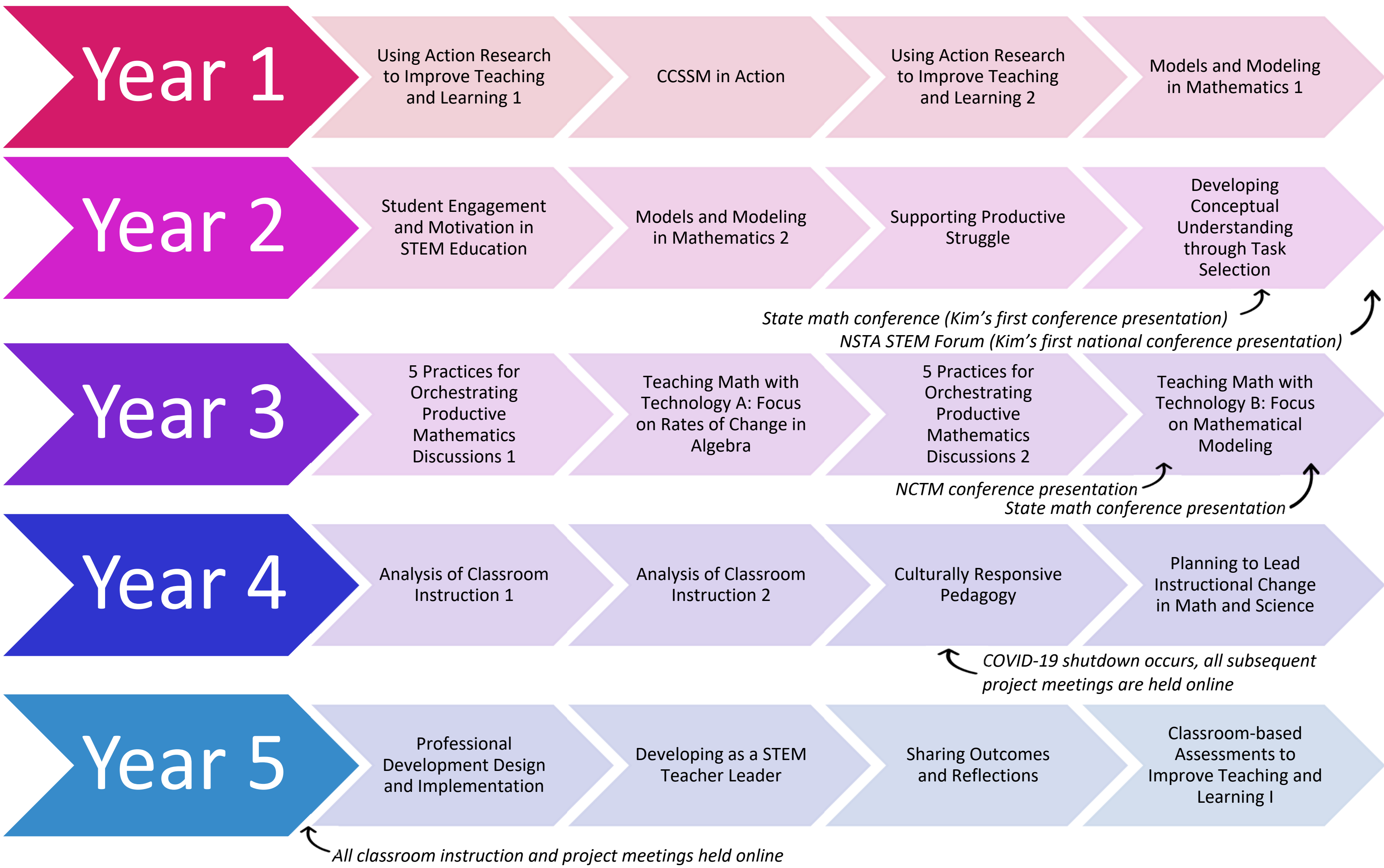
In her work with MMTP, Kim completed all 20 of her micro-credentials, although some were significantly delayed. Kim noted in personal conversations that she had a perfectionist tendency, and she was often reluctant to let go of some of her work and open it up for assessment and feedback. Kim's timeline with MMTP is shown in Figure 21.

Throughout her time with MMTP, Kim was an avid learner and she approached learning with enthusiasm. She was interested in learning anything she could on pedagogical topics. She noted that her experience in her alternate certification program was less than ideal and that she learned some of the foundational aspects of teaching through her experience with MMTP.

> I came in from [an alternate certification program] which basically, their model was that I would be learning as I went along. I had a one-month summer intensive institute. And then I had an emergency license for two years where I learned how to, and I was taking classes at the same time…They modeled it after Teach for America where they give you an intensified dive into all the different things they thought you would need to become a teacher. And then they place you in it. And then you continue taking classes as you were in that placement. But I would say, was I ready to be a teacher? No. And they put us in Tamarack High School which was the school nobody wanted to be assigned to. It was the dumping ground for students that were washing out in other places. It was eventually closed. And so it was a very, very, very, very challenging placement…Unfortunately, by placing us in a school like that, we weren't allowed to learn how to become teachers. We became excellent in behavior management. Otherwise, we weren't going to make it…I never had the foundational stuff from a student-teacher-type experience, so I didn't have any of that foundational stuff, and it was only through MMTP that I had access to it. (Nixon, final interview, post-Y5)

**Figure 21**

*Kim Nixon's Timeline of Work with MMTP*



Over the course of MMTP, some notable shifts occurred in Kim's teaching. As she stated, Kim began with gaps in her knowledge for teaching. When MMTP began, she was concerned about knowledge that students might be missing and the impact of their missing knowledge on their ability to learn. Although the shifts in Kim's leadership were not as prominent, these shifts also occurred as MMTP supported her growth as a leader. Kim's artifacts for her micro-credentials, her videorecorded lessons, and her interviews provide evidence of the changes in Kim's teaching practice as she began to experience trust in her students, and changes in Kim's leadership as she put herself forward as an expert in classroom technology during COVID-19. In the next two sections, I will explore these changes in Kim's teaching and leadership and share episodes that illustrate these changes.

**Evolution of Kim's Teaching Practice: Trusting Students and Focusing on Students' Conceptual Understanding**

At the surface, the observation rubrics for Kim's teaching appear to show inconsistencies in her use of the effective teaching practices across the years of MMTP. However, an examination of her recorded classes, micro-credential submissions, and other artifacts reveals shifts in Kim's teaching practice and indications that her beliefs about teaching and learning also shifted. However, some of her practices were impacted by the move to online teaching necessitated by the COVID-19 pandemic. Table 8 contains a summary of Kim's rubric scores using the MMTP Classroom Observation Tool (Appendix F).

**Table 8**

*Heatmap Visualization of Kim Nixon's Classroom Observation Rubric Scores over Time.*

| | App | Y1 | Y2 | Y3 | Y4[1] | Y5[2] | Post-Y5[3] |
|---|---|---|---|---|---|---|---|
| *Goals* | 1 | 1 | 3.5 | 3.5 | | 2 | 2 |
| *Tasks* | 2 | 2 | 3 | 3 | | 3 | 2 |
| *Representations* | 1 | 2 | 3 | 3 | | 4 | 2 |
| *Teacher Discourse* | 2 | 1 | 2 | 2.5 | | 0 | 2 |
| *Student Discourse* | 2 | 2 | 3 | 2 | | 0 | 2 |
| *Questions* | 1 | 2 | 3 | 2 | | Not obs | 2 |
| *Fluency from understanding* | 1 | 2 | 4 | 3.5 | | Not obs | 2 |
| *Struggle* | Not obs | 1 | 3 | 2 | | Not obs | Not obs |
| *Evidence* | 1 | 1 | 3 | 2 | | 1 | 3 |

[1] Year 4 observation was scheduled for a date after March 13, 2020, when schools closed due to COVID-19.
[2] Year 5 classes and observation were conducted entirely online and may not be indicative of typical teaching.
[3] Kim's final observation occurred in April, 2022.

When Kim began MMTP, she displayed practices consistent with other teachers in her school, which tended toward having students in rows, with the teacher demonstrating a procedure and the students practicing the procedure. However, Kim seemed discontented with this approach and had tried having her students working in groups, investigating mathematics, and applying mathematics to application problems. From the start, she expressed an interest in cross-discipline collaboration, having her students engage more deeply with the Standards for Mathematical Practices, examining questions patterns that diverged from Initiation-Response-Feedback, and factors that influenced classroom environment.

Kim's initial beliefs about math teaching and learning at the beginning MMTP indicated that she wanted to use high-demand tasks and exploration of mathematical concepts to build understanding, but she stated that she may not have had the pedagogical tools to do so effectively. She expressed concern that students had gaps in their knowledge that could prevent them from moving forward. As quoted above,

> I came in from [an alternate certification program] which basically, their model was that I would be learning as I went along. I had a one-month summer intensive institute. And

then I had an emergency license for two years where I learned how to, and I was taking classes at the same time…They modeled it after Teach for America where they give you an intensified dive into all the different things they thought you would need to become a teacher. And then they place you in it. And then you continue taking classes as you were in that placement. But I would say, was I ready to be a teacher? …Unfortunately, by placing us in a school [with discipline problems], we weren't allowed to learn how to become teachers. (Nixon, final interview, post-Y5)

For the first observation in the first year, Kim's lesson goals were based on student performance, and she had her students working through solving systems of equations.

> We know we are successful when we can solve a system of linear equations using the substitution method. (Nixon, success criteria for observed lesson, Y1)

For this lesson, she included problem such as those in Figure 22 in her planning.

**Figure 22**

*Problems Planned by Kim for Use in Her First Observed Lesson*

3) $5x - 2y = 3$
$y = 2x$

4) $2y + x = -15$
$x = 3y$

5) $4x + 7y = 19$
$y = x + 9$

6) $y = 6x + 11$
$2y - 4x = 14$

2) There are 13 animals in the barn. Some are chickens and some are pigs. There are 40 legs in all. How many of each animal are there?

Although she had a specific goal and a contextual problem planned, Kim abandoned the contextual problem in favor of having students practice the procedure. She stated,

> They really didn't achieve what I wanted with the word problem and so I couldn't continue with differentiating. The plan was to have the students [use] a new substitution

> method, don't hold them back, challenge them with some application problems. And so that's why I teamed them the way I did. And so when they didn't catch on, I try, I try, I try, and then I thought, now they just don't get it. Today we need to cycle back. So that flexibility, I guess, was a good thing, but it was discouraging. It's like, oh my gosh, you don't know this. (Nixon, post-observation interview, Y1)

Kim's work in the first year showed a willingness to use teaching practices with which she was not yet comfortable. The goals she wrote in the first year were fairly specific performance goals.

> We know we are successful when we can (1) fit a trendline to scatterplot data, and determine the linear function in point slope form; (2) interpret the meaning of slope in the context of the model; and (3) use the linear model to solve "what if" problems. (Nixon, lesson plan for CCSSM in Action MC, Y1)

The above goal was used for a task that could be considered d*oing mathematics*, where students would recommend a menu price for a restaurant dish based on the trends in the cost of the main ingredient and other factors. However, the scaffolding in the task included rules of thumb for determining prices, steps that led students toward creating and using a line of fit, and charts and tables of prices for the ingredients over time. The scaffolding for the task somewhat reduced the level of cognitive demand, although it remained a high-demand, *procedures with connections* task. She considered the lesson successful since students met the learning goals and she was impressed with "the willingness of the teacher/class to attempt this problem given its rigor and dependence on student teamwork." (Nixon, narrative for CCSSM in Action MC, Y1)

Kim noticed that students, despite having gaps in their mathematical understanding, were willing to struggle with interesting, high-demand problems that involved making sense of and using mathematics. Near the end of the first year, Kim had her students engage with a very open problem about zombies and exponential growth, where students had to make assumptions and seek out information in order to find a solution to the question.

> One member of your group is a zombie. How long will it take everyone in [our city] to become a zombie? How long before everyone in [our state] is a zombie? How long before everyone in the world is a zombie? Find a function that will model this and express it graphically and algebraically. (Nixon, task for Models and Modeling 1 MC, Y1)

> It is clear students struggle with the math involved in this activity. However, the groups were encouraged to struggle and, as a result, most developed a solution to the problem. The degree of engagement, perseverance and enjoyment was greater than a typical algebra class. (Nixon, narrative for Models and Modeling 1 MC, Y1)

In the second and third years, it became evident that Kim felt more confident with using high-demand tasks and maintaining the demand of the tasks. She built in opportunities for students to demonstrate their understanding in different ways, such as the task in Figure 23, where students have to show their understanding of exponential models by writing a story that uses exponential growth.

**Figure 23**

*Task used by Kim for use in her observed lesson, Y2*

> We've studied zombies, kings and peasants, and viruses. Now it is your turn to work with your team to create a problem which demonstrates your understanding of exponential models.

This shows that Kim was building trust in students to engage with the mathematics. This trust manifested in a number of ways. First, the way she talked about her goals shifted. While her written goals continued to be performance goals, when Kim elaborated on her goals verbally in the pre-conference interviews, she phrased them as learning goals.

> Today, we're working with exponential modeling and my goal is for students to understand growth factor, to actually pick apart the exponential equation using graphs, tables, charts. (Nixon, pre-classroom observation interview, Y2)
>
> Today we are working on multiplying binomials. [I hope] that they will understand this special case of binomials. That they might be able to generalize. That they'll understand perfect squares. That they will use the rectangle model [for multiplication] and actually see that they could use distributive property. (Nixon, pre-classroom observation interview, Y3)

Kim was supporting her students' conceptual understanding as a precursor to and in conjunction with developing procedural fluency. Her tasks opened up from students being able to reproduce procedures and toward students making sense of mathematics, using prior learning in novel ways, and making sense of mathematical concepts before learning procedures. In one lesson, Kim challenged students to match distance vs. time graphs as their movement was picked up by a motion sensor, supporting students' understanding of slope and y-intercept of each graph by using students' own movements.

> The goal of building procedural fluency from conceptual understanding is stressed in this lesson. The students are challenged to replicate the graph by walking across the classroom. Then they work together to discover the relationships between their actions and the graph. Finally, they formalize the procedures for writing the walking instructions. (Nixon, narrative for Teaching Math with Technology A: Focus on Rates of Change MC, Y3)

Kim also opened up an investigation she had previously used, which involved using an area model for multiplication to factor quadratics and discover patterns in perfect square trinomials and difference of square binomials. Rather than giving students a procedure to follow, Kim allowed them to explore and play with the model and make sense of it at their own pace.

> The students were at all different places in that investigation, and yet it worked. And I was able to check with students to see their level of understanding. And I was hearing positive thumbs up from most of them. All of them. (Nixon, post-classroom observation interview, Y3)

Kim had moved from a position of "telling kids math" to allowing them to explore and make sense.

> I used to answer too quickly for students. Now I try to be vague, push them to an answer. And no matter what level the student was at, that strategy allowed them to move forward. For this lesson, I did, I thought ahead of time, what kind of problems we would have, what kind of questions I might have to come back to the student with when they ask their question. I mean that kind of preparation is probably new. Just knowing what to think about is, you know. (Nixon, post-classroom observation interview, Y3)

> From my perspective, planning, teaching, and assessing this lesson allowed me to teach the essential concept (rate of change) without have students memorize anything. Rather, students could experience and visualize the concept via the walking and graphical representation. (Nixon, narrative for Teaching Math with Technology A: Focus on Rates of Change MC, Y3)

At the same time, Kim also worked toward supporting her students' assessments of their own understanding, noting the link between feedback and student self-assessment with student engagement and achievement.

> A new idea from [Working Inside the Black Box (Black, P., et al., 2004)] was that by improving formative assessment, student engagement and achievement could be raised. The fact that feedback through grading would result in higher engagement was not intuitive to me…A teacher can start by working with students to develop their self-assessment skills. Another idea from the Black Box article was to incorporate a "traffic light" for self-assessment…In my classroom, it is used as a formative assessment during student work times. (Nixon, narrative for Engagement and Motivation MC, Y2)

In the fourth year, Kim continued to investigate her teaching and continued to expand her trust in students to take ownership of their learning. She also looked for ways to engage students who might otherwise disengage from the class.

> It was the first time I attempted such a wide-open activity. The various stations were exploring different types of functions by collecting and analyzing data. I learned that students were highly engaged, and this included several who rarely did more than sleep in class. (Nixon, narrative for Analysis of Teaching 1 MC, Y4)

> [I wondered] whether students identified as "low academic status" will increase participation rates when teacher(s) make a conscious effort to include the students in class / small group discussions built around tasks with multiple entry points. A student with low academic status was identified by the responses to the student self-assessment survey questions "I believe I have strong math skills" and "I'm certain I can understand the ideas taught in this course" …The choice of a task with multiple entry points and solution paths is critical. This [analysis] shows that a project-based activity encourages greater teacher contact with all students, student engagement and academic success. (Nixon, narrative for Analysis of Teaching 2 MC, Y4)

> I am working at becoming self-aware. Given my background, I have many blind spots to explore. Participation in several book studies has really allowed me to become comfortable with the tenets of CRP. However, this is a journey and I am still working on it. I believe all students will learn and know I have had success with many students with low scores and little confidence. There are certain students I struggle to connect with and want to improve my understanding of the system's impact on them. (Nixon, narrative for Culturally Responsive Pedagogy MC, Y4)

When instruction shifted online due to COVID-19, Kim and her students, like many others, had difficulty adapting to the new mode of teaching and learning. However, Kim embraced the challenge just as she had embraced all of the previous challenges. She became adept at using multiple technologies as she tried to provide good learning experiences for her students. Through personal conversations I had with her, I discovered that she had created and deployed many Desmos activities. These allowed her to monitor her students' learning from a distance.

The observation for Year 5 occurred at the end of the school year, as students were reviewing for their final exams. Kim stated to me that it did not provide an example of what was typical of her teaching that year. And yet, Kim continued to try to engage her students in learning and use different methods, and she continued to hold high expectations for her students.

> I would say this virtual setting makes it even more difficult because we really do have a fair number of students that just have not invested in their learning this year. And so how do you review what they don't know? I can't reteach everything. And so to try to find that sweet spot is a little bit challenging. I really liked these students that went off into the breakout room. Because we haven't done a lot of breakout rooms. And the fact that they

went out there and they were sharing screens and talking about the math, I think that's outstanding…I actually really think holding them accountable to say, you know what, you've got to do some work. And then you get these questions. You're just not going to passively sit there and copy stuff. That's not the way it's going to work. (Nixon, post-classroom observation interview, Y5)

In the year following online instruction, Kim was able to return to having students work collaboratively to make sense of mathematics, and she was able to listen to what her students were saying about what they were learning.

> They're not where I want them to be, and they told me so on their way out. I was asking them, do you get this? I was asking, you know, I'm confident, I'm not confident, I'm somewhere in between. And I did not hear a lot of confidence, and even the ones that said they were, they had some mistakes. (Nixon, post-classroom observation interview, post-Y5)

> That's something that I'm doing new this year, which is really looking to see where their gaps are. Really looking to see where their misconceptions will be. And so now I just kind of try to brainstorm by myself and figure out where those are and try to give the kids a heads up on some of it. And even in that discussion I can just by the looks on their faces, I knew they were going to struggle with. (Nixon, post-classroom observation interview, post-Y5)

This interview also marked a shift in Kim's framing of student understandings, as can be seen in her reference to gaps in their knowledge rather than what they did not know or could not do.

Although developing procedural fluency from conceptual understanding was not observed during online teaching in Year 5, in the observation after Year 5 Kim appeared to have returned to using procedures more. However, it's difficult to discern the reason for this move. This was the only instance of Kim's teaching that was available after MMTP ended. Kim acknowledged that she was unable to find a better task for the lesson and defaulted to the textbook (Springboard Algebra).

> I actually checked four different places to see if there was a more engaging opportunity for this. And then decided no, I'll just go with the book. Because I didn't find anything. But it's not for lack of effort. (Nixon, post-classroom observation interview, post-Y5)

Reflecting on her time with MMTP, Kim herself stated that her big changes came in supporting conceptual understanding and increasing student engagement.

> [I'm] really trying to bring in more conceptual first and then hitting the procedural after. And just really making that a focus. And so what does that look like? It makes my room look totally different in just how I pitch a lesson. I still get pushback on that. My co-teacher in the one class says, "Well, I think you should just tell him how to do it all first and then you can play with this other stuff later." So it's an interesting push-pull. And I will even say to this co-teacher, I'll say, "Yeah, I hear what you're saying and I'm not convinced my way is gonna work. But I know this other way is not working." And so that's kind of where we're at with that and so I feel like I've totally changed the way I teach. (Nixon, final interview, post-Y5)

> I'm going to go back to a teacher that saw me teach when I was in that second year at [my previous school] and she said, "Well, I don't understand, you don't have any engagement in your classroom." And I know that now, I mean, just the other day, somebody said, "You know, you're the most engaging math teacher in the building." So

> for that to be, that's one huge change. I really believe if the kids aren't engaged, they're really not going to be taking in this material. (Nixon, final interview, post-Y5)

**Evolution of Kim's Leadership: Sharing Knowledge with the Larger Community**

When MMTP began, Kim's leadership within her building was mostly informal, although she was a member of the school's literacy committee. Most of her department leadership was as a collaborator with other teachers in her department.

> In my current math department I am recognized as a teacher who collaborates with other teachers. We meet on our own time to review the algebra pacing guide and to develop individual lessons. I actively share my lessons and materials with other teachers within my school. A number of us review student work in order to understand student misconceptions with the material. (Nixon, narrative for MMTP application, pre-Y1)

Kim initially did not seem interested in learning about teacher leadership. She did not pursue the initial leadership MCs that were offered. However, over the course of MMTP, Kim became interested in sharing what she was learning with other teachers in her school, in the district, and in the larger community. In the second year, Kim co-presented at the state math teachers' conference in May (with another teacher from her school) and at the NSTA STEM Forum in July (with a group of MMTP teachers). In the third year, Kim presented at both the state conference and at the annual NCTM conference. She was scheduled to present at various conferences that were cancelled due to COVID-19, although she returned to presenting at the state and national levels after conferences resumed. Kim later expressed that this was one of her favorite things about MMTP.

> I loved the part where you encouraged us to come present at conferences. Because that experience was really helpful. Through [the state conference], through the national one,

> you know, through the science one, and actually a writers' one I went to. So presenting, encouraging us to present I think was a really nice part of the program. (Nixon, final interview, post-Y5)

Kim expressed frustration that some teachers in her building were not open to what she wanted to share, but that she sought out people in her building that she could collaborate with.

> In my math department, I am recognized as a teacher with strong instructional practices who includes many strategies to promote student learning and engagement. I am also recognized as a teacher who successfully utilizes technology in my classroom. The challenge is for me to figure out how to influence my colleagues. We are an experienced, but very traditional team…I believe I can share with my algebra group and math department some ways to improve student engagement using technology, especially in a virtual setting. This will be a difficult task because of the traditional teaching style currently used by the math teachers. Teachers in my math department use direct instruction and online Khan or Deltamath programs. There is little attention given to promoting student engagement or utilizing questioning techniques…The tricky part in all of this is the culture in my math department. I might have the best ideas which are solutions to current instructional challenges. I could present these ideas in an interactive way. The final success may be outside my control…Although my target teachers may be entrenched and resistant to change, I also have teachers within my building and district to influence. I will actively seek out these other educators. (Nixon, narrative for Planning to Lead Instructional Change MC, Y4)

Kim began sharing her knowledge at her school during the COVID-19 pandemic when teachers were struggling with online instruction. During the 2020-2021 school year, Kim shared her knowledge about teaching with technology, especially using Desmos as a teaching tool in both math and non-math classes. She also shared her learning about culturally relevant teaching and increasing engagement using culturally relevant material.

> The groups who participated in the PD were a bit hesitant to learn and use a new application, however, I was pleased that a number of them did. We continue to collaborate on Desmos activities and at the start of each unit, share relevant activities. As a result of this initiative, I have enhanced the skills within the department and have gained the reputation for facilitating PD within our building. (Nixon, narrative for Professional Development Design and Implementation MC, Y5)

> Even in a virtual environment, I was successful in collaborating with my math colleagues. The number of PD's I facilitated increased over the year from 3 to 5. The number of resources shared also increased over the year. (Nixon, narrative for Sharing Outcomes and Reflections MC, Y5)

Despite this success, Kim continued to express frustration at not having a position of formal leadership in her building.

> I will say one of my giant frustrations is, what kind of influence do I have within my immediate building? It looks like from reading [through the initial goals] that it looks like at one point in time I had more collaboration and ability to move things forward than I do now, but that's not necessarily anything that I can directly control. Some of that's not, but it's not that it's not a goal of mine, it's just on hold. (Nixon, final interview, post-Y5)

At the end of MMTP, Kim had the confidence, desire, and knowledge to lead other teachers in her building in exploring their teaching practices.

> It is a struggle to affect change within the math department. I am an informal leader and, therefore, am trying to win colleagues over to making changes. I feel progress was made with all but 2 math teachers. That is pretty good considering we were virtual most of the school year. It is much easier to get people to consider changes in a private conversation. I know that I am respected as a teacher leader within our department and building. I expect to keep advocating for change (Nixon, narrative for Sharing Outcomes and Reflections MC, Y5)

Kim continued her advocacy after MMTP officially ended. Along with another MMTP math teacher and an MMTP environmental science teacher, Kim took on the task of creating, proposing, and piloting a new mathematics course that focused on the Standards for the third year of high school. This new course focuses on problem-based learning using social justice topics, argument-driven inquiry, and using mathematics to advocate for social change. The course was piloted in five schools in the 2022-2023 school year.

**Linking Kim's Learning Outcomes to the Design of MMTP**

The design of MMTP supported Kim's learning in several ways. I will outline these supports in her learning using my framework for teacher learning (Figure 5). Specifically, the teacher-centered design of MMTP was crucial for Kim's learning as an experienced teacher who entered the profession as a second career (context). Her learning was also impacted by the focus on pedagogical content knowledge and mathematical knowledge for teaching (knowledge), by the community aspect of MMTP (community), by being able to reflect on her teaching in a supported manner (assessment), and by being encouraged to share what she had learned with the larger math teacher community (community).

MMTP supported Kim's learning at the place she was at in her career. Her lack of formal training in education and her love of learning motivated Kim to actively engage in learning with MMTP.

> I had never really learned how to teach. I knew how to do procedures and step by step and very traditional approach. But I didn't really have any great instructional strategies to address engagement, to really push the kids into the conceptual side of learning. (Nixon, final interview, post-Y5)

Kim noted that her needs were not being met in her current position.

> In general, there is a disconnect between the LPS Vision, including structures/systems and the River Willow math department's implementation of the Vision and systems…For example, teachers have been encouraged to collaborate and analyze student work. This has only occurred one time in the previous nine years. (Nixon, narrative for Developing as a STEM Teacher Leader MC, Y5)

Kim credits, in part, the MMTP community in pushing her learning and her teaching practices forward. She got both feedback and inspiration from the larger MMTP community.

> I have learned a tremendous amount in MMTP. I became a teacher as a "career changer" with no formal background in teaching. MMTP provided the instructional background that has allowed me to develop into an educator…Some [of the MCs], I have embraced, and others are on-going challenges to continue trying to improve on the badge elements. Some of these badges have been quite difficult for me. However, through the support and collaboration I have found within the MMTP group, I keep getting better. (Nixon, narrative for Planning to Lead Instructional Change MC, Y4)

Kim found the collaboration with her MMTP colleagues to be a critical part of moving her knowledge forward.

> When we would share our posters around or just share what we were doing, I was just always so amazed at what people came up with and you never think of it, how would I know what I don't know? So that piece of it was really helpful. Yeah, so that was valuable, seeing what other people were doing. (Nixon, final interview, post-Y5)

> One constant throughout these five years has been a chance to collaborate with others who are really focused on continued improvement in their practice. [Interviewer: It sounds like that was important to you from the beginning.] Yes. Both collaboration with other math teachers and collaboration across areas. (Nixon, final interview, post-Y5)

Kim also noted the sense of personal satisfaction that she got when she was encouraged to share her knowledge with the larger math teaching community.

> I loved the part where you encouraged us to come present at conferences. Because that experience was really helpful through [state math conference], through the national one, you know through the science one and actually a writers one I went to. So encouraging us to present I think was a really nice part of the program. (Nixon, final interview, post-Y5)

She credited the combination of learning and then sharing her learning in her school with changing how she interacted with her students and with giving her the confidence to make those changes.

> The culturally responsive teaching, that was really above and beyond and that really lit a fire under me. Because then after that I actually took it back to my building and did professional development on culturally responsive teaching. And that actually changed the way I talked to my students…Even the students said, oh my gosh, look how you're

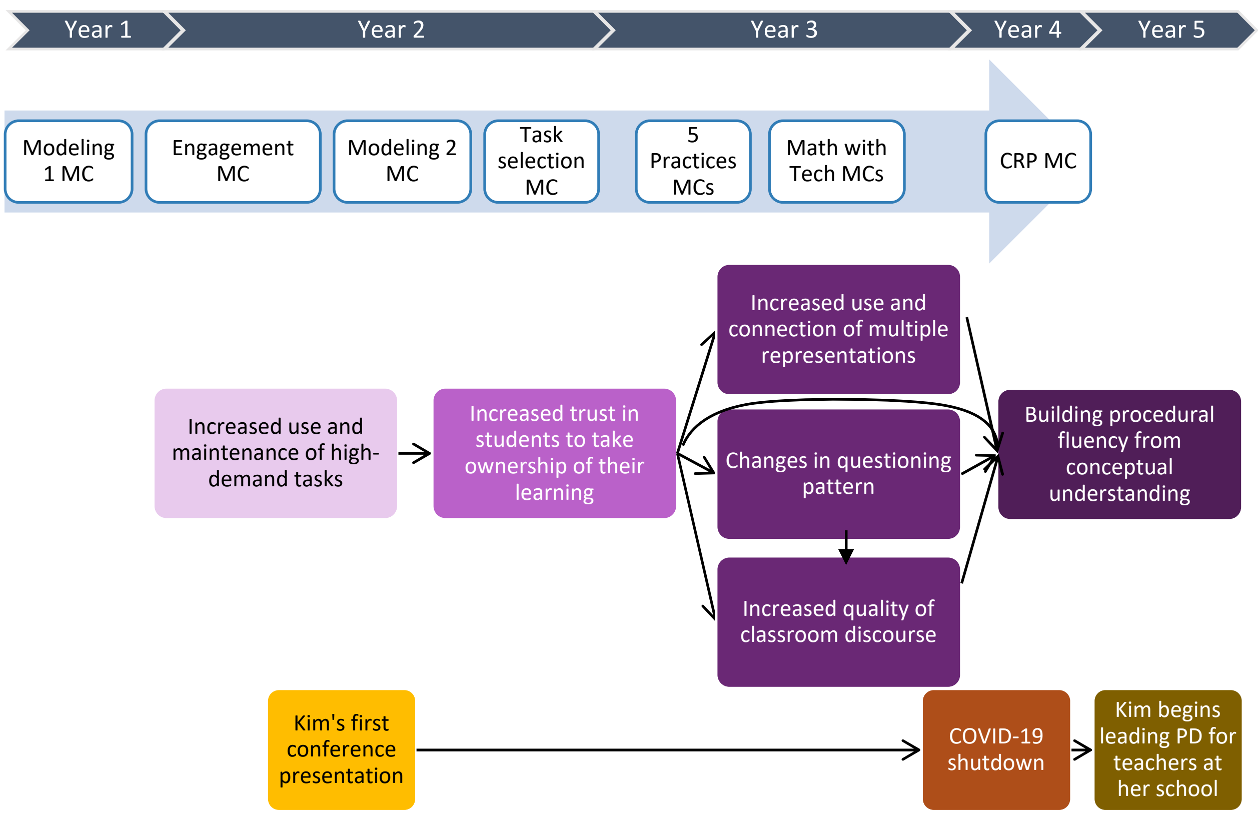
talking. And I said yeah, but it's OK 'cause I'm confident now being able to do that. (Nixon, final interview, post-Y5)

**Summarizing Kim's Learning Pathway**

Turning to Kim's learning from the perspective of my research questions, how did Kim's teaching change through her participation in MMTP? I will summarize the answers to sub-questions one and three below. A summary of Kim's trajectory is shown in Figure 24.

**Figure 24**

*Trajectory of the Changes in Kim's Teaching Practices and Leadership, Including Notable Micro-credentials and Events.*




From the start, Kim expressed a deep desire to learn (teacher-centered: motivation). Kim began by investigating her questioning, a thread that would follow her through several of her

MCs. Because of the structure of MMTP and the MCs, Kim was able to investigate aspects of her teaching that were of interest to her (teacher-centered). During the first year, Kim also took an interest in using mathematical modeling and the modeling cycle as a way to teach mathematics content, which proved to be of interest to her students (context, assessment).

Seeing how students took interest and increased their engagement with these tasks, Kim began incorporating more high cognitive demand tasks into her teaching as she learned more about mathematical modeling through the multiple MCs that featured modeling (knowledge, coherence, assessment: using feedback). Her trust in students to work independently increased as she learned what motivated them and began allowing students to have agency in their own learning (context, assessment: feedback).

The 5 Practices MCs and technology MCs, fueled by her increased trust in students to take responsibility for learning, correlated with an increase in Kim's use and connection of mathematical representations and with a change in her questioning away from funneling patterns and toward planning for and using assessing and advancing questions (knowledge). Combined with all of the above, by the third year, Kim's lessons (as represented by her observations and lesson-based artifacts shared through MMTP) showed a marked decrease in her giving information to students and an increase in having her students build conceptual understanding of mathematical ideas. Although observations of her teaching showed a possible reversion to former methods during online instruction during COVID-19, she expressed unhappiness with this turn and she tried to re-incorporate some of what she had learned after schools re-opened, showing a change in her knowledge for teaching and her beliefs about students.

At this time, encouraged by the members of MMTP, Kim was also sharing her knowledge with the larger math community by presenting at conferences (community). She focused on presentations around engagement, motivation, and the use of the 5 Practices (knowledge). This gave her a sense of personal gratification and further motivated her (teacher-centered). When COVID-19 forced the closing of schools, and supported by the MMTP community, Kim was in a position to take on leading the teachers in her department and building through the difficult steps of moving instruction online (context, community).

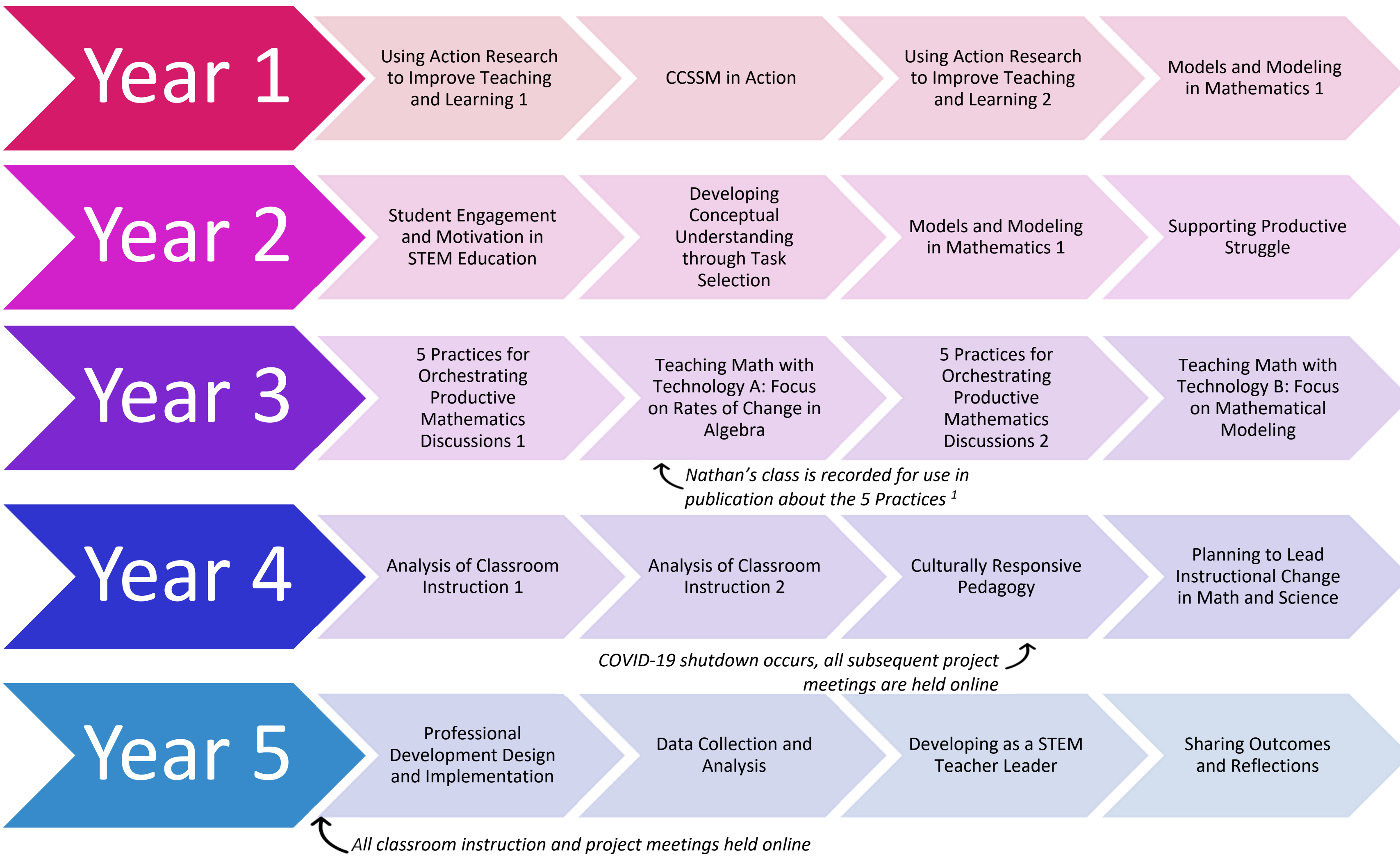
**Nathan Inman**

> *After participating in this cycle of research-plan-action-reflect a number of times in the last few years, I now approach the implementation of math activities (and lesson planning in general) through a different lens. (Inman, narrative for Planning to Lead Instructional Change MC, Y4)*

When MMTP began, Nathan had been teaching for nine years. Nathan is a teacher at Arbor Vitae High School, a large magnet high school that is known for its International Baccalaureate program and has a competitive admission process. Over the five years, Nathan's classes included either Algebra 1 or Geometry along with IB Calculus and Math Topics courses. Nathan is the chair of the math department at his school. In his work with MMTP, Nathan completed all 20 of his micro-credentials. Nathan's timeline with MMTP is shown in Figure 25.

**Figure 25**

*Nathan Inman's Timeline of Work with MMTP*




[1] The name of the publication is redacted for blinding purposes.

**Evolution of Nathan's Teaching Practice: Changes in Beliefs about Students and How They Learn**

An analysis of Nathan's teaching and writing indicates that he experienced changes in his beliefs about students and how they learn. When MMTP began, Nathan's teaching focused more on lecture and content delivery. By the end of MMTP, Nathan had shifted to using much more exploration of mathematical ideas, including using modeling tasks. Nathan's observed lessons reflect these rather dramatic shifts in his teaching. (Table 9 contains a summary of Nathan's rubric scores using the MMTP Classroom Observation Tool (see Appendix F).) (Note: The first two years, Nathan's observed classes were IB Math Studies HL, where students were studying advanced mathematical topics (Calculus, vectors, etc.). In subsequent years, Nathan's observed classes were Algebra 1. However, the shifts also occurred in his advanced classes, which I support below with his micro-credential narratives.)

**Table 9**

*Heatmap Visualization of Nathan Inman's Classroom Observation Rubric Scores over Time.*

| | App | Y1 | Y2 | Y3 | Y4[1] | Y5[2] | Post-Y5[3] |
|---|---|---|---|---|---|---|---|
| *Goals* | 0 | 1 | 1 | 3 | | 3 | 4 |
| *Tasks* | 2 | 2 | 3 | 3 | | 3 | 4 |
| *Representations* | 0 | 1 | 2 | 3 | | 4 | 3 |
| *Teacher Discourse* | 2 | 1 | 1 | 3 | | 3 | 3 |
| *Student Discourse* | 1 | 1 | 2 | 2 | | 2 | 2 |
| *Questions* | 1 | 1 | 1 | 3 | | 3 | 3 |
| *Fluency from understanding* | 1 | 1 | 1 | 3 | | 3 | 4 |
| *Struggle* | 0 | 0 | 2 | 2 | | 0 | 3 |
| *Evidence* | 1 | 0 | 3 | 3 | | 1 | 3 |

[1] Year 4 observation was scheduled for a date after March 13, 2020, when schools closed due to COVID-19.
[2] Year 5 classes and observation were conducted entirely online and may not be indicative of typical teaching.
[3] Nathan's final observation occurred in December, 2021.

At the beginning of MMTP, Nathan was very concerned with a number of aspects of teaching typical of teachers who use lecture-based content delivery. Nathan wanted to create an efficient learning environment, where the maximum amount of content could be covered in the time given. Nathan used language that categorized and labeled students, such as "students who are highly motivated and those who have developed significant math skills" (narrative for Action Research 2 MC, Y1); "weaker students," "top few students," and "lower end students" (narrative for Task Selection MC, Y2); and "mixed-ability grouping" (narrative for Supporting Productive Struggle MC, Y2).

At the beginning of MMTP, Nathan was concerned with using time efficiently and communicating as much mathematics as possible in his 53-minute math classes.

> My rationale for this focus [on using a flipped classroom structure] was a suspicion that technology could create better efficiencies in the delivery of curriculum, which would in turn provide time to work with authentic applications of content…The great strength that this method provides is its efficiency; we can cover material faster. (Inman, narrative for Action Research 1 MC, Y1)
>
> I see the amount of curriculum we must cover throughout the year as hurdle, so I move through material quicker than it might be successfully digested by some students. (Inman, narrative for Task Selection MC, Y2)

Nathan noted the pressure to cover large amounts of mathematical content in each school year. He distinguished between modeling tasks and content, indicating that he viewed modeling tasks as an additional piece to incorporate into his teaching rather than using modeling as a means for students to learn mathematics.

> Another item that I connected with, and continually wrestle with, is the time share between content and good math modeling tasks. I start the year with the best intentions, but I inevitably get wrapped up in the race to deliver all of the content that I'm supposed to get through. Within that, there are definitely moments when I know that students are

> not following me through the finer points of the curriculum that we are covering, and I question whether just letting them play with mathematics would be a better use of our time, even though there is no new content being delivered. (Inman, narrative for Models and Modeling 1 MC, Y1)

In the second year, Nathan began reflecting on the degree he removed his students' struggle, showing a level of reflection about his practices that was not present in the first year. This seemed to mark a shift in Nathan's thinking, toward mathematics as a way of thinking and that learning mathematics is done when students wrestle with concepts.

> Too many times I have removed the struggle element from my students and allowed them to complete a task without gaining a deeper level of understanding. (Inman, narrative for Supporting Productive Struggle MC, Y2)

Nathan began working on reducing the amount he was leading his students through tasks. He noticed that when students worked through cognitively demanding tasks with less scaffolding, they seemed to show more conceptual understanding.

> The impact [of using cognitively demanding tasks with reduced scaffolding] on student learning appeared to be quite positive…I believe this to be one of the highest percentages of proficiency on this unit since I've been teaching the course, although I don't have the numbers to back that up. Regardless, I believe that the scaffolding focus and attention to cognitively demanding tasks allowed students to perform higher than they would have otherwise. (Inman, narrative for Task Selection MC, Y2)

Nathan identified student struggle, collaboration, and discussion of math ideas as aspects of his practice to work on.

> Being able to make sense of a problem, work with a group and present a solution in a descriptive and organized format are the goals I will be working towards. (Inman, narrative for Models and Modeling 2 MC, Y2)
>
> Quite honestly, I have not been tremendously effective in supporting productive struggle over my 10 years as a teacher…Too many times I have removed the struggle element from my students and allowed them to complete a task without gaining a deeper level of understanding. The class structure chosen for my task selection usually would pair challenging tasks with group dynamic and easily attainable tasks with individual work. On reflection, my students have engaged in far more individual work than group tasks which reflects the level of structured challenge that I've presented…In hindsight, I don't believe the tasks given were as hearty and challenging as they could have been. (Inman, narrative for Supporting Productive Struggle MC, Y2)

In reflecting on his learning in the second year, Nathan stated that he "Improved understanding of how students can find day-to-day value in their knowledge and increased understanding of the importance of modeling" (Inman, CLADE, Y2).

Beginning in the third year and continuing through to the end of MMTP, Nathan shifted his classroom focus from using procedures to obtain correct answers to exploring mathematical concepts and building procedural fluency from conceptual understanding. Prior to the third year, there were no instances in Nathan's artifacts that were coded as "building procedural fluency from conceptual understanding." From the third year forward, Nathan regularly incorporated conceptual understanding as a precursor to procedural fluency. For instance, in the third year, Nathan chose a Desmos activity that led students to identifying the common solution of two linear equations as a precursor to solving systems of linear equations using other methods, building their understanding of what it means to find the solution for a system.

> The task did a nice job of leading students to that understanding, as it identified ordered pairs found on lines as "solutions" to those linear equations in the first two questions. Then, in question 4, it asked students to identify the common solution for both linear equations, which leads students to deduce that the common solution is found where the two lines intersect. (Inman, narrative for Teaching Math with Technology A: Focus on rates of change MC, Y3)

Significantly, in the third year, Nathan completed two MCs on the 5 Practices for Orchestrating Productive Mathematics Discourse and had his class recorded to be part of a then-upcoming publication on using the Five Practices for Orchestrating Productive Mathematics Discourse[1].

> You know, having been a part of the [5 Practices] book was a big experience. I'll never give a math task the same way ever again, just because you can see how well that brings the whole thing together. And I'm sure I have my own take. That's why I like it too. And I'm going through this with my student teacher right now too, I'm trying to let him explore his own thing before I get in there and tell him, hey, this is how you should do it. Because maybe the way I do it plays to my strengths and is different to somebody else's. But obviously we should be thinking about what're the student voices we're going to get centered on this, and why are we doing that, and what order are we doing it in? And that's the selecting and sequencing parts of that are things that I'm glad that I've thought more about versus the way I was doing it before. (Inman, final interview, post Y5)

[1] The name of the publication is redacted for blinding purposes.

Nathan also completed two MCs on using technology to teach mathematics. The second of these, as part of a lesson on separable differential equations, appeared to have an impact on Nathan's views of how students learn. As opposed to his views in earlier years, Nathan had come to highly value modeling tasks as a method of teaching content and not as an add-on after students had learned some content.

> While examples of applications given in a direct instruction manner can be lazily done without full engagement, this task (which was completed with groups of 3) required significant thought and understanding to complete. (Inman, narrative for Teaching Math with Technology B: Focus on Modeling MC, Y3)
>
> The goal was to show how utilizing these types of equations could apply the theory of Newton's Law of Cooling in order to find an equation to predict some of the missing pieces of a scenario involving the cooling of an object…I've taught this lesson for the last 4 years, and always taught this piece simply through the use of an example problem…I wanted students to have a stronger connection between the values we would be substituting in to our equation. I also hoped that they would gain a better realization for the power of this math process. (Inman, narrative for Teaching Math with Technology B: Focus on Modeling MC, Y3)

The number of times Nathan used language that categorized and labeled students also decreased considerably in the third year. By the fourth year, Nathan had stopped using this language, which demonstrates a sizeable shift in his beliefs about how students think and learn. This language did not return for the remainder of the project and—based on personal conversations with Nathan—does not appear to have returned since the project ended.

In the final two years, Nathan seemed to work through some of the cognitive dissonance between how he taught before and how his practices had changed, indicating another shift in his beliefs about learning and how students learn.

> A key point made about funneling that was eye-opening to me was "Students will not immediately understand the significance of this series of questions because they view asking questions as being characteristic of the teacher's role" (Herbel-Eisenmann & Breyfogle, 2005). I had never considered that students did not understand the purpose for my line of questions, but that is most likely what has predominately occurred through many of my questioning lines. (Inman, narrative for Analysis of Teaching 1 MC, Y4)

The ways Nathan talked about his students' understanding also shifted, as he worked through his cognitive dissonance. He showed that he now valued student thinking, creativity, and collaboration.

> I know that the most common question I ask is a yes/no or short answer question. I do not think that is uncommon among teachers. We like to hear the chorus of students knocking soft-ball sized questions repeatedly out of the park. And despite my knowledge that these questions tend not to be thought provoking and that they may in fact cause students on all ends of the knowledge continuum to remove themselves from the conversation, they are my default style…I think that the yes/no or short answer question is my way of feeling like I'm providing students with a voice in the classroom, but in actuality that's probably not true. (Inman, narrative for Analysis of Teaching 1 MC, Y4)

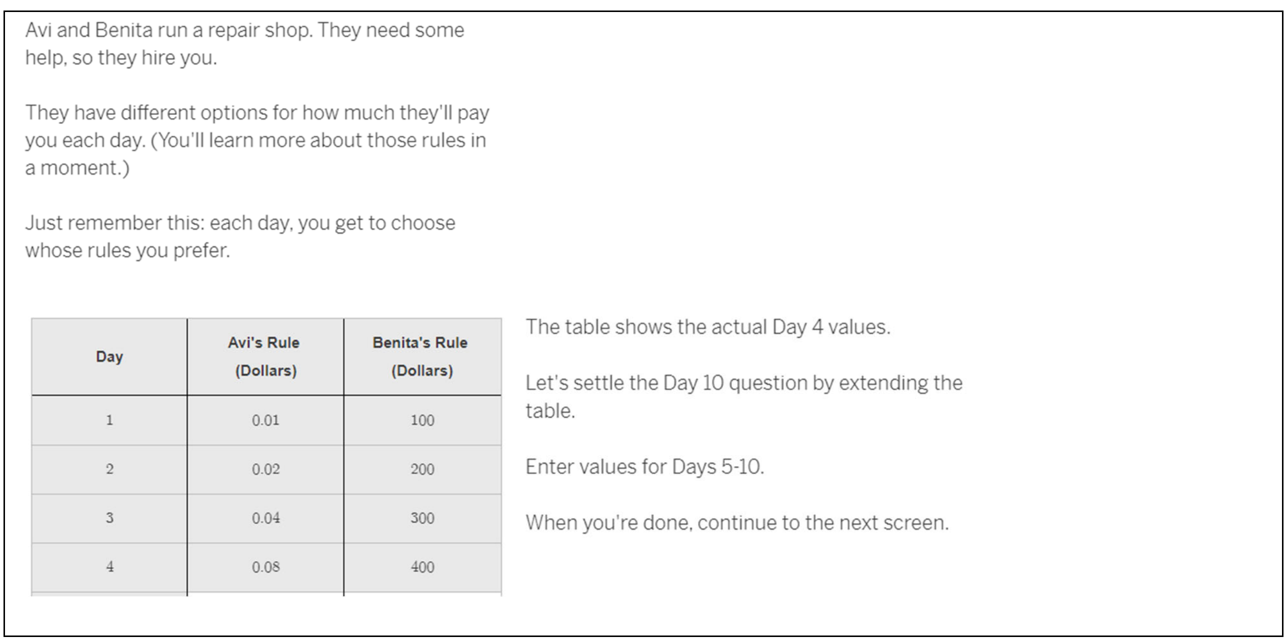
Nathan was open about discussing his cognitive dissonance, such as when he discussed the dilemma between having students work independently and having students work collaboratively.

After participating in this cycle of research-plan-action-reflect a number of times in the last few years, I now approach the implementation of math activities (and lesson planning in general) through a different lens. While many times I believe that tasks should be started individually so as to not stifle individual creativity and personal engagement, I have also found that the sharing of ideas and methods through the small group format can significantly aid in knowledge growth of other students. Additionally, the further explanation of a students' thinking can help that student further understand and internalize their own thinking. (Inman, narrative for Planning to Lead Instructional Change, Y4)

Despite teaching online in Year 5, Nathan continued to have success engaging students in math tasks designed to support their conceptual understanding. In one task, Nathan had students compare pay rates. (See Figure 26.) He used this task to introduce students to exponential functions and have them make comparisons to linear functions.

**Figure 26**

*Introductory Lesson on Exponential Functions (Desmos, 2021)*



Avi and Benita run a repair shop. They need some help, so they hire you.

They have different options for how much they'll pay you each day. (You'll learn more about those rules in a moment.)

Just remember this: each day, you get to choose whose rules you prefer.

| Day | Avi's Rule (Dollars) | Benita's Rule (Dollars) |
|---|---|---|
| 1 | 0.01 | 100 |
| 2 | 0.02 | 200 |
| 3 | 0.04 | 300 |
| 4 | 0.08 | 400 |

The table shows the actual Day 4 values.

Let's settle the Day 10 question by extending the table.

Enter values for Days 5-10.

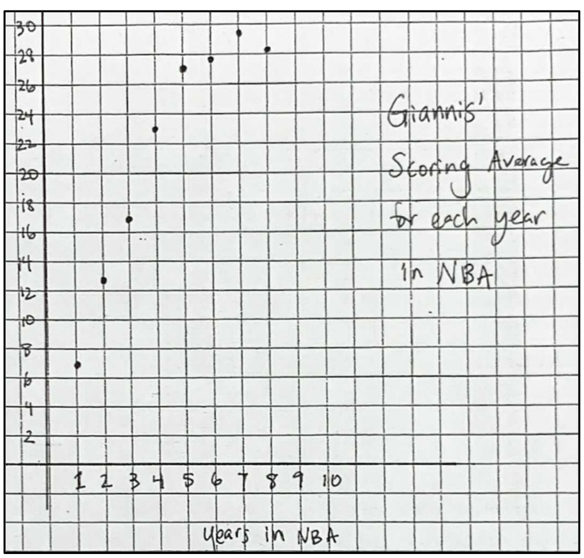
When you're done, continue to the next screen.

This lesson is an introductory lesson to exponential relationships…This lesson provides an opportunity for students to explore the differences between linear and exponential relationships in an informal manner. The Desmos technology offers a great platform to explore these ideas in a way that they can be easily made sense of, and that they can be visualized in a number of ways. (Inman, narrative for Teaching Math with Technology B: Focus on Modeling MC, Y5)

In a different lesson after MMTP had ended, Nathan used a graph of Giannis Antetokounmpo's scoring average over his years in the NBA (Figure 27). He used this figure to have students make predictions about future scoring averages, which was leading toward the realization that relationships are not always linear.

**Figure 27**

*Graph from Nathan's Algebra I Class*




We're going to look at some modeling with data. We're gonna try and impose a linear trend onto some data, and we've kind of worked with fairly linear data so far. Today I'm going to try and shift them into trying to put a linear model onto something that may or may not be linear so we can start to look forward to future trends. I hope that they'll

> really reinforce the fact that they can come up with an equation of a line, even if the data might not be specifically points that go through that. So really, kind of looking at, we find these two points that are on this line and then we can write the equation and make use of the equation in a real life. (Inman, pre-classroom observation interview, post-Y5)

Additionally, Nathan kept looking for ways to assess what his students were understanding and ways for them to engage in dialogs about mathematics.

> Another way this [Desmos] task removes barriers is that positions students as capable to solve the problem …Since this is an introduction to exponential relationships, it is helpful for students to have tables and graphs provided for them to work within and extrapolate. This allows them to feel capable in taking on a new challenge…One way I supported students in this task was by stopping them once I saw all students had reached a critical slide in the Desmos task, and then asking questions to the whole group, as well as sharing some student responses…Students who had drawn incorrect conclusions [could] adjust their thinking, so that they could move forward with a better understanding…The task is quite iterative, allowing for self-reflection as students are able to see the visual output of their calculations and possibly revise. It was also found in the large group share outs that helped some students refine their thinking with help from their classmates. It was also not "done in a bubble" but with calculated guidance from myself and classmates alike. (Inman, narrative for Teaching Math with Technology B: Focus on Modeling MC, Y5)

At the end of MMTP, Nathan affirmed how much he valued getting feedback from his students and how much he respected their opinions about teaching and learning. This highlights a shift to asset-focused thinking and demonstrates how much Nathan's views of students had changed since he began MMTP.

> Asking students to give me honest feedback and then valuing it more now than I did before. Before I did this, I saw the relationship as something where, oh, they're just gonna brown nose, you know. They're just trying to tell me things that I want to hear. That said, I didn't really make great use of survey tools or, more so just peppering them with questions about how they felt about the activity. And honestly, just really honest feedback that has helped me shape what I've done going forward. (Inman, final interview, post Y5)

**Evolution of Nathan's Leadership: Shared Leadership and Collective Vision**

Throughout his time with MMTP, Nathan was the chair of the mathematics department at his school. Early on, he noted that teachers at his school sometimes had conflicting motivations. Nathan did not express an interest in the leadership MCs offered in Year 2 and Year 3. However, in the fourth year, when the MMTP facilitation team had teachers begin to develop leadership plans for the following year, Nathan became focused on how he was leading his department.

> I also learned that when teaching teachers it is important to view them as both learners and contributors, as they will be valuable members of the learning construct. And I learned that going through a significant shift in practice is best done with a group, which can help troubleshoot and come up with solutions more effectively. (Inman, CLADE, Y4)

This need to examine the ways he led his department became much more pressing when the schools closed due to COVID-19. He shifted his initial focus for his department (exploring culturally relevant pedagogy) to accommodate for the needs of the teachers as they began the work of moving to online instruction.

> My department has been very proactive in learning about technology resources that could be helpful as soon as we knew that our year was at least going to start with virtual

> instruction. Seeing that action to take things upon themselves, I will ask department members to lead PD sessions to give an intro into new technologies. I believe some members will be eager to take that role, which should go far to create buy-in from those that might not be as motivated and also in really building a solid fabric of a learning community that could operate in a very free-flowing and informal manner. (Inman, narrative for Professional Development Design MC, Y5)

Nathan recognized that it would be difficult to lead collective teacher learning unless they had a shared vision of what high-quality online teaching and learning should look like.

> We worked to define and develop a shared vision for high quality mathematics teaching and learning. This was a significant challenge in a new teaching environment for us all, but we worked collectively to establish what that would look like and how it would function. I think the biggest key to our success was the fact that it was very much shared. All members of the department came to the table with ideas and were willing to try new things and share their experiences. (Inman, narrative for Developing as a STEM Teacher Leader MC, Y5)

Using this shared vision, Nathan and his department were able to productively move forward with creating a plan for their own learning about ways to engage students in online learning.

> We began by sharing out on what we knew about it after our brief experience in the spring [of 2020], although it was widely admitted that student interaction was so low that it was difficult to measure the effectiveness of many things. We then went on to list the challenges we would be facing and then the questions we wanted answered as we would begin to plan for the upcoming school year. I…set another meeting for 2 weeks later and asked everyone to explore and learn as much as they could to respond to those challenges

and questions by then… [The second meeting] was quite informative and it shared the burden of a huge learning curve more collectively among our department. It also served to quell the fears and nervousness of a lot of us about the unknown of such a new experience…It really caused a lot of people in our department to take leadership roles over different areas of rolling out education in a virtual platform. (Inman, narrative for Planning to Lead Instructional Change MC, Y4)

Nathan credited both the shared vision and the distribution of leadership as reasons why his department had success engaging students in learning online.

The data we gathered was around teacher feedback on the creation and implementation of these tasks, as well as the student feedback from their participation in the tasks. The survey data showed a significantly higher level of student engagement with use of these new instructional platforms than with direct instruction methods. (Inman, narrative for Developing as a STEM Teacher Leader MC, Y5)

The biggest part that [I learned], when you are planning something [for teacher learning], when you can get people to buy into your plan, when you can plan in such a way that [the teachers] are going to become contributors to it, I think you're going to have sparkling results, at least more so than what you would have had. So that was something that I learned a lot about and will hope to make use of in future leadership roles that I take on. (Inman, video narrative for Sharing Outcomes and Reflections MC, Y5)

**Linking Nathan's Learning Outcomes to the Design of MMTP**

The design of MMTP supported Nathan's learning in several ways. Referring to my framework for teacher learning (Figure 5), Nathan's learning was impacted by the overall coherence of the content of MMTP (knowledge), by the relevance of the learning to his own needs (teacher-centered), by having his learning based in his own classroom (context), by the support he received in assessing the impact of his learning (assessment), by the monetary compensation he received for his work (teacher-centered), and by using his students' thoughts to assess the impact of his learning (context and assessment).

Nathan saw the things he was learning through MMTP as being relevant to his work and to his learning needs. Despite the amount of work that was expected from the teachers, Nathan seemed to view it as a factor in improving his teaching practice. He also acknowledged that financial compensation for his work was a factor in continuing.

> Something I saw the value in, I never felt like I was asked to do something that wasn't benefiting me. Obviously the money helped to make me want to run through the finish line, 'cause there were definitely times where it was…this is a struggle. The struggle is real right now. But I always knew that after the fact when the dust settled, all of these things that I had done were going to make me better, and so it's just like, drive through it and you'll be able to appreciate this a lot more on the back end. Your it will make you better at your job. And I definitely believe that happened. (Inman, final interview, post-Y5)

Nathan appreciated the extended period of time and the coherence of learning over time.

> I think the time was the timeline was effective. The fact that we had time to build some of those skills that we would then make use of in the later years in the project…The arc of the project was really great. You know it scaffolded so well that we were able to feel successful. (Inman, final interview, post-Y5)

Along with the extended time, Nathan felt that having the work be based in his own classroom and teaching was a key part of his learning. He valued the expectation of self-reflection and self-assessment that is part of teacher action research.

> I think just the whole arc of the planning of it, especially for how long this was, was really different than most of the PD that I've been a part of. And then to being able to apply it immediately to my classroom, my students come, and study those effects, and then reflect on it too…There's been PD where I've been given things and enacted them in my classroom, but then never that time to sit down and actively reflect on it and summarize my thoughts. That's obviously pretty big. (Inman, final interview, post-Y5)

Nathan also came to value the input of students and used their feedback to drive his learning and changes in his teaching.

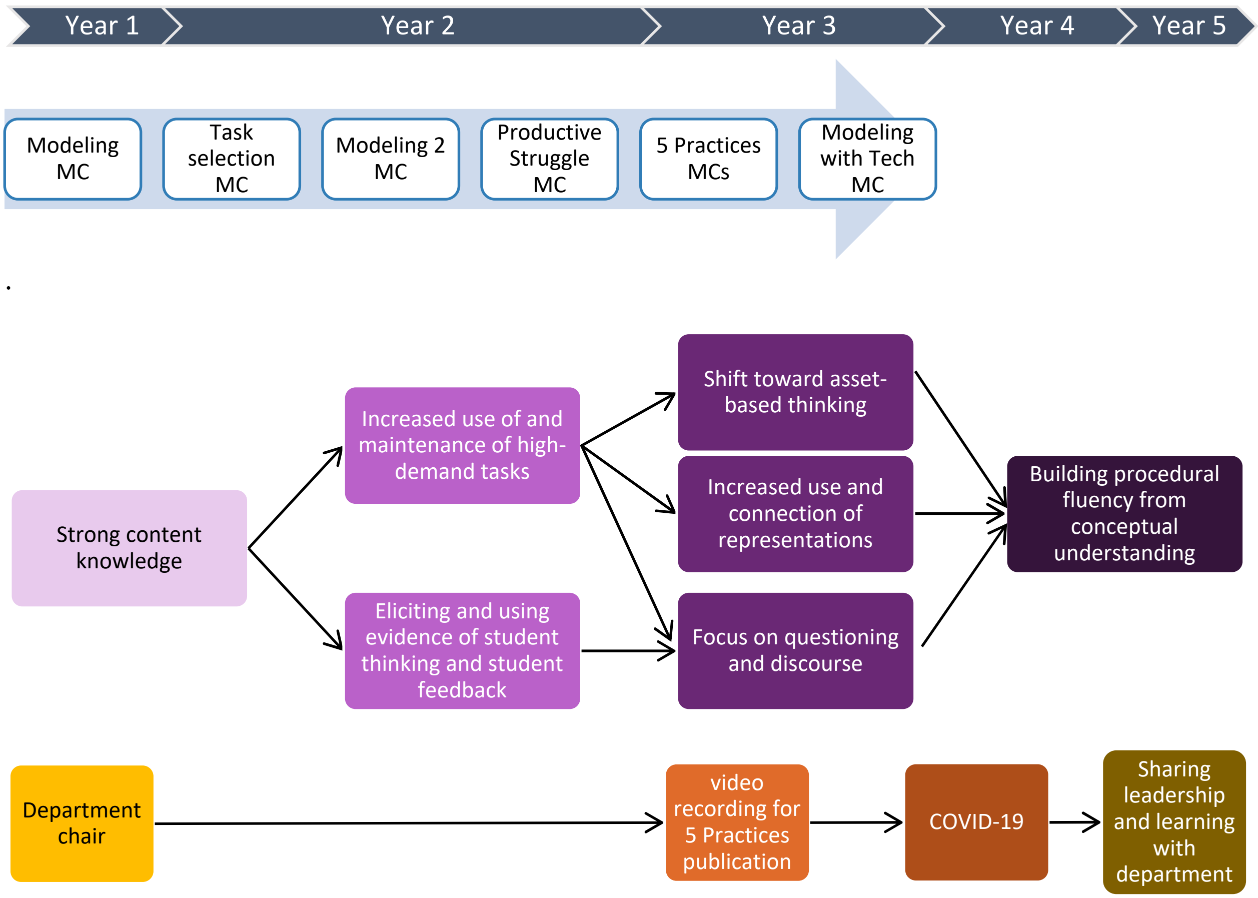
> Asking students to give me honest feedback and then valuing it more now than I did before…And honestly, just really honest feedback that has helped me shape what I've done going forward. (Inman, final interview, post Y5)

**Summarizing Nathan's Learning Pathway**

Examining Nathan's learning from the perspective of my research questions, how did Nathan's teaching change through his participation in MMTP? I will summarize the answers to my research sub-questions one and three below. A summary of Nathan's overall trajectory with MMTP is shown in Figure 28.

**Figure 28**

*Trajectory of the Changes in Nathan's Teaching Practices and Leadership, Including Notable Micro-credentials and Events.*




Nathan began MMTP with strong mathematics content knowledge. He had been teaching upper-level Calculus and IB Math Topics courses for several years (context). Nathan was teaching in a traditional manner, using lecture-based methods. In his first MCs, Nathan investigated a flipped-classroom model in his Calculus class (teacher-centered, context). While he found that it increased the efficiency of content delivery, he was not satisfied that students were completing the work outside of class (context, assessment).

For the first Modeling MC, Nathan seemed frustrated that modeling was something to do in addition to existing content. He was not certain where he would find the time to incorporate modeling as intended (context). Over the course of the first three years, Nathan continued to explore ways to incorporate mathematical modeling and high-demand tasks as a means of learning mathematics (teacher-centered, knowledge). Simultaneously, through a requirement to incorporate student voice into his micro-credential work, Nathan began soliciting feedback from students on the methods he was using to teach his classes (assessment). Students reacted positively, both to being asked to give feedback and to the increased expectations of high-demand tasks (assessment).

Nathan's views on students, their knowledge, and how they learn began to shift from using deficit language to categorize students to being more asset-based (teacher-centered). As he investigated supporting productive struggle and using the 5 Practices, his questioning shifted from funneling questions to assessing and advancing questions that identified and followed students' own lines of thinking (knowledge, beliefs). Nathan experienced some cognitive dissonance in trying to resolve his beliefs about individual vs. group work and correct use of procedures vs. exploring mathematical concepts (assessment, knowledge).

The long period of time for his learning allowed him to talk with others, investigate different practices, get feedback, and make refinements (context, community, knowledge, assessment). When schools closed for COVID-19, Nathan found himself in a position to be able to successfully deploy engaging learning experiences with his students, who were all learning from home. Even in that difficult position, Nathan was able to build his students conceptual understanding of mathematics.

His expertise also allowed Nathan to position his department members as resources for each other. He was able to share his knowledge of creating and using engaging Desmos activities with students. Likewise, by empowering the other members of his department to become experts in other platforms, the teachers were able to share the burden of shifting to online teaching and were all recognized as being assets to each other and succeeding at teaching during COVID when many other teachers had difficulties.

**Colleen Moore**

> *My goal is for everyone to feel comfortable to have discussions with their peers about math to be given the chance to increase their confidence, agency and understanding. (Moore, narrative for Culturally Responsive Teaching MC, Y4)*
>
> *Finding Restorative Practices provided a strong foundation to the vision for my math classroom and any concept I added. Restorative Circles were flexible enough to include content becoming Restorative Math Circles, and through these I had a way to actively change beliefs and attitudes toward math and increase community, trust, and math discourse. (Moore, article written for the state mathematics journal[1], post-Y5, used with permission from the author)*

Colleen had been teaching for eight years when MMTP began. She was teaching at Elm School, a large, comprehensive middle/high school. After the first year, after facing several challenges at her school that left her feeling discouraged and unsupported, Colleen made the decision to leave the district for a new position in a suburban district. In the second year, she began teaching in a large high school in a suburban district, and she remained at that school through the rest of MMTP. In her time with MMTP, Colleen primarily taught Algebra 1 and Algebra 2 courses.

In her work with MMTP, Colleen completed all 20 of her micro-credentials, although some were significantly delayed. Colleen noted her lack of confidence multiple times when

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[1] The names of the article and journal are redacted for blinding purposes.

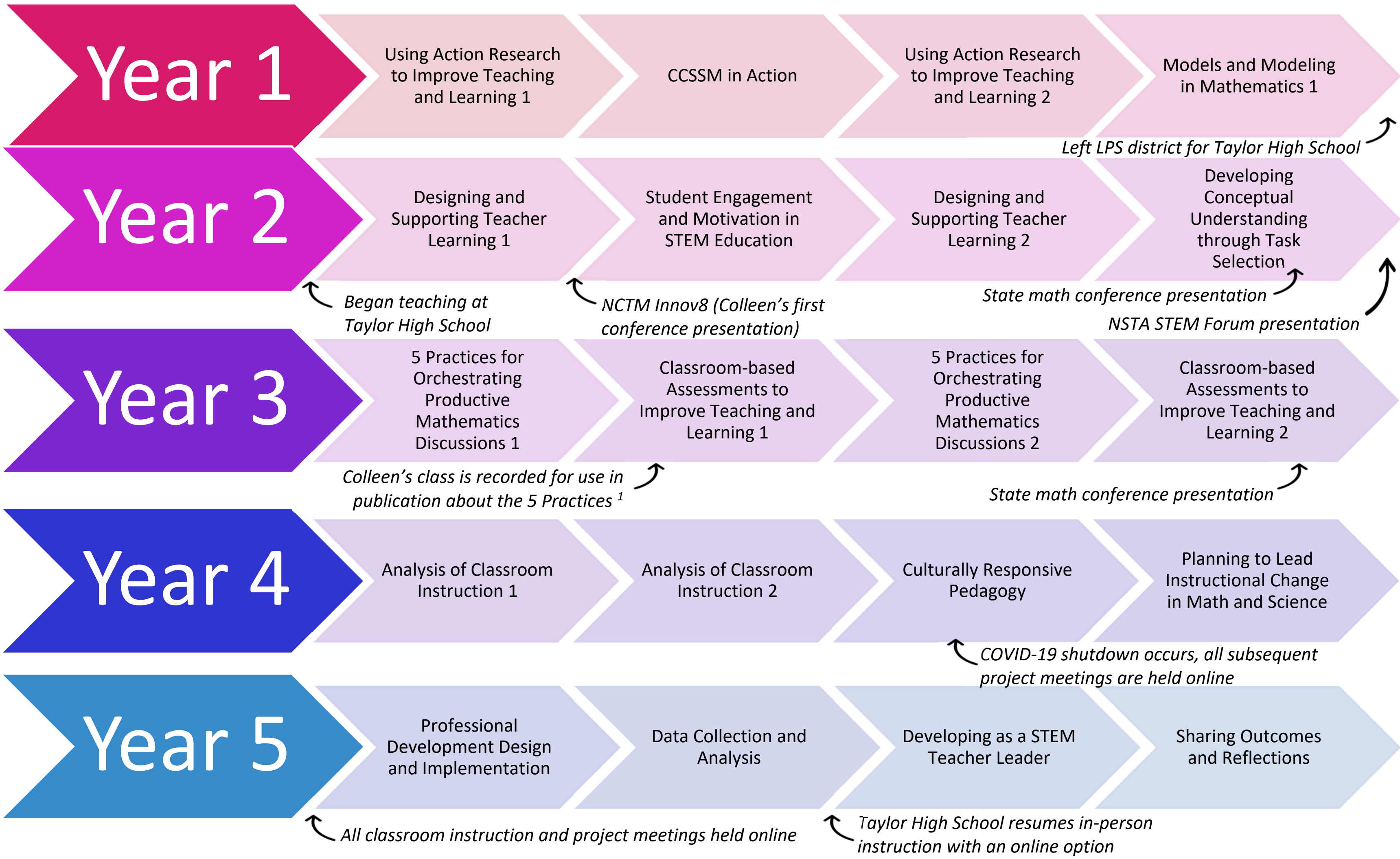
discussing the written work, often worrying that it was not good enough. She did have to revise and resubmit several of her MCs, but she was grateful for all feedback and used the suggestions to improve her work. Colleen's timeline with MMTP is shown in Figure 29.

Colleen's trajectory differed somewhat from the other teachers. From the start, Colleen had (and continues to have) a strong focus on using restorative practices in her classroom. She uses circles in her teaching in order to build community and trust among her students. She also uses circles to teach mathematics content, which was an idea and skill she developed as she progressed with MMTP, leading her to become a pioneer of using circles in this way. (See Figure 30 for a description of the essential elements of a restorative math circle.) From the very beginning of MMTP, whenever it was feasible, Colleen focused her action research questions on using circles to teach mathematics content.

> I would like to explore restorative justice circles, technology, questioning methods and word choices to see how that can encourage more Math discourse. (Moore, narrative for MMTP application, pre-Y1)
>
> What ways do restorative practices influence the mathematics classroom environment and student mathematics achievement? (Moore, narratives for Action Research 1 and 2 MCs, Y1)
>
> How can we ensure all students feel comfortable to discuss and thus participate in their math community? (Moore, narratives for Designing and Supporting Teacher Learning 1 and 2 MCs. Y2)

**Figure 29**

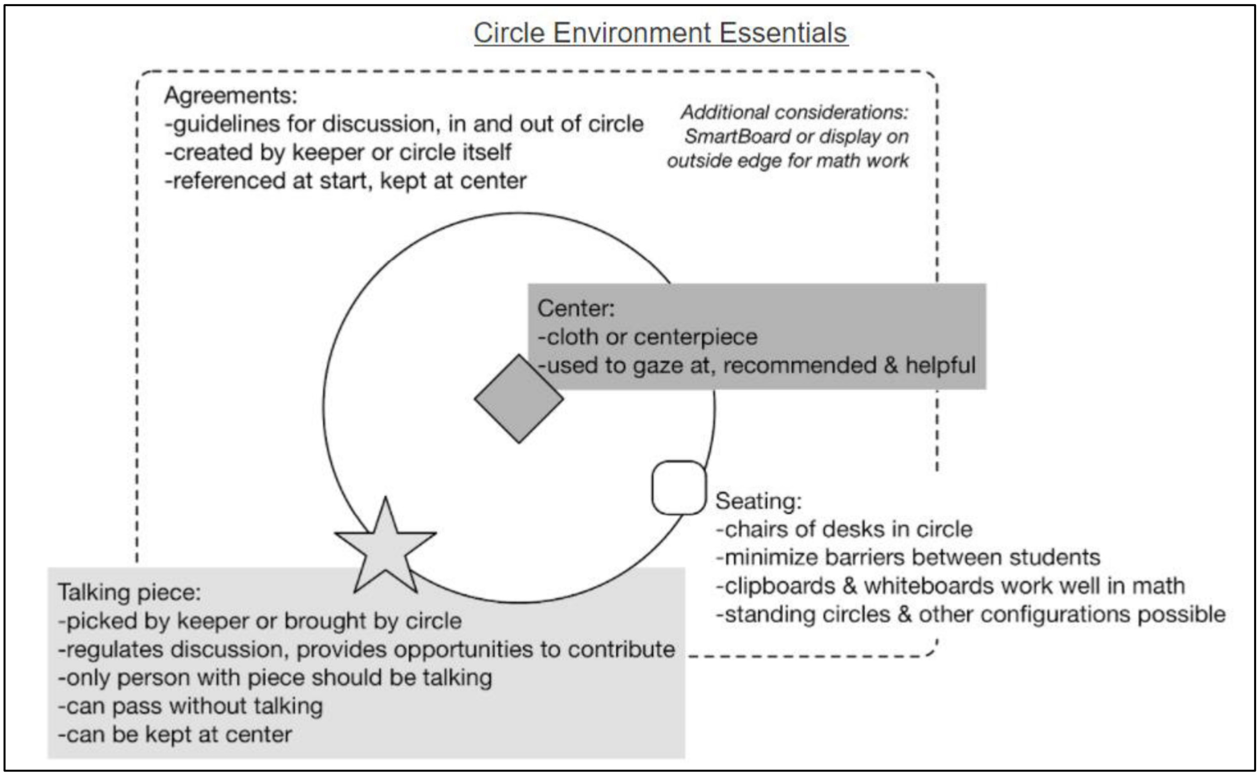
*Colleen Moore's Timeline of Work with MMTP*




[1] The name of the publication is redacted for blinding purposes.

**Figure 30**

*Elements of Restorative Math Circles (Moran, 2022)*




Additionally, Colleen wanted to share her knowledge of using restorative circles to each math content. As MMTP progressed, she was encouraged to present at workshops and conferences. The themes of building her own confidence and building a classroom community of learners were the two strongest themes in her work. In the next two sections, I will expand on the changes in Colleen's teaching and how her confidence as a leader grew.

**Time Evolution of Colleen's Teaching Practice: Building a Community of Learners**

From the onset, Colleen wanted to increase discourse in her classroom. Throughout MMTP, this did not change. However, Colleen became focused on using restorative practices and circles as a means for increasing mathematics discourse, and this led to changes in her teaching practices. (Table 10 contains a summary of Colleen's rubric scores using the MMTP Classroom Observation Tool (see Appendix F).)

**Table 10**

*Heatmap Visualization of Colleen Moore's Observation Rubric Scores over Time.*

| | App[1] | Y1 | Y2 | Y3 | Y4[2] | Y5[3] | Post-Y5[4] |
|---|---|---|---|---|---|---|---|
| *Goals* | | 1 | 2 | 1 | | 1.5 | 4 |
| *Tasks* | 3 | 2 | 2 | 3 | | 2.5 | 3 |
| *Representations* | 2 | 1 | 3 | 2 | | 3 | 3 |
| *Teacher Discourse* | | 2 | 3 | 2 | | 2 | 4 |
| *Student Discourse* | 1 | 2 | 2 | 2 | | 1 | 2 |
| *Questions* | | 1 | 2 | 2 | | 2 | 3 |
| *Fluency from understanding* | 3 | 1 | 2 | 4 | | 4 | 4 |
| *Struggle* | | 2 | Not obs | 2 | | Not obs | 3 |
| *Evidence* | 2 | 1 | 3 | 2 | | 1 | 3 |

[1] Colleen's application video was not submitted because of technical difficulties. Some scores are approximated based on her written narrative.
[2] Year 4 observation was scheduled for a date after March 13, 2020, when schools closed due to COVID-19.
[3] Colleen's Year 5 spring semester classes and observation were conducted using mostly in-person instruction with a few students online, and may not be indicative of typical teaching.
[4] Colleen's final observation occurred in May, 2022.

For her first action research question, Colleen expressed her desire to increase mathematics discourse in her classroom. However, she did not have a strong idea of how to accomplish this. Colleen had training in using Montessori methods with secondary students, Socratic seminars, AVID (Advancement Via Individual Determination), and restorative practices.

> Math talk is thus an important part of a successful math classroom but fostering an atmosphere where everyone feels comfortable to share their justifications is also equally important…Montessori for adolescents and Avid both mention Socratic seminar as ways to foster math discussion. The National Council of Teachers of Mathematics (NCTM) had an article in their November 2015 edition on "Creating Math Talk Communities: Use these five strategies to encourage meaningful discussion" …Although all of these have

proven to be helpful strategies, it still seemed to be missing the framework and continuum of community building necessary to provide a safe environment for sharing of ideas. This needs to be considered when bridging from community building topics to discussions with a math focus. (Moore, narrative for Action Research 1MC, Y1)

Colleen was concerned that her students may not have had the knowledge to productively engage in mathematics discourse, and wanted to use circles to build trust, teach students how to have math discussions, and foster their mathematical understanding.

> High schoolers, especially Freshmen, may be new to this idea of math discussion and may need to be taught to first appropriately talk to each other to be able to successfully engage in math discourse…It seems to be assumed that students will work autonomously or with a few reminders, taking on the huge endeavor of problem solving with peers. Even with explicit lessons on the ways to talk to each other, it seems to be a reaction to something that is happening, without being proactive—community building can engage the students even further into a feeling of something larger than just the discussion at hand…The format and facilitation of the discussion is again important, allowing each student to share their ideas without being interrupted. This idea of every student being heard and comfortable is often not explicitly discussed in many math discourse articles…Trust is also an important part of restorative circles and need to be fostered in the circle to encourage participation by all. (Moore, narrative for Action Research 1 MC, Y1)

> By bringing Math Discourse and Restorative Circles together, I hope to provide trust and community to engage all learners. (Moore, poster for Action Research 2 MC, Y1)

Colleen began looking for ways to incorporate restorative circles into her teaching and ways to assess the efficacy of circles. She met with limited success in the first year, although her success increased as she became more experienced with circles.

> With only at most 7 circles in a class, there were limited opportunities to collect and improve the collection. Students would often not submit work and although I felt it may indicate lack of knowledge, it was still inconclusive. Timing was also an issue, the flow of the circle often had the assessment seeming like an interruption of the process. I thus decided to focus my results on graphs found using the observational rubrics during circle time. I got hung up on wanting to include everything but felt that since check-ins at the start of each circle were consistent and thus comparable, it was the best way to honestly portray some of the successes of the Restorative Circles…The circle process had improved and I felt that the number of responses per minute per circle captured some of that. The other data analyzed was the number of responses per circle. In one class it increased significantly and in the other it remained constant with the time it took for responses significantly decreasing, shown in the responses per minute graph…I am now planning on starting restorative circles/Socratic seminars at the beginning of the school year next year to further the progression I feel that I will obtain…I am still pondering what methods of data collection I will feel is important and will thus continue to do so with this work. (Moore, narrative for Action Research 2 MC, Y1)

Upon changing schools at the beginning of the second year, Colleen continued to develop her use of circles as a means for building relationships with students. She focused on building a community of trust and increasing discourse and engagement in her classroom. She found that incorporating different warm-ups, such as images from websites such as Estimation 180, Which

One Doesn't Belong, Would You Rather, and Visual Patterns, increased the opportunities for discourse between students.

> All parts of the Circle process address the presence and progression of trust. It encourages participation and even can work as an indicator as to the level of trust present…Teacher-Student interaction is something I am always working towards so I wanted to focus on something else to drive a different kind of motivation or engagement…Given the idea of exploring the start of each class, I liked the idea of taking that time use different kinds of class "warm-ups" to engage or re-engage students, all the while building their relationship with mathematics and hopefully their motivation. (Moore, narrative for Engagement and Motivation MC, Y2)
>
> Students who had previously engaged continued to do so. What really struck me was observing students who were usually not engaged in previous warm-ups or lessons was specially interesting to me. Many of those students were taking the class for the second time. There was a "buzz" added to the class; students were engaged in discovery with potential for discourse. I felt like I had opportunities to connect with them and the math in a different way, all while developing skills such as estimating, pattern predictions and curiosity. (Moore, narrative for Engagement and Motivation MC, Y2)

Colleen also grouped her students in ways that reinforced that the group was also its own small restorative circle and could be productively used to help students connect with each other and to support their mathematical understanding.

> I also feel using restorative practices builds up the trust of the students to participate in activities in front of the class, a possible connect to engaging the students in the work as well. (Moore, narrative for 5 Practices 1 MC, Y3)

> And when they go into groups, they're going to small circle and group to just kind of get to know their group members a little bit and then kind of see how they're working in the small groups together and then kind of where those conceptions are for [the homework]. (Moore, post-classroom observation interview, Y2)
>
> Because I wanted students to connect to each other before attempting the problem and get a chance to share whatever level of connection they had with baseball as a way to also connect and see their opinions on the task valued, I chose to start with restorative circles in small groups. (Moore, narrative for 5 Practices 2 MC, Y3)

At the same time, Colleen seemed to be shifting the purpose of the tasks she was using with her students. In a lesson on radical functions, Colleen connected the radical and quadratic functions, and students expanded their understanding of previously discovered exponent rules to include fractional exponents.

> I hope students will learn that some of the past concepts are still relevant and place them with our new concepts. I hope the students will feel more confident and learn solving [radical] equations and really double-checking them, and why that double-check is so important to understand those extraneous solutions. Again, really emphasizing that and how it connects with some of the quadratic work that we had done previously…And then I hope that students learn exponential properties and how they connect with radicals. (Moore, pre-classroom observation interview, Y3)

In another lesson on solving systems of linear equations, Colleen wanted her students to understand the meaning of the solution of a system of linear equations and where that solution can be found in the different representations of the system (equation, graph, table, and physical model). She used the context of stacks of two different types of cups, and elicited from the students the question, “When will the two stacks have the same number of cups and be the same height?” By having her students engage in this lesson, Colleen intended to build their understanding of the meaning of the solution of a linear system before having them explore different procedures for solving systems.

Colleen continued to refine her beliefs about student discourse, restorative practices, and her rationales for using both in the classroom. Colleen shared that she believed that productive classroom discourse was linked with student comfort in the classroom, with a shared sense of the classroom as a learning community, and, ultimately, building positive mathematical identities for students.

> My goal is for everyone to feel comfortable to have discussions with their peers about math to be given the chance to increase their confidence, agency and understanding. (Moore, narrative for Culturally Responsive Teaching MC, Y4)
>
> The need for putting these feelings into action and having them work for us is where I feel Restorative Practices and specifically Restorative Circles can be beneficial. They are a great way to facilitate discourse in a structure that embraces and expects change. This is what I want students in my classroom to feel…There is a need for consideration of these in classrooms and again, math is no exception and might need more due to some of the trauma continually created by some current and past math practices…My goals with Restorative Practices to be cognitive of the relationships in my classroom and use these practices to proactively and, if needed, relatively cultivate these relationships. By relationships, I mean student to student, student to teacher and student to mathematics. Identifying and attending to these as well as making sure discourse is fair, students can feel more connected and included in their math experience. This meets another goal of

my school; a positive math identity. (Moore, narrative for Planning to Lead Instructional Change MC, Y4)

I've been onto restorative circles and that is where I needed to go, and I needed to work and figure out more about that and why it worked and what I liked about it and how I could explore that to create that discourse that I really want in my classroom. And through that community and through that better questioning and better engagement. So I probably kind of latched on to that for my engagement. (Moore, final interview, post-Y5)

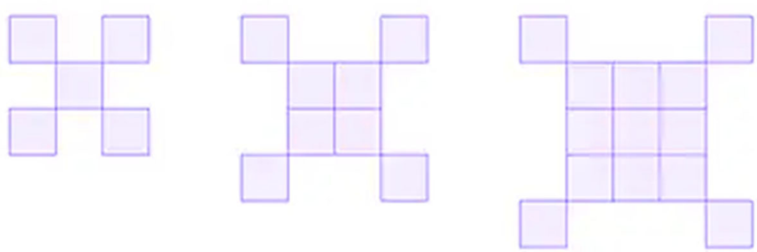
The thing that helped me a lot with that is the restorative practice idea or just everything with the students and hearing their voices…I really value [student dialogue] in a much more positive way. With student opinions, I definitely value that a lot more than I have before I just making sure that they feel safe in the classroom and understood and heard. (Moore, final interview, post-Y5)

Through building students' trust in her and each other, Colleen felt more confident implementing high-demand tasks and using those tasks to help students build their conceptual understanding as a precursor to introducing procedures. In the year following MMTP, Colleen had her students using a pattern to introduce quadratics and build their understanding of quadratic growth (Figure 31). Colleen noted that this task and the discussion she had planned for were use because of the work she did with MMTP and the work she did preparing to be video recorded for the 5 Practices publication.

Because of my work of 5 Practices, I was able to do 5 Practices with this task, where before, I would have done the task and I wouldn't have been able to do it as well…And so I was able to use the same monitoring chart that I had used before and really just changed a couple of things about it. There was less strategies, so I cut out a couple and then left out a couple places for additional methods. I made sure I had a non-starting group. I made sure had a group with tables. I made sure I had a group that was emerging with the equation but not comfortable. And maybe they needed to check their equation. I had a group that was very comfortable with their equation…I think just listening to students and really making sure—just because of the videotaping I would have to do and making sure that their voice was highlighted more than mine. I'm not saying as much and making the students say that because of the videotaping I did. (Moore, post-classroom observation interview, post-Year 5)

**Figure 31**

*Task Used by Colleen During the Post-Year 5 Observed Lesson*



(a) How many boxes would the fourth picture have? Explain how you found your answer.

(b) How many boxes would the 9th picture have? Explain how you found your answer.

(c) How many boxes would the 10th picture have? Explain how you found your answer.

(d) How many boxes would the nth picture have? Explain how you found your answer. I) What can you say about relationships you found in this pattern?

(f) Create a graph of this pattern. Are there any more observations you can make after viewing the graph?

I didn't really care about the equations as much, but I did want to make sure that they really discovered those quadratic relationships, and then I figured out that the equation

> was very friendly to find, so I wasn't too worried about them finding an equation here…But in the pattern they're adding on every time, so then that was really cool to see that emerge too, because they had to create the equation…And they saw quadratics. They got to see the quadratic relationship. They got to see the quadratic table. They got to see the quadratic graph. (post-classroom observation interview, post-Y5)

**Evolution of Colleen's Leadership: Gaining Confidence as an Expert**

When MMTP began, Colleen was extremely hesitant about having her classroom recorded. Although she continued to be nervous throughout her time with MMTP, Colleen became less self-conscious having her teaching observed and analyzed.

> I know my teaching well from my perspective but do not like getting videotaped and watching the video. The process of videotaping myself and just viewing is something I need to practice to get better at it. Because of constructive comments made to me about my teaching when I was first learning, I am often hypersensitive to the idea of messing up…Because of this hyperawareness when getting videotaped, I was wondering what my teaching would look like. Teaching without being videotaped used to make me nervous on its own but as a veteran teacher, I can find a strong flow that I enjoy and feels balanced. When videotaped, I don't often feel that flow but again, something I want to work on. (Moore, narrative for Analysis of Teaching 1 MC, Y4)

This gaining of confidence is mirrored in Colleen's experiences as a leader of teachers. From the start, Colleen wanted to lead teacher learning opportunities, although her goals for that learning were not completely clear.

> By exploring more about mathematics and [its] connections, I feel that I would be a more confident teacher and be able to engage my students into different aspects of applied

mathematics…Developing some professional development is where I see myself aspiring to provide leadership in my school and the district. I look forward to the possibility of being selected and challenging my art of teaching to become a better educator of my students in this district. (Moore, narrative for MMTP application, pre-Y1)

Teacher leadership was something that I really wanted to work towards. And presenting, and I just didn't know what I would be presenting. (Moore, final interview, post-Y5)

The experience of presenting to the cohort of MMTP teachers also gave Colleen confidence in opening up her classroom and her practices, marking a first step toward being comfortable as a knowledgeable authority. Colleen indicated that the process of sharing out the results of classroom action research with her peers was valuable for her own learning.

As a presenter, I actually felt more confident than I thought I would even though my "poster" nor data collection was collect. My one take-away from this is to become more confident in my research. I really enjoyed the feedback from the observers. (Moore, reflection following group poster sharing for Action Research 1 MC, Y1)

Because of all of this work [with Culturally Responsive Teaching] as well as the work of other badges, I know of data driven resources to draw from to improve my teaching and present about my findings to help improve others. The continued cycle of being challenged and growing in this process has also given me a lot of confidence in myself to be the leader I know I want to be. (Moore, narrative for Planning to Lead Instructional Change MC, Y4)

I think confidence was an issue for me. I sometimes needed to be more confident, you know, like my thoughts and what I wanted to do. Sometimes I don't think I convinced myself? So I tried to do like I had done before and it had maybe worked for some people

> [in MMTP] but then I really learned that I had to convince myself first about these things and then if other people [in MMTP] had questions, and I would be like, oh, OK, I can see why their different perspective would add on to what I already had. (Moore, final interview, post-Y5)

> I hated [presenting my action research] because I was always behind, but I liked the peer feedback about the badges. But I was always behind. But I really did appreciate the flexibility of that, not being like, you don't have a badge already done, we're not going to allow you to present. People we get to present whatever their ideas were and that really helped me gain the confidence of then to finish that, so I really appreciated that flexibility. (Moore, final interview, post-Y5)

Through the process of presenting to her fellow MMTP teachers, Colleen began to grow more confident in her knowledge and abilities. In the second year, the facilitation team encouraged her to present at a national NCTM conference. She acknowledged that it was difficult for her to present herself as an expert, but that she found the experience incredibly valuable.

> Presenting was so nerve-racking for me, and that's something else that I did because of [MMTP] only…Getting out and presenting is something that I have, you know, I don't see myself in the classroom for all of my years. And if I am that's great. Cause I know now like I will continue to learn and continue to grow as a teacher leader through some of the opportunities that I've had because of [MMTP]. And one of those is presenting and getting out of the classroom and thinking, you know, if this is going well in my classroom, how can I scale-up?…I forget which badge that was, planning for leading for change, but it was like that scale-up factor, whatever, scaling up and just thinking about it outside of your classroom like people could replicate it. So that's something that I'm

> definitely less nervous now when I present, or to say my opinions, or, you know I just feel more confident. (Moore, final interview, post-Y5)

Later that same year, Colleen presented at the state math teachers' conference. She continued presenting at state conferences until COVID-19 forced their cancellation.

During the fifth year and the following year, Colleen held her own series of three workshops for people who were interested. She solicited her own participants from the group of MMTP teachers and from a virtual book study that she had been part of.

Since MMTP has ended, Colleen continued (and still continues) to present at state and national conferences. She has begun writing about using restorative practices to teach math content and has had an article published in the state's professional organization's journal.

> Through that [state conference] presentation, one of the participants from there is part of the [state math teachers' professional organization] journal and he asked me to write an article about why restorative practices in the math classroom…And I want to continue this. I want to continue doing workshops and presenting out to willing participants that can use this in their classroom and, you know, kind of that power of that circle. I want to pass that on. I feel like it's really important in math classrooms and I want to continue doing this. (Moore, narrative for Professional Development Design MC, Y5)

**Linking Colleen's Learning Outcomes to the Design of MMTP**

The design of MMTP supported Colleen's learning in several ways. With regard to aspects from my framework for teacher learning (Figure 5), Colleen placed tremendous value on the supportiveness of the MMTP community as a whole (community). She was impacted by the consideration of her individual learning needs (teacher-centered), by the coherence of the learning over time (knowledge and context), and by her ability to focus on a topic that she considered important (restorative practices and circles) (teacher-centered).

More than anything, Colleen valued the MMTP community of teachers and facilitators. She stated that the positive support and flexibility of the participants and facilitators were key parts of encouraging her to learn.

> I think I'm really critical of myself. So I think I have to be careful of that. Probably attributes to some of my burn out, right? I think in the teacher profession I don't know if we get to grow in such a comfortable environment with support like this. It was nice to be able to see some of my work in the more positive light that probably I should have been doing. (Moore, final interview, post-Y5)
>
> I liked the peer feedback about the badges, but I was always behind. But I really did appreciate the flexibility of that, not being, like, you don't have a badge already done, we're not going to allow you to present. People got to present whatever their ideas were and that really helped me gain the confidence of then to finish that, so I really appreciated that flexibility. (Moore, final interview, post-Y5)
>
> I think it was really important that we came together for that Saturday, that became like a ritual that we all really missed when we were virtual. (Moore, final interview, post-Y5)

The support of the community gave Colleen some of the confidence that she had been lacking beforehand.

> So I feel very confident now in kind of why I do certain things about restorative circles and why I do certain things in my classroom, so it's been fun to kind of figure that out too, just to know that I have good intuition to try those things and then think back on why I do them. (Moore, final interview, post-Y5)

Colleen also appreciated the extended length of time and the way that the MC opportunities were cohesive over time, both aspects that had been lacking in her master's degree program and her school-based PD.

> I think it gave me the growth opportunities that I was looking for and that maybe that I didn't always find cohesively in class. In my schools. (Moore, final interview, post-Y5)
>
> I feel like that because of the five-year program, it was just such a nice build. It was so cohesive in its build. And it was like that immersion into it because we always kind of brought along with it, we would have professors, you know, would be able to contact them when we needed them for help or ideas. So, yeah, this would probably be the best professional development that I've had for math teaching in general. Just because it was so cohesive and supportive and ongoing. (Moore, final interview, post-Y5)

In addition, Colleen found the aspects of incorporating student voice into her work to be key in creating the classroom environment she wanted. While not explicitly part of my initial framework, getting feedback from students is a component of assessment of one's learning.

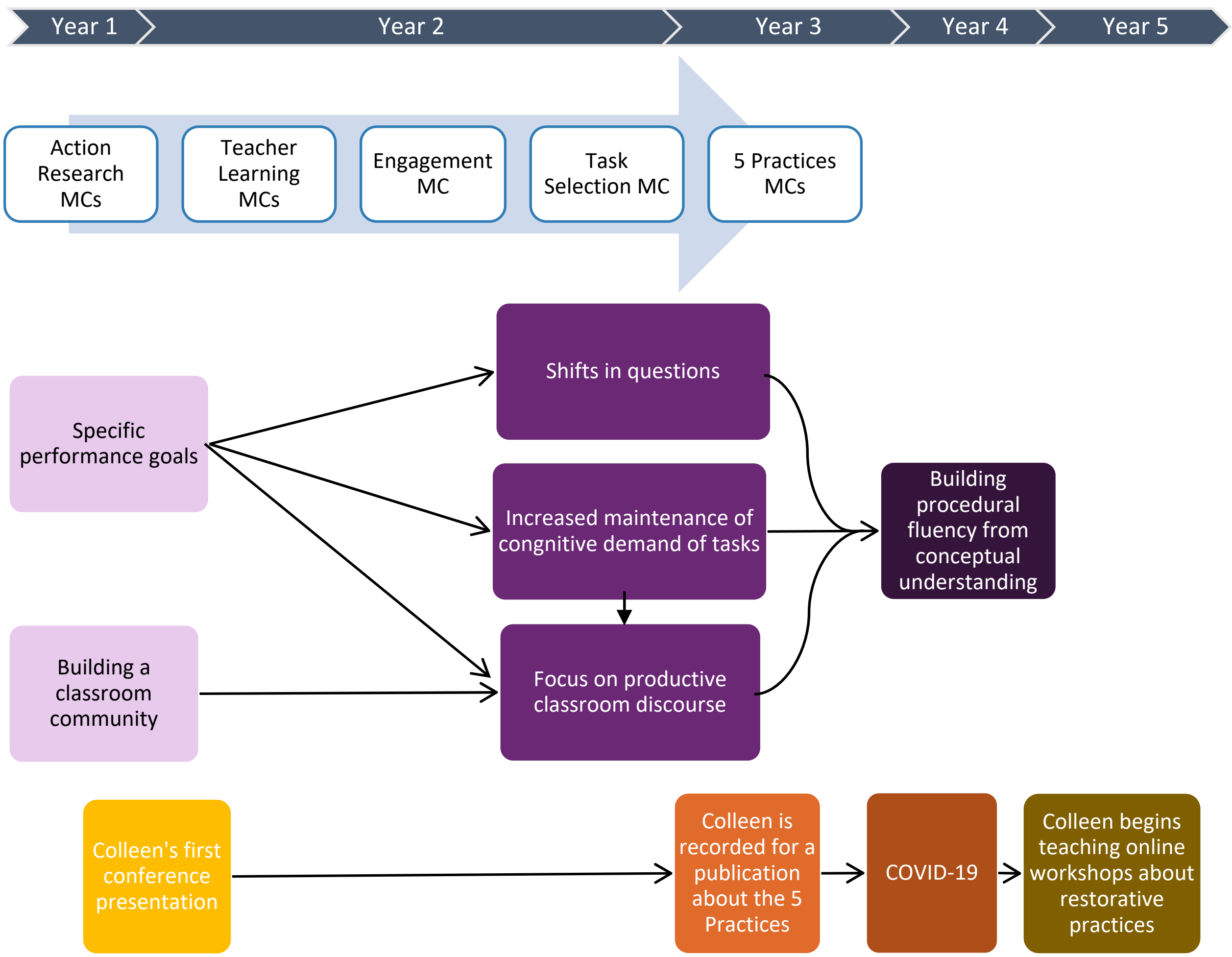
> With student opinions, I definitely value that a lot more than I have before. Just making sure that they feel safe in the classroom and understood and heard. (Moore, final interview, post-Y5)

**Summarizing Colleen's Learning Pathway**

Shifting to Colleen's learning from the perspective of my research questions, how did Colleen's teaching change through her participation in MMTP? I will summarize the answers to my sub-questions one and three below. A summary of Colleen's trajectory is shown in Figure 32.

**Figure 32**

*Trajectory of the Changes in Colleen's Teaching Practices and Leadership, Including Notable Micro-credentials and Events.*




From the beginning, Colleen was interested in classroom discourse and in using restorative practices and circles to build a discourse community. In her first MCs, she had the agency to investigate these areas of interest (teacher-centered). Colleen began with very specific performance goals, and she continued to use performance goals throughout (prior knowledge).

As she refined her use of restorative practices and circles in both the classroom and in her MC work with MMTP (teacher-centered, knowledge), Colleen shifted the questions she was asking to include more open questions and fewer funneling questions. These seemed to be particularly impacted by the task selection MC, the first 5 Practices MC, and the inclusion in the 5 Practices publication (knowledge). Given that one of Colleen's initial goals was to increase the mathematical discourse in her classroom, the combination of specific goals, high-level questions, high-demand tasks, and a community of learners all combined to allow her to work (and currently continue working) toward that goal (teacher, knowledge).

Colleen cited the impact of the MMTP community as influential in her learning (community). Despite frequently being behind in the expected work, Colleen always shared what she was doing in her classroom and looked forward to both getting feedback from and giving feedback to the others in MMTP (community, assessment). She solicited her students' thoughts on the restorative practices in the classroom and used this feedback to make adjustments when necessary (context, assessment).

Because of the encouragement of the community, Colleen felt empowered to share her knowledge of restorative practices with the larger math teacher community (knowledge, community). Although she had hoped to be able to share her knowledge in person, Colleen developed and presented a series of online synchronous workshops on using restorative practices and circles in teaching mathematics (community).

## Cross-case Analysis and Summary of Findings

Examining all four teachers' work, there are some notable commonalities in their learning and in their changes in teaching practices. These include the common phase of their careers, increasing attention to students' conceptual understanding as a way to support procedural fluency, increased enactment of high cognitive demand tasks, and the common changes in their leadership. In the next section, I will connect these threads common to the four teachers.

**Commonalities across All Four Teachers**

All four teachers came to MMTP at very similar points in their careers. They were all experienced teachers, with eight to nine years of experience each. They taught in very different schools and came from different educational backgrounds (both through a traditional teacher certification pathway and teaching as a second career). However, when MMTP started, they seemed to have a similar need for learning. Two were motivated by the opportunity to get paid to learn. All four had the confidence expected of experienced teachers. In their applications, they all shared aspects of teaching that they were interested in investigating: assessment, questioning, discourse, and modeling. All had master's degrees, yet all expressed that their learning needs were not being met in their current positions.

Considering the career phase each was at, they all had a comfortable routine and a solidified teacher identity (Broad & Evans, 2006; Huberman, 1995). Although they were both still relatively young, two were department leaders. The other two were recognized as having expertise and had some informal leadership. They were progressing toward the proverbial professional plateau described by Day and Huberman by not having their professional learning needs met in their current contexts (Day, 1999; Day & Sachs, 2004; Huberman, 1995).

The four teachers' participation in MMTP moved them forward (collectively and individually) in several ways. While the teachers did not earn micro-credentials related to specific mathematics content, they each learned about different topics meant to grow their mathematical knowledge for teaching and pedagogical content knowledge (Ball et al., 2008).

Specifically, all four teachers increased their use of high cognitive demand tasks, including tasks that use mathematical modeling (which can be considered instances of *Doing Mathematics*), which correlates with their learning about selection and enactment of high-demand tasks (Boston, 2013; Boston & Smith, 2009, 2011). For three of the four, the use of these tasks was either driven by or drove changes in the teachers' instructional goals from performance goals to learning goals (Smith et al., 2017, 2020). In addition to incorporating more high-demand mathematics tasks, all four teachers maintained the demand of the tasks, indicating shifts in beliefs about how students learn (Garrison, 2011; Simon et al., 2000; Wilhelm et al., 2017). Notably, for three of the four, these changes have remained after the MMTP project ended.

Along with changes in the selection and maintenance of high-demand tasks, all four teachers shifted instruction to include more attention to conceptual understanding as a precursor to developing procedural fluency (NCTM, 2014). Although student outcomes were beyond the scope of this study, increasing attention to students' conceptual understanding is associated with gains in student achievement (Boaler & Staples, 2008; Hill et al., 2005; Kunter et al., 2013). This is a surprising result, considering that none of the MCs explicitly addressed building procedural fluency from conceptual understanding.

For three teachers, the shift toward teaching for conceptual understanding was supported by questioning practices that reduced funneling toward a specific solution pathway and increased questions that assessed and advanced student thinking (Boston et al., 2017; Herbel-Eisenmann & Breyfogle, 2005). The specific instruction in the 5 Practices for Orchestrating Productive Mathematics Discourse (Smith et al., 2020; Smith & Stein, 2018) and the inclusion of three of the four teachers in a publication on the 5 Practices was followed by changes in teachers' discourse patterns to include more student-student discourse in class discussions and to feature more artifacts of student thinking.

All teachers did not improve every aspect of their teaching practice. To expect them to do so would be unreasonable (Leinwand, 1994). However, that they all moved forward on several aspects of their teaching practice—and that many of those shifts appear to be sustained—seems remarkable. To think about the changes in their practice differently, each of them began MMTP (albeit to different degrees) with a view of students as receptacles of knowledge. All of them ended with a productive view of a classroom as a community of individuals who bring in their own unique combinations of experience and knowledge that can be used as assets to drive the learning of the classroom community. To some degree, each held a traditional school-mathematics perspective, and all moved toward a perception-based perspective of mathematics (Simon et al., 2000). Most had a problem-solving view of mathematics teaching (Beswick, 2012), but also held a calculational orientation toward mathematics and had barriers that prevented them from fully embracing a conceptual orientation (A. G. Thompson et al., 1994). However, when MMTP ended, and based on the changes in their practice that indicate an increased emphasis on conceptual understanding, it appears that they each experienced a shift in orientation from calculational to conceptual.

The themes of leadership were unanticipated by me, and yet it makes sense that they occurred since one of the initial goals of MMTP was to increase teachers' leadership capacity. Beginning in the second year, when teachers were able to choose different learning pathways, one (Colleen) fully embraced the leadership MCs, one (Nolan) completed one of the leadership MCs, and two were not interested in the leadership MCs.

By the fourth year, after the departure of the facilitation team member responsible for the earlier leadership MCs, the leadership MCs shifted in focus from theory and practice to solely on practice. The leadership also broadened in scope to account for leadership development at different levels. Because of the explicit expectation that all teachers would engage in leadership in some way, all of the teachers progressed as leaders by following the path they each chose. Nolan created a coaching protocol. Colleen has become a recognized expert in using restorative practices as a means of teaching mathematics content. Nathan encouraged shared leadership and expertise during COVID-19, leading to greater efficacy in teaching for his department as a whole. Kim's knowledge of educational technology positioned her as a leader in her building in helping teachers transition to online learning, and the connections she made through MMTP led her to collaboratively develop and pilot a mathematics course focused on social justice and environmental science.

Viewing these changes through the lens of the PRIME Leadership Framework (NCSM, 2008), all of these teachers developed leadership of self and leadership of others in teaching and learning. In seeking out opportunities to share knowledge at conferences and through writing, Kim and Colleen also developed their leadership in the extended community in teaching and learning. They also each developed their leadership of self in equity, and made steps toward leadership of others and (in one case) leadership in the extended community.

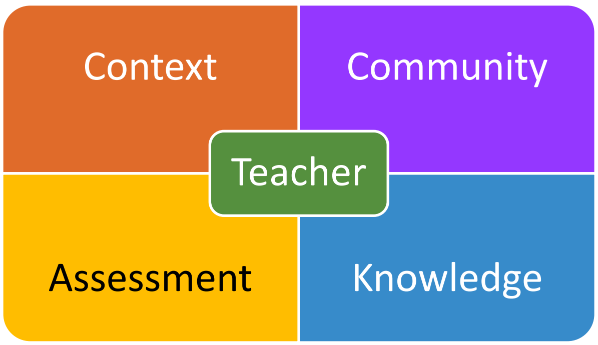
In the next section, I will link the changes in teachers' practices and leadership with my framework for teacher learning and the design of MMTP as a learning experience.

**Linking Teacher Learning with the Design of MMTP**

Turning to my framework for teacher learning (Figure 33), I can link many aspects of teacher learning with the professional learning components of MMTP. I previously shared the theory behind my framework for teacher learning. I will examine each aspect of the framework and its connection to teacher learning in MMTP.

**Figure 33**

*Components of Professional Learning*




***Teacher-Centered Learning***

In MMTP, the teachers were the primary consideration. We wanted to develop the pedagogical content knowledge and leadership capacity of experienced teachers (Loucks-Horsley et al., 2009; Smith, 2001). To that end, the teachers had agency to choose topics to investigate that were of interest to them. In the first year, the MCs were structured to offer everyone a broad view of three of the major components of MMTP: classroom action research, teaching based on the Common Core State Standards for Mathematics, and mathematical modeling. However, within those broad MCs, teachers had the freedom to investigate questions that were relevant to them. We had hoped that this would prove motivating for teachers, and this appears to have been the case for these four teachers.

When introducing the MCs, we always shared the rationales for the MCs with teachers so that they understood the reasons behind what we were asking them to learn (Bandura, 2001; Knowles, 1989). In the case of the two action research MCs, we wanted them to guide them through the process of conducting classroom action research. For the CCSSM and modeling

MCs, we shared the reasons for aligning teaching with the CCSSM and the benefits of using modeling to teach mathematics.

In the second and third years, we sought input from teachers regarding their learning interests. We surveyed teachers to elicit their personal needs and goals, created a small catalog of MCs to choose from for the year, and then developed and deployed the MCs based on what the teachers themselves wanted to learn (Ryan & Deci, 2000; Wlodowski, 2008). Teachers chose their MCs, such as Designing and Supporting Teacher Learning, Task Selection, or Supporting Productive Struggle, based on their learning needs and the needs of their classrooms. Rather than discounting teachers' existing knowledge, at the beginning of each MC, teachers were encouraged to share what they already knew with the community (Farmer et al., 2003; Putnam & Borko, 2000). We used their existing knowledge to move their own understanding forward.

Teachers used the experiences in their classrooms and the discussions with colleagues to construct knowledge and meaning (Kolb, 1984). Because their learning was rooted in their own classrooms, the teachers were able to see the impact of their learning and practices on their students. This was a gradual process for the four teachers. The more they saw the impacts of their learning on their students, the more likely they became to continue the experiential learning cycle of plan → experience → reflect → develop conclusions → formulate new plans—a cycle that mirrors the teacher action research cycle of question → examine literature → plan → implement and collect data → analyze data → share results → refine the question.

***Context-Oriented Learning***

Because the MCs were designed to use teacher action research, the teachers' own contexts were an integral part of their learning. The MCs were meant to directly support the daily work of teaching (Smith, 2001). Situating the learning within their own classrooms meant that the teachers were using their own student work, their own curriculum, and their own plans as means of learning (Loucks-Horsley et al., 2009; Stein et al., 1999). They could make changes to plans and observe the impact on students over long periods of time. They were able to reflect on their learning and consider how to integrate new learning into their practice.

***Community-Oriented Learning***

MMTP was a collaborative community. My research only investigated the learning of four participants, but 18 other LPS math and science teachers and seven facilitators were also part of this community, which formed a community of practice (Lave & Wenger, 1991). The consistency of the community meant that the participants came to trust each other and were able to open up without judgment. Although they did not begin MMTP with a shared vision, the four teachers came to a shared vision of mathematics teaching and learning through their collaboration and conversation (Sowder, 2007), with their vision being shaped through their experiences with MMTP.

On more than one occasion, the four teachers (individually) experienced cognitive dissonance around their learning. For Nathan, it was the conflict between the restricted time he had to teach a large amount of content and his emerging conception-based perspective of mathematics. He also experienced conflict between his desire for his students to be individually capable of solving mathematics problems and his knowledge that students learn collaboratively. For Kim, there was dissonance between her desire to use high-demand tasks and her fear that her students would not be able to complete the tasks. For Nolan, it was the conflict between feeling like he needed to communicate mathematics to his students in order for them to learn to students communicating mathematics to each other. Despite the internal conflicts, each teacher was also able to work their own dissonance through conversations with the group and by getting feedback from other MMTP members. None of them avoided the dissonance; each tried their best to resolve it.

***Knowledge-Oriented Learning***

The MCs the four teachers pursued focused on developing their mathematical knowledge for teaching and (for two teachers) leadership knowledge. MCs that focused on engagement and motivation, task selection, and the 5 Practices were meant to improve teachers' pedagogical content knowledge. MCs that focused on mathematical modeling and on using classroom technology to teach math were focused on their specialized content knowledge of mathematics. All of these included examinations of their own students' work to assess the impact of their learning on their students' conceptual understanding (Smith, 2001).

For these four teachers, there were instances of transformative learning (Smith, 2001; C. L. Thompson & Zeuli, 1999). Nathan's understanding of mathematical modeling was transformed from being an addition to existing content to becoming the means for teaching content. Colleen's understanding of restorative practices transformed from being a means to build community in her class to a means of teaching math content. Nolan's understanding of high-demand tasks allowed him to transform his thinking about what it meant for students to be successful.

***Assessment-Oriented Learning***

Each of the teachers engaged in the action research cycle of question → examine literature → plan → implement and collect data → analyze data → share results → refine the question. Inherent in this design is the need to assess the impact of the plan on the students. To that end, teachers frequently assessed their students' understanding in multiple ways, both formally and informally, since the ultimate end of their participation was to improve student outcomes. These assessments of understanding provided the teachers with feedback about the impacts of their plans, which in turn allowed them to self-assess and revise when necessary.

The MCs were also developed to require some consideration of student voice. For these four teachers, this often meant surveying their students. Kim and Nathan both noted how much they had come to value hearing from their students and getting feedback from their students.

The teachers also received feedback from the MMTP facilitators and other teachers. The whole group met every two months or so, sometimes more frequently. Teachers would get feedback from each other on their action-research-in-progress from both peers and facilitators. Facilitators would assess the MCs, and teachers would receive feedback in that way as well. Sometimes, the teachers would be required to revise their MC submissions, and so the action → assessment → feedback loop would play out several times.

The MMTP facilitators were also transparent about engaging in their own action → assessment → feedback loop regarding the project design and MCs. When an aspect of MMTP was problematic, the facilitation team would reassess and formulate a new plan, such as when the timing of the meeting schedule in the first year proved to be overwhelming. Other times, when aspects of MCs were not progressing as intended, the facilitation team would adjust the expectations for the MC and split it into two parts, such as for the first Action Research MC and the Designing Teacher Learning MCs.

This case study examined four teachers' learning over the course of their five years of participation with MMTP. Individually and collectively, the teachers experienced changes in their teaching practice and in their leadership. Their changes in practice followed four pathways: changing notions of student success, building trust in students to take ownership over their learning, building a community of learners, and changing beliefs about students and how they learn. The changes in leadership followed four pathways: establishing credibility, sharing knowledge with the larger community, gaining confidence as an expert, and shared leadership and collective vision. Collectively, the teachers increased their attention to students' conceptual understanding following learning about selection and enactment of high-demand tasks and discourse practices. I linked the individual and collective changes in teachers' practice with my framework for teacher learning.

## Chapter 6: Discussion and Conclusions

The purpose of this study was to uncover changes in the teaching practices of four mid-career secondary mathematics teachers as a result of their participation in the Midwest Master Teacher Partnership, a five-year practice-based professional development project that was a collaboration between an urban university and a large urban school district. The study attempts to address the learning needs of the mid-career teachers that are not being met due to a mismatch between existing school-based professional development that is offered. Teachers at different stages of their careers have different learning needs and school-based learning experiences are often not differentiated to account for teachers at different phases of their career.

I developed a framework for teacher learning to explore elements of professional development that I hypothesized would be beneficial for supporting learning for mid-career teachers. This framework puts the teacher at the center of the learning experiences. Considering the teacher first, learning experiences should also consider teachers' context and classrooms. They should attend to teachers' learning needs and include cohesive work that develops relevant aspects of teachers' mathematical knowledge for teaching over long periods of time. Teacher learning should incorporate a community of teacher-learners that engage in a collective construction of knowledge. Teachers should have multiple opportunities for assessment, including assessing the impact of their learning on student outcomes and getting feedback on their learning.

The heart of learning in MMTP was teacher action research, a cycle where teachers formulate a question related to their practice, examine existing literature, create a plan of action, implement the plan, collect and analyze data, share results with the community, revise their questions, and repeat the cycle. To support teacher action research, the MMTP facilitation team created micro-credentials that first taught teachers how to conduct action research and then focused on aspects of mathematical knowledge for teaching and pedagogical content knowledge. I examined the structure of MMTP based on my framework for teacher learning.

This case study included a convenience sample of four mid-career secondary mathematics teachers. Each had been teaching for eight to nine years, and each taught at four different schools in the same large, urban school district. I coded material from each of the teachers, including application materials, all micro-credential work, classroom video, interviews, lesson documents, and written and video reflections completed by the teachers. These materials were coded using values coding, under the theory that what they chose to write about would reflect what they valued. The first-cycle codes were then examined across time to elicit changes in the teachers' practices and possible changes in beliefs over time.

## Discussion of the Findings

To answer the question, "How have teachers' practices changed through their participation in a practice-based professional development project?", the themes that emerged for each teachers' individual changes in practice were changing notions of student success, building trust in students to take ownership over their learning, building a community of learners, and changing beliefs about students and how they learn. In addition, I noticed themes relating to teachers' leadership, which I had not anticipated. These themes were establishing credibility, sharing knowledge with the larger community, gaining confidence as an expert, and shared leadership and collective vision. In their leadership, the teachers followed different paths. Two were eager to share what they learned with the larger community through presentations and writing, and one is becoming a known expert in using restorative practices and circles to teach math content. The other two saw changes to their leadership within their school. One developed a coaching protocol for the members of his department. The other helped his department develop their shared vision for online learning and encouraged the teachers to develop expertise that they could share with the larger department, thereby cultivating a system of shared leadership and expertise that helped the math teachers to successfully transition to online learning during the COVID-19 pandemic.

Turning to the sub-questions, “What trajectories did teachers’ changes in practice take? How did the nature of their participation in MMTP impact teachers’ pedagogical practice?”, as a group, at the end of MMTP, teachers enacted and maintained more high-demand tasks than at the beginning of MMTP. All teachers were active MMTP participants, and all but one completed four teacher action research projects each school year. All shared their results with the MMTP cohort and facilitators and gave feedback on their colleagues’ work. All four teachers earned micro-credentials related to the 5 Practices for Orchestrating Productive Mathematics Discourse, and all experienced some changes in their classroom discourse. At the end of MMTP, all teachers were supporting developing students’ conceptual understanding as a precursor to procedural fluency. To me, this last result was unexpected. Each of the four teachers earned micro-credentials related to the 5 Practices, mathematical modeling, selection and enactment of tasks. Three of the teachers completed micro-credentials on supporting students’ productive struggle, using technology to teach mathematics, and an additional examination of mathematical modeling. Although each of these incorporated discussions of developing students’ conceptual understanding, no micro-credential explicitly addressed developing procedural fluency from conceptual understanding.

Turning to my second sub-question, “How did teachers’ mathematical knowledge for teaching and beliefs about teaching mathematics evolve over the course of MMTP?”, I was able to infer changes in beliefs by examining the teachers' changes in practices. The most notable change in beliefs occurred with Nathan, whose practice shifted from using predominantly lecture and practice to develop students' procedural knowledge to using high-demand tasks and class discussion to develop students' conceptual understanding. He demonstrated a change in the language he used to discuss students, from deficit-based language that used labels of "high" and "low" for students to using asset framing when he talked about students. This indicates a shift in Nathan's beliefs about how students learn and what they are capable of achieving.

Kim also demonstrated changes in her teaching that point to changes in her beliefs. Initially, Kim was hesitant to use high-demand tasks and focused on helping her students develop their procedural knowledge, suggesting a belief that students would have difficulty working with high-demand tasks without previous instruction. As her learning with MMTP progressed, Kim began releasing the responsibility for learning onto the students. She held them to higher expectations and had them struggle with more cognitively demanding tasks. Kim used her students' natural curiosity and creativity as a catalyst for learning.

My final sub-questions, "What pathways did teachers take in their professional learning with MMTP? What factors shaped their movement on the pathways? How did the nature of their participation in MMTP impact teachers' attitudes toward professional development and their thoughts about future engagement in professional learning?", were answered through the narratives in the previous chapter. Although each took similar pathways through the micro-credentials offered by MMTP, the directions they chose to pursue to investigate the topics varied. Colleen was motivated by her desire to build a discourse community in her classroom through the use of restorative practices, and thus many of her MCs incorporated restorative practices and circles. Kim wanted to improve her questioning, and so she integrated analyses of questioning into some of her MCs. Nathan became quite interested in mathematical modeling, and used modeling tasks as the basis for several of his action research plans.

Given that this is a case study, I am led to the question: What is this entire study a case of? In my view, this study is a case of taking the needs of experienced teachers into consideration when planning and implementing professional development. It is a case of four experienced teachers who had the potential to become cynical about professional learning experiencing a revitalization (of sorts) in the middle years of their careers.

It is a case of seeing changes in teacher practice when cohesive learning is sustained over a long period of time. MMTP was designed using principles of practice-based professional development (Smith, 2001) and teacher action research (Pine, 2009) to drive transformative teacher learning. These are not new ideas. The mathematics education and mathematics teacher education communities have known for decades that there are methods for teaching teachers that are effective for creating changes in teachers' practices. This is a case of learning being facilitated by taking teachers' existing knowledge, teachers' contexts, teachers' community, assessments of teachers' learning, and the teachers themselves into consideration when designing professional development.

Finally, this is a case of what happens when teachers are allowed to have agency over their own learning and the impact that can have on the teachers' beliefs about teaching and learning. There were unanticipated effects on both teachers' practices and their leadership that indicated changes in their beliefs. When the teachers learned about the importance of writing clear mathematical goals that support learning, the importance of using and maintaining high-demand mathematical tasks, and ways to conduct effective classroom discourse, each teacher showed changes in their practice that gave evidence of a change in beliefs that moved away from lecture and telling and toward developing students' conceptual understanding before teaching procedures.

## Limitations

Parts of this study, notably the final year and three months, took place during the COVID-19 pandemic. Observations of teaching were incomplete in the fourth year and took place using a different medium than was typical. Consequently, the teachers' practices during the fifth year may not have accurately reflected the practices the teachers may have used had the 2020-2021 school year been a regular school year. Attempts were made to mitigate this drastic change in teaching by obtaining permission to observe classes in the following year, but students, teachers, and guests were still subject to social distancing expectations, which may have continued to impact how teachers conducted their classes. Likewise, due to COVID-19, the final interviews were conducted over Zoom rather than in-person. The use of remote interviewing may have impacted communications between the interviewer and the participant.

The four teachers in this case study are all white, middle-class, native English speakers with master's degrees. They had all been teaching for eight or nine years at the beginning of MMTP. Consequently, the data is not a representative sample of the district's teachers. Additionally, as the researcher, I had close working relationships with all four participant teachers. There exists a possibility of bias in my analysis and writing because of these close relationships. I attempted to maintain awareness of potential discomfort as I performed my analyses and crafted the narratives, but because I employed member-checking, there is a possibility of unconscious bias on my part.

This study does not directly or quantitatively measure student learning outcomes or teacher knowledge. These quantitative measurements are beyond the scope of the study.

## Future Research

In this study, I explored the impacts of teacher learning on changes in teachers' practice. One unanticipated result was that teachers shifted their emphasis from teaching procedures to building students' conceptual understanding as a precursor to developing procedural fluency. This was unanticipated because it was not a shift that was directly addressed by any of the MMTP MCs. I am left wondering about the mechanism that supported this shift. It is possible that this shift emerged from changes in teachers' beliefs from a calculational orientation to a conceptual orientation, or that it emerged from an increased use of high cognitive demand tasks, or it may have emerged from another factor that is not considered here. Additional insights could be gained by examining mechanisms that support teachers in shifting their emphasis from teaching procedures to building students' conceptual understanding as a precursor to developing procedural fluency.

This study did not directly address teachers' mathematical knowledge. While mathematics content was an implied part of the learning experiences and mathematical tasks were used to drive pedagogical learning, I wonder about the potential impact on teachers of attending to specific areas of mathematics content, such as exponential functions or probability.

Further research would be necessary to assess the impact of micro-credentialing on teachers' practices. The MCs offered through MMTP focused on a specific subset of learning experiences designed to grow teachers' mathematical knowledge for teaching within a community of learners. As the micro-credential ecosystem grows and more opportunities are emerging for teachers to earn MCs, teachers have the opportunity to conduct teacher action research and earn MCs without the support of a community. What is the impact on teachers' learning of earning MCs within a community of learners versus without the support of a community? Are there ways for MC issuers to support learning within a community?

Additionally, MMTP was unique in that the MCs were a cohesive collection of learning experiences over time. While some MCs are grouped in "stacks" of MCs with like content or learning goals, most MCs can be earned one at a time. As such, they then create short-term learning opportunities. What is the long-term effect on teachers' practices of these individual MCs?

## Recommendations

Teachers do not work in a vacuum. Likewise, their learning should not take place in a vacuum. Like our students, teachers are complex individuals with motivations and needs of our own. These motivations and needs must be considered by those who wish to support teacher learning.

Experienced secondary mathematics teachers must be supported in their professional learning. To do so, those who provide teacher learning opportunities must center the experienced teachers themselves. For mid-career mathematics teachers' MKT to grow productively, providers must identify teachers' existing knowledge and assets, and use those to move teachers forward. Providers must use teachers' own learning needs. If we want to impact teachers' practice, their learning must be transformative—it needs to change practice rather than add to their existing practice. And the learning experiences must give teachers reasons to deeply examine their existing beliefs and practices and time so that teachers can productively work through cognitive dissonance.

This type of professional learning does not have to be on the same scale as MMTP. Schools and districts can foster long-term, coherent professional learning opportunities for experienced, mid-career teachers that incorporate learning communities, teacher action research, and micro-credentials at low or no cost. A key component, however, would be that the teachers have the time and agency to determine their learning pathways and to investigate areas of practice that are of interest to them. In some cases, this would mean that school and district administrators would have to have trust in experienced teachers to be in control of their own learning, in much the same way we as teachers place trust in our students to take responsibility for their learning.

In addition to being supported by school and district experts, universities are often eager to form partnerships with local schools and districts. There is a degree of expertise that university faculty can offer schools and districts. If teacher learning experiences are long-term, and if experienced teachers maintain agency over the direction of their learning, the university faculty can become a trusted member of a teacher learning community. However, care must be taken to ensure that trust is built so that the university faculty are not viewed as outsiders telling teachers how to do their job.

MMTP was a National Science Foundation-funded partnership between a research university and a large, urban school district. As such, the participating teachers had the luxury of being paid for their time spent engaging in professional learning, a luxury that is often afforded to other professions. Being that teaching is a publicly funded profession, policymakers need to support experienced teachers in their professional learning endeavors. This could be through better funding of public schools to pay teachers for their time spent in professional learning and through increased support for district-university partnerships. As professionals, teachers deserve the same considerations and benefits provided to those in other, non-publicly funded professions.

## Concluding Remarks

MMTP provided the opportunity for a group of teachers from different schools within the same district to come together for five years and learn as a community. It supported teachers as individuals as they engaged in learning. Over this long period of time, some individual practices began shifting toward more productive practices. These changes were supported by the MMTP community, and some have been sustained since MMTP ended. The leadership that the teachers developed aided them as they navigated the uncertainties of teaching during COVID-19 and has had impacts beyond their own schools as they reach out to the larger math teaching community.

My hope is that my findings will support the assertion that teacher learning for experienced, mid-career teachers must consider the teacher and their needs, experiences, motivations, context, community, knowledge, and opportunities for feedback as a complex whole and not as individual parts. Teachers are not a monolithic entity. We know what works for supporting teachers as they move from experienced to expert, and it is vitally important to keep experienced teachers in the profession. Experienced teachers are one of our greatest resources for training the next generations of teachers. They are one of our greatest resources for ensuring ALL students have access to high-quality mathematics learning experiences.

# REFERENCES


Acree, L. (2016). *Seven lessons learned from implementing micro-credentials*. https://www.fi.ncsu.edu/wp-content/uploads/2016/02/microcredentials.pdf

Adamson, F., & Darling-Hammond, L. (2012). Funding disparities and the inequitable distribution of teachers: Evaluating sources and solutions. *Education Policy Analysis Archives*, *20*(37). https://doi.org/10.14507/epaa.v20n37.2012

Aguirre, J., Mayfield-Ingram, K., & Martin, D. B. (2013). *The impact of identity in K-8 mathematics: Rethinking equity-based practices*. National Council of Teachers of Mathematics.

Alfinio, F. (2007). Examining disparities in mathematics education: Achievement gap or opportunity gap? *The High School Journal*, *91*(1), 29–42.

Anyon, J. (1981). Social class and school knowledge. *Curriculum Inquiry*, *11*(1), 3–42.

Arbaugh, F., & Brown, C. A. (2004). What makes a mathematical task worthwhile? Designing a learning tool for high school mathematics teachers. In R. N. Rubenstein & G. W. Bright (Eds.), *Perspectives on the teaching of mathematics: Sixty-sixth yearbook* (pp. 27–41). National Council of Teachers of Mathematics.

Arbaugh, F., & Brown, C. A. (2005). Analyzing mathematical tasks: A catalyst for change? *Journal of Mathematics Teacher Education*, *8*(6), 499–536. https://doi.org/10.1007/s10857-006-6585-3

Archer, J., Kerr, K. A., & Pianta, R. C. (2014). Why measure effective teaching? In T. J. Kane, K. A. Kerr, & R. C. Pianta (Eds.), *Designing teacher evaluation systems: New guidance from the Measures of Effective Teaching project* (pp. 1–5). Jossey-Bass.

Association of Mathematics Teacher Educators. (2017). *Standards for preparing teachers of* *mathematics*. https://amte.net/standards

Ball, D. L., & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In G. Sykes & L. Darling-Hammond (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 3–32). Jossey Bass.

Ball, D. L., Thames, M. H., & Phelps, G. C. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407. https://doi.org/10.1177/0022487108324554

Ball, D. L., & Wilson, S. M. (1990). Knowing the subject and learning to teach it: Examining assumptions about becoming a mathematics teacher. *Annual Meeting of the American Educational Research Association*. https://www.researchgate.net/profile/G_Mcdiarmid/publication/265065132_KNOWING_THE_SUBJECT_AND_LEARNING_TO_TEACH_IT_EXAMINING_ASSUMPTIONS_ABOUT_BECOMING_A_MATHEMATICS_TEACHER_1/links/54ad59af0cf24aca1c6f1d69/KNOWING-THE-SUBJECT-AND-LEARNING-TO-TEACH-IT-EX

Bandura, A. (1971). *Social learning theory*. General Learning Press.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology*, *52*, 1–26.

Banilower, E. R., Boyd, S. E., Pasley, J. D., & Weiss, I. R. (2006). *Lessons from a decade of mathematics and science reform: A capstone report for the local systemic change through teacher enhancement initiative*.

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). *Report of the 2018 NSSME+* (Issue December). Horizon Research, Inc.

http://horizon-research.com/NSSME/2018-nssme/research-products/reports/technical-report

Baron, E. J. (2018). The effect of teachers' unions on student achievement in the short run: Evidence from Wisconsin's Act 10. *Economics of Education Review*, *67*(September), 40–57. https://doi.org/10.1016/j.econedurev.2018.09.003

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., Klusmann, U., Krauss, S., Neubrand, M., & Tsai, Y.-M. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal*, *47*(1), 133–180. https://doi.org/10.3102/0002831209345157

Bell, C. A., Wilson, S. M., Higgins, T., & McCoach, D. B. (2010). Measuring the effects of professional development on teacher knowledge: The case of developing mathematical ideas. *Journal for Research in Mathematics Education*, *41*(5), 479–512. https://doi.org/10.5951/jresematheduc.41.5.0479

Berg, C. A. (2019). *SeeMeTeach® teacher observation tool*. World Class Teaching LLC. https://www.seemeteach.com/

Berger, R. (2015). Now I see it, now I don't: Researcher's position and reflexivity in qualitative research. *Qualitative Research*, *15*(2), 219–234. https://doi.org/10.1177/1468794112468475

Berry, B., Airhart, K. M., & Byrd, P. A. (2016). Microcredentials: Teacher learning transformed. *Phi Delta Kappan*, *98*(3), 34–40. https://doi.org/doi.org/10.1177/0031721716677260

Beswick, K. (2012). Teachers' beliefs about school mathematics and mathematicians' mathematics and their relationship to practice. *Educational Studies in Mathematics*, *79*, 127–147. https://doi.org/10.1007/s10649-011-9333-2

Blank, R. K., & de las Alas, N. (2009). *Effects of teacher professional development on gains in student achievement: How meta analysis provides scientific evidence useful to education* *leaders* (Issue June).

Boaler, J., & Staples, M. (2008). Creating mathematical futures through an equitable teaching approach: The case of railside school. *Teachers College Record*, *110*(3), 608–645.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, *33*(8), 3–15. https://doi.org/10.3102/0013189X033008003

Boston, M. D. (2006). *Developing secondary mathematics teachers' knowledge and capacity to implement instructional tasks with high levels of cognitive demand*.

Boston, M. D. (2012). *Instructional quality assessment classroom observation tool*.

Boston, M. D. (2013). Connecting changes in secondary mathematics teachers' knowledge to their experiences in a professional development workshop. *Journal of Mathematics Teacher Education*, *16*(1), 7–31. https://doi.org/10.1007/s10857-012-9211-6

Boston, M. D., Dillon, F., Smith, M. S., & Miller, S. (2017). *Taking action: Implementing effective mathematics teaching practices*. National Council of Teachers of Mathematics.

Boston, M. D., & Smith, M. S. (2009). Transforming secondary mathematics teaching: Increasing the cognitive demands of instructional tasks used in teachers' classrooms. *Journal for Research in Mathematics Education*, *40*(2), 119–156. https://doi.org/10.2307/40539329

Boston, M. D., & Smith, M. S. (2011). A "task-centric approach" to professional development: Enhancing and sustaining mathematics teachers' ability to implement cognitively challenging mathematical tasks. *ZDM - International Journal on Mathematics Education*, *43*(6), 965–977. https://doi.org/10.1007/s11858-011-0353-2

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. National Academies Press.

Brinkmann, S., & Kvale, S. (2015). *InterViews: Learning the craft of qualitative research interviewing*. SAGE Publications.

Broad, K., & Evans, M. (2006). *A review of literature on professional development content and delivery modes for experienced teachers*. https://www.oise.utoronto.ca/guestid/ite/UserFiles/File/AReviewofLiteratureonPD.pdf

Brown, M. W. (2009). The teacher-tool relationship. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), *Mathematics teachers at work: Connecting curiculum materials and classroom instruction* (pp. 17–36). Routledge.

Calderhead, J. (1981). Stimulated recall: A method for research on teaching. *British Journal of Educational Psychology*, *51*(2), 211–217. https://doi.org/10.1111/j.2044-8279.1981.tb02474.x

Campbell, P. F., Nishio, M., Smith, T. M., Clark, L. M., Conant, D. L., Rust, A. H., DePiper, J. N., Frank, T. J., Griffin, M. G., & Choi, Y. (2014). The relationship between teachers' mathematical content and pedagogical knowledge, teachers' perceptions, and student achievement. *Journal for Research in Mathematics Education*, *45*(4), 419–459. https://doi.org/10.5951/jresematheduc.45.4.0419

Candela, A. G. (2016). Mathematics teachers' perspectives on factors affecting the implementation of high cognitive demand tasks. In M. B. Wood, E. E. Turner, M. Civil, & J. A. Eli (Eds.), *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 315–322). The University of Arizona. http://www.pmena.org/pmenaproceedings/PMENA 38 2016 Proceedings.pdf

Capobianco, B. M., & Feldman, A. (2006). Promoting quality for teacher action research:

Lessons learned from science teachers' action research. *Educational Action Research*, *14*(4), 497–512. https://doi.org/10.1080/09650790600975668

Carlsen, W. S. (1999). Domains of teacher knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 133–144). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47217-1_5

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C.-P., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. *American Educational Research Journal*, *26*(4), 499–531. https://doi.org/10.3102/00028312026004499

Cartier, J., Smith, M. S., Stein, M. K., & Ross, D. (2013). *5 practices for orchestrating task-based discussions in science*. National Council of Teachers of Mathematics.

Carver-Thomas, D., & Darling-Hammond, L. (2017). *Teacher turnover: Why it matters and what we can do about it*. https://doi.org/10.1093/intqhc/mzg078

Castro Superfine, A., & Li, W. (2014). Exploring the mathematical knowledge needed for teaching teachers. *Journal of Teacher Education*, *65*(4), 303–314. https://doi.org/10.1177/0022487114534265

Cator, K., Schneider, C., & Vander Ark, T. (2014). *Preparing teachers for deeper learning: Competency-based teacher preparation and development* (Issue April). https://www.gettingsmart.com/publication/preparing-teachers-deeper-learning/

Center for Teaching Quality, & Digital Promise. (2017). *Continuing the educator micro-credential movement* (Issue October). https://digitalpromise.org/wp-content/uploads/2016/03/October2017_MCs_FINAL3.pdf

Chapman, O. (2002). Belief structure and inservice high school mathematics teacher growth. In G. C. Leder, E. Pehkonen, & G. Torner (Eds.), *Beliefs: A hidden variable in mathematics education?* (pp. 177–193). Kluwer Academic Publishers.

Charalambous, C. Y. (2010). Mathematical knowledge for teaching and task unfolding: An exploratory study. *Elementary School Journal*, *110*(3), 247–278. https://doi.org/10.1086/648978

Clark, C. M., & Lampert, M. (1986). Study of teacher thinking: Implications for teacher education. *Journal of Teacher Education*, *37*(5), 27–31.

Clark, C. M., & Peterson, P. L. (1976). *Teacher stimulated recall of interactive decisions*.

Clark, C. M., & Peterson, P. L. (1984). *Teachers' thought processes*.

Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Education Evaluation and Policy Analysis*, *12*(3), 311–329.

Consortium for Mathematics and Its Applications, & Society for Industrial and Applied Mathematics. (2016). *GAIMME: Guidelines for assessment & instruction in mathematical modeling education*. http://www.siam.org/reports/gaimme.php

Copur-Gencturk, Y. (2015). The effects of changes in mathematical knowledge on teaching: A longitudinal study of teachers' knowledge and instruction. *Journal for Research in Mathematics Education*, *46*(3), 280. https://doi.org/10.5951/jresematheduc.46.3.0280

Copur-Gencturk, Y., & Papakonstantinou, A. (2016). Sustainable changes in teacher practices: a longitudinal analysis of the classroom practices of high school mathematics teachers. *Journal of Mathematics Teacher Education*, *19*(6), 575–594. https://doi.org/10.1007/s10857-015-9310-2

Corbin, J., & Strauss, A. (2015). *The basics of qualitative research: Techniques and procedures* *for developing grounded theory*. SAGE Publications.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications.

Cross, D. I. (2009). Alignment, cohesion, and change: Examining mathematics teachers' belief structures and their influence on instructional practices. *Journal of Mathematics Teacher Education*, *12*(5), 325–346. https://doi.org/10.1007/s10857-009-9120-5

Dall'Alba, G., & Sandberg, J. (2006). Unveiling professional development: A critical review of stage models. *Review of Educational Research*, *76*(3), 383–412. https://doi.org/10.3102/00346543076003383

Dapaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education*, *34*, 12–25. https://doi.org/10.1016/j.tate.2013.03.001

Darling-Hammond, L. (1998). Unequal opportunities. *The Brookings Review*, *16*(2), 28–32.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Education Policy Analysis Archives*, *8*(1). https://epaa.asu.edu/ojs/article/view/392

Day, C. (1999). *Developing teachers: The challenges of lifelong learning*. Falmer Press.

Day, C., & Sachs, J. (2004). Professionalism, performativity and empowerment: Discourses in the politics, policies and purposes of continuing professional development. In C. Day & J. Sachs (Eds.), *International handbook of the continuing professional development of* *teachers* (pp. 3–32). Open University Press.

Denzin, N. K., & Lincoln, Y. S. (2011). *The SAGE handbook of qualitative research* (3rd ed.). SAGE Publications.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Desimone, L. M., & Garet, M. S. (2015). Best practices in teachers' professional development in the United States. *Psychology, Society and Education*, *7*(3), 252–263. https://doi.org/10.25115/psye.v7i3.515

Desmos. (2021). *Avi and Benita's Repair Shop*. Desmos.Com. https://teacher.desmos.com/activitybuilder/custom/56c7457e11c7724106e683b1?collections=featured-collections%2C5da6462c8b305273be677729

Dewey, J. (1902). *The child and the curriculum*. The University of Chicago Press.

Digital Promise. (2020a). *Educator micro-credentials*. https://digitalpromise.org/initiative/educator-micro-credentials/

Digital Promise. (2020b). *Explore micro-credentials*. https://microcredentials.digitalpromise.org/explore

Dobie, T. E., & Anderson, E. R. (2021). Noticing and wondering to guide professional conversations. *Mathematics Teacher Learning & Teaching PK-12*, *114*(2), 94–102. https://doi.org/10.5951/MTLT.2020.0210

Doerr, H. M., Goldsmith, L. T., & Lewis, C. C. (2010). *Professional development research brief: Mathematics professional development*.

Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. *Educational Psychologist*, *23*(2), 167–180. https://doi.org/10.1207/s15326985ep2302_6

EdReports. (2021). *Reports center*. https://www.edreports.org/reports?s=math

Edwards, T. G., & Hensien, S. M. (1999). Changing instructional practice through action research. *Journal of Mathematics Teacher Education*, *2*(2), 187–206. https://doi.org/10.1023/A:1009951121246

Elliott, J. (2009). Building educational theory through action research. In S. E. Noffke & B. Somekh (Eds.), *The Sage handbook of educational action research* (pp. 28–38). SAGE Publications.

Emden, C. (2016). *For white folks who teach in the hood... and the rest of y'all too: Reality pedagogy and urban education*. Beacon Press.

Ernest, P. (1989). *The impact of beliefs on the teaching mathematics*. Mathematics Teaching: The State of the Art. http://webdoc.sub.gwdg.de/edoc/e/pome/impact.htm

Farmer, J., Gerretson, H., & Lassak, M. (2003). What teachers take from professional development: Cases and implications. *Journal of Mathematics Teacher Education*, *6*(4), 331–360. https://doi.org/10.1023/A:1026318709074

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). *A longitudinal study of learning to use children's thinking in mathematics instruction*. *27*(4), 403–434.

Fennema, E., & Franke, M. L. (1992). Teachers' knowledge and its impact. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 147–164). MacMillan Publishing Company.

Fenwick, T. J. (2001). *Experiential learning: A theoretical critique from five perspectives*.

Freire, P. (2000). *Pedagogy of the oppressed*. Bloomsbury Academic.

Fuson, K. C., Kalchman, M., & Bransford, J. D. (2005). Mathematical understanding: An introduction. In M. S. Donovan & J. D. Bransford (Eds.), *How students learn: History, mathematics, and science in the classroom* (pp. 217–256). National Academies Press.

Garet, M. S., Porter, A. C., Desimone, L. M., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945. https://doi.org/10.3102/00028312038004915

Garrett Holbert, R. M. (2015). Classroom community and possible selves: implications for midcareer teacher seminars. *Teachers and Teaching*, *21*(1), 44–60. https://doi.org/10.1080/13540602.2014.928124

Garrison, A. L. (2011). *The cognitive demand of mathematical tasks: Investigating links to teacher characteristics and contextual factors*. https://peabody.vanderbilt.edu/docs/pdf/tl/Garrison_SREE_2011.pdf

Gersten, R., Taylor, M. J., Keys, T. D., Rolfhus, E., & Newman-Gonchar, R. (2014). *Summary of research on the effectiveness of math professional development approaches (REL 2014-010)*. http://ies.ed.gov/ncee/edlabs

Gess-Newsome, J., & Lederman, N. G. (1999). *Examining pedagogical content knowledge*. Kluwer Academic Publishers.

Gibson, D., Ostashewski, N., Flintoff, K., Grant, S., & Knight, E. (2015). Digital badges in education. *Education and Information Technologies*, *20*(2), 403–410. https://doi.org/10.1007/s10639-013-9291-7

Gleason, J., Livers, S. D., & Zelkowski, J. (2015). *Mathematics classroom observation protocol* *for practices: Descriptors manual*. http://jgleason.people.ua.edu/mcop2.html

Goldhaber, D., Lavery, L., & Theobald, R. (2015). Uneven playing field? Assessing the teacher quality gap between advantaged and disadvantaged students. *Educational Researcher*, *44*(5), 293–307. https://doi.org/10.3102/0013189X15592622

Gray, D. E. (2014). *Doing research in the real world* (3rd Editio). SAGE Publications.

Gray, L., & Taie, S. (2015). *Public school teacher attrition and mobility in the first five years: Results from the first through fifth waves of the 2007-08 beginning teacher longitudinal study (NCES 2015-337)*. https://nces.ed.gov/pubs2011/2011318.pdf

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Press.

Gutiérrez, R. (2018). Political conocimiento for teaching mathematics. In S. E. Kastberg, A. M. Tyminski, A. E. Lischka, & W. B. Sanchez (Eds.), *Building support for scholarly practices in mathematics methods* (pp. 11–37). Information Age Publishing.

Hammond, Z. (2015). *Culturally responsive teaching and the brain*. Corwin.

Hancock, D. R., & Algozzine, B. (2017). *Doing case study research: A practical guide for beginning researchers*. Teachers College Press.

Hargreaves, A. (2000). Four ages of professionalism and professional learning. *Teachers and Teaching*, *6*(2), 151–182. https://doi.org/10.1080/713698714

Harris, L. M., & Bain, R. B. (2010). Pedagogical content knowledge for world history teachers: What is it? How might prospective teachers develop it? *The Social Studies*, *102*(1), 9–17. https://doi.org/10.1080/00377996.2011.532724

Hawley, W. D., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning* *profession: Handbook of policy and practice* (pp. 127–150). Jossey Bass.

Henningsen, M. A., & Stein, M. K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematical thinking and reasoning. *Journal for Research in Mathematics Education*, *28*(5), 524. https://doi.org/10.2307/749690

Herbel-Eisenmann, B., & Breyfogle, M. L. (2005). Questioning our patterns of questioning. *Mathematics Teaching in the Middle School*, *10*(9), 484–489.

Hiebert, J., Morris, A. K., Berk, D., & Jansen, A. (2007). Preparing teachers to learn from teaching. *Journal of Teacher Education*, *58*(1), 47–61. https://doi.org/10.1177/0022487106295726

Hill, H. C., & Ball, D. L. (2004). Learning mathematics for teaching: Results from California's Mathematics Professional Development Institutes. *Journal for Research in Mathematics Education*, *35*(5), 330–351.

Hill, H. C., & Ball, D. L. (2009). The curious—and crucial—case of mathematical knowledge for teaching. *Phi Delta Kappan*, *91*(2), 68–71.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education*, *39*(4), 372–400.

Hill, H. C., Blunk, M. L., Charalambous, C. Y., Lewis, J. M., Phelps, G. C., Sleep, L., & Ball, D. L. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition and Instruction*, *26*(4), 430–511. https://doi.org/10.1080/07370000802177235

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal*, *42*(2), 371–406. https://doi.org/10.3102/00028312042002371

Ho, A. D., & Kane, T. J. (2013). *The reliability of classroom observations by school personnel*.

Huberman, A. M. (1995). Professional careers and professional development: Some intersections. In T. R. Guskey & M. Huberman (Eds.), *Professional development in education: New paradigms and practices* (pp. 193–224). Teachers College Press.

Huinker, D., & Hedges, M. (2015). Comparison of student and teacher perceptions of mathematics teaching practices. *National Council of Teachers of Mathematics Research Conference, Boston, MA*. https://s3.amazonaws.com/conference-handouts/2015-nctm-bostonresearch/pdfs/HuinkerHedges-PtA-NCTMResearch2015.pdf

Jacob, R., Hill, H. C., & Corey, D. (2017). The impact of a professional development program on teachers' mathematical knowledge for teaching, instruction, and student achievement. *Journal of Research on Educational Effectiveness*, *10*(2), 379–407. https://doi.org/10.1080/19345747.2016.1273411

Jacobs, V. R., Franke, M. L., Carpenter, T. P., Levi, L., & Battey, D. (2007). Professional development focused on children's algebraic reasoning in elementary school. *Journal for Research in Mathematics Education*, *38*(3), 258–288. https://doi.org/10.2307/30034868

Jaworski, B. (2006). Theory and practice in mathematics teaching development: Critical inquiry as a mode of learning in teaching. *Journal of Mathematics Teacher Education*, *9*(2), 187–211. https://doi.org/10.1007/s10857-005-1223-z

Johnson, S. (2021). *A decade after Act 10, it's a different world for Wisconsin unions*. Wisconsin Public Radio. https://www.wpr.org/decade-after-act-10-its-different-world-wisconsin-unions

Jones, D. L., & Tarr, J. E. (2007). An examination of the levels of cognitive demand required by probability tasks in middle grades mathematics textbooks. *Statistics Education Research Journal*, *6*(2), 4–27.

Kane, T. J., Kerr, K. A., & Pianta, R. C. (Eds.). (2014). *Designing teacher evaluation systems: New guidance from the Measures of Effective Teaching project*. Jossey-Bass.

Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping children learn mathematics*. National Academy Press. https://doi.org/10.17226/9822

Knowles, M. S. (1989). The making of an adult educator: An autobiographical journey. In *The making of an adult educator: An autobiographical journey.* Jossey Bass.

Koellner, K., Jacobs, J., & Borko, H. (2011). Mathematics professional development: Critical features for developing leadership skills and building teachers' capacity. *Mathematics Teacher Education and Development*, *13*(2008), 115–136.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Krauss, S., Brunner, M., Kunter, M., Baumert, J., Blum, W., Neubrand, M., & Jordan, A. (2008). Pedagogical content knowledge and content knowledge of secondary mathematics teachers. *Journal of Educational Psychology*, *100*(3), 716–725. https://doi.org/10.1037/0022-0663.100.3.716

Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional competence of teachers: Effects on instructional quality and student development. *Journal of Educational Psychology*, *105*(3), 805–820. https://doi.org/10.1037/a0032583

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*.

Cambridge University Press.

Leinhardt, G., & Smith, D. (1984). Expertise in mathematics instruction: Subject matter knowledge. *Paper Presented at the 68th American Educational Research Association Meeting*.

Leinwand, S. (1994). Soundoff: Four teacher-friendly postulates for thriving in a sea of change. *The Mathematics Teacher*, *87*(6), 392–393. https://doi.org/10.5951/MT.87.6.0392

Lloyd, G. M. (1999). Two teachers' conceptions of a reform-oriented curriculum: Implications for mathematics teacher development. *Journal of Mathematics Teacher Education*, *2*, 227–252.

Lopes, A. (2006). Participatory action research. In V. Jupp (Ed.), *The Sage dictionary of social research methods* (pp. 216–217). SAGE Publications.

Lortie, D. C. (1975). *Schoolteacher: A sociological study*. University of Chicago Press.

Loucks-Horsley, S., & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics*, *99*(5), 258–271. https://doi.org/10.1111/j.1949-8594.1999.tb17484.x

Loucks-Horsley, S., Stiles, K. E., Mundrey, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics* (Third). Corwin.

Ma, L. (1999). *Knowing and teaching elementary mathematics*. Lawrence Erlbaum Associates.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47217-1_4

Maruyama, G., & Ryan, C. S. (2014). *Research methods in social relations* (Eighth). John Wiley & Sons, Ltd.

Masingila, J. O., Olanoff, D., & Kimani, P. M. (2018). Mathematical knowledge for teaching teachers: Knowledge used and developed by mathematics teacher educators in learning to teach via problem solving. *Journal of Mathematics Teacher Education*, *21*(5), 429–450. https://doi.org/10.1007/s10857-017-9389-8

Maskit, D. (2011). Teachers' attitudes toward pedagogical changes during various stages of professional development. *Teaching and Teacher Education*, *27*(5), 851–860. https://doi.org/10.1016/j.tate.2011.01.009

McCrory, R., Floden, R., Ferrini-Mundy, J., Reckase, M. D., & Senk, S. L. (2012). Knowledge of algebra for teaching: A framework of knowledge and practices. *Journal for Research in Mathematics Education*, *43*(5), 584. https://doi.org/10.5951/jresematheduc.43.5.0584

McDuffie, A. R., Choppin, J., Drake, C., & Davis, J. (2018). Middle school mathematics teachers' orientations and noticing of features of mathematics curriculum materials. *International Journal of Educational Research*, *92*, 173–187. https://doi.org/10.1016/j.ijer.2018.09.019

McGatha, M. B., Bay-Williams, J. M., McCord Kobett, B., & Wray, J. A. (2018). *Everything you need for mathematics coaching: Tools, plans, and a process that works for any instructional leader, grades K-12*. SAGE Publications.

McLeod, S. (2013). *Kolb - learning styles*. Simply Psychology. https://simplypsychology.org/learning-kolb.html

Merriam, S. B., & Bierema, L. L. (2014). *Adult learning: Linking theory and practice*. Jossey Bass.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (Fourth). Jossey Bass.

Mezirow, J. (1990). *Fostering critical reflection in adulthood*. Jossey Bass.

Miles, M. B. (1995). Forward. In T. R. Guskey & M. Huberman (Eds.), *Professional development in education: New paradigms and practices*. Teachers College Press.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd Editio). SAGE Publications.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054.

Mohr-Schroeder, M., Ronau, R. N., Peters, S., Lee, C. W., & Bush, W. S. (2017). Predicting student achievement using measures of teachers' knowledge for teaching geometry. *Journal for Research in Mathematics Education*, *48*(5), 520–566.

Monte-Sano, C. (2011). Learning to open up history for students: Preservice teachers' emerging pedagogical content knowledge. *Journal of Teacher Education*, *62*(3), 260–272. https://doi.org/10.1177/0022487110397842

Moran, C. L. (2022). Restoring relationships in mathematics. *Wisconsin Teacher of Mathematics*, *2022*(1), 25–35.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical content knowledge. In *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 21–50). Kluwer Academic Publishers.

National Council of Teachers of Mathematics. (1991). *Professional standards for teaching* *mathematics*. National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all*. National Council of Teachers of Mathematics.

National Council of Teachers of Mathematics. (2018). *Catalyzing change in high school mathematics: Initiating critical conversations*. National Council of Teachers of Mathematics.

National Governors Association Center for Best Practices, & Council of Chief State School Officers. (2010). *Common core state standards for mathematics*. National Governors Association Center for Best Practices, Council of Chief State School Officers. http://www.corestandards.org/

National Mathematics Advisory Panel. (2008). *Foundations for success*. https://doi.org/10.3102/0013189X08329195

NCSM. (2008). *The PRIME leadership framework: Principles and indicators for mathematics education leaders*. Solution Tree.

Newton, J. (2006). Action research. In V. Jupp (Ed.), *The Sage dictionary of social research methods* (pp. 2–3). SAGE Publications.

NGSS Lead States. (2013). *Next generation science standards*. The National Academies Press. https://www.nextgenscience.org/

Ostashewski, N., & Reid, D. (2015). A history and frameworks of digital badges in education. In T. Reiners & L. C. Wood (Eds.), *Gamification in Education and Business* (pp. 187–200). Springer International Publishing. https://doi.org/10.1007/978-3-319-10208-5_10

Otten, S., & Soria, V. M. (2014). Relationships between students ' learning and their participation during enactment of middle school algebra tasks. *ZDM - International Journal on Mathematics Education*, *46*, 815–827. https://doi.org/10.1007/s11858-014-0572-4

Ottmar, E. R., Rimm-Kaufman, S. E., Larsen, R. A., & Berry, R. Q. (2015). Mathematical knowledge for teaching, standards-based mathematics teaching practices, and student achievement in the context of the responsive classroom approach. *American Educational Research Journal*, *52*(4), 787–821. https://doi.org/10.3102/0002831215579484

Papay, J. P., Bacher-Hicks, A., Page, L. C., & Marinell, W. H. (2017). The challenge of teacher retention in urban schools: Evidence of variation from a cross-site analysis. *Educational Researcher*, *46*(8), 434–448. https://doi.org/10.3102/0013189X17735812

Parker, F., Bartell, T. G., & Novak, J. D. (2017). Developing culturally responsive mathematics teachers: Secondary teachers' evolving conceptions of knowing students. *Journal of Mathematics Teacher Education*, *20*(4), 385–407. https://doi.org/10.1007/s10857-015-9328-5

Patton, M. Q. (2015). *Qualitative research & evaluation methods*. SAGE Publications.

Peske, H. G., & Haycock, K. (2006). *Teaching inequality* (Issue June).

Philipp, R. A. (2007). Mathematics teachers' beliefs and affect. In F. K. Lester (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 257–315). Information Age Publishing.

Piburn, M., Sawada, D., Turley, J., Falconer, K., Bartley, B., Benford, R., Bloom, A., Isom, M., & Judson, E. (2000). *Reformed teaching observation protocol (RTOP) reference manual*. http://www.public.asu.edu/~anton1/AssessArticles/Assessments/Chemistry Assessments/RTOP Reference Manual.pdf

Pine, G. J. (2009). *Teacher action research: Building knowledge democracies*. SAGE Publications.

Pink, D. (2011). *Drive: The surprising truth about what motivates us*. Riverhead Books.

Polikoff, M. S. (2015). How well aligned are textbooks to the Common Core State Standards in Mathematics. *American Educational Research Journal*, *52*(6), 1185–1211. https://doi.org/10.3102/0002831215584435

Polly, D., Mcgee, J. R., Wang, C., Lambert, R. G., Pugalee, D. K., & Johnson, S. (2013). The association between teachers' beliefs, enacted practices, and student learning in mathematics. *The Mathematics Educator*, *22*(2), 11–30.

Probst, B. (2015). The eye regards itself: Benefits and challenges of reflexivity in qualitative social work research. *Social Work Research*, *39*(1), 37–48. https://doi.org/10.1093/swr/svu028

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4–15. http://www.jstor.org/stable/1176586

Reason, P. (2006). Choice and quality in action research practice. *Journal of Management Inquiry*, *15*(2), 187–203. https://doi.org/10.1177/1056492606288074

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211–246. https://doi.org/10.3102/00346543075002211

Remillard, J. T., & Heck, D. J. (2014). Conceptualizing the curriculum enactment process in mathematics education. *ZDM - International Journal on Mathematics Education*, *46*, 705–718. https://doi.org/10.1007/s11858-014-0600-4

Rogers, K. C., & Steele, M. D. (2016). Graduate teaching assistants' enactment of reasoning-and-proving tasks in a content course for elementary teachers. *Journal for Research in Mathematics Education*, *47*(4), 372–419.

Rowland, T., Huckstep, P., & Thwaites, A. (2005). Elementary teachers' mathematics subject knowledge: The knowledge quartet and the case of Naomi. *Journal of Mathematics Teacher Education*, *8*(3), 255–281. https://doi.org/10.1007/s10857-005-0853-5

Rowland, T., & Turner, F. (2007). Developing and using the 'Knowledge Quartet': A framework for the observation of mathematics teaching. *The Mathematics Educator*, *10*(1), 107–123.

Rust, F. O. (2009). Teacher research and the problem of practice. *Teachers College Record*, *111*(8), 1882–1893.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation. *American Psychologist*, *55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Saderholm, J., Ronau, R. N., Brown, E. T., & Collins, G. (2010). Validation of the diagnostic teacher assessment of mathematics and science (DTAMS) instrument. *School Science and Mathematics*, *110*(4), 180–192. https://doi.org/10.1111/j.1949-8594.2010.00021.x

Saldaña, J. (2021). *The coding manual for qualitative researchers* (Fourthi). SAGE Publications.

Sears, R., & Chávez, Ó. (2014). Opportunities to engage with proof: the nature of proof tasks in two geometry textbooks and its influence on enacted lessons. *ZDM - International Journal on Mathematics Education*, *46*, 767–780. https://doi.org/10.1007/s11858-014-0596-9

Sherin, M. G., & van Es, E. A. (2003). A new lens on teaching: Learning to notice. *Mathematics Teaching in the Middle School*, *9*(2), 92–95.

Shulman, L. S. (1986). Those who understand: Knowledge and growth in teaching. *Educational*

*Researcher*, *15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–21.

Silver, E. A., Ghousseini, H., Charalambous, C. Y., & Mills, V. (2009). Exploring the curriculum implementation plateau. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), *Mathematics teachers at work: Connecting curiculum materials and classroom instruction* (pp. 245–265). Routledge.

Silver, E. A., & Stein, M. K. (1996). The QUASAR project: The "revolution of the possible" in mathematics instructional reform in urban middle schools. *Urban Education*, *30*(4), 476–521. https://doi.org/10.1177/0042085996030004006

Silverman, J., & Thompson, P. W. (2008). Toward a framework for the development of mathematical knowledge for teaching. *Journal of Mathematics Teacher Education*, *11*(6), 499–511. https://doi.org/10.1007/s10857-008-9089-5

Simon, M. A. (2006). Key developmental understandings in mathematics: A direction for investigating and establishing learning goals. *Mathematical Thinking and Learning*, *8*(4), 359–371. https://doi.org/10.1207/s15327833mtl0804_1

Simon, M. A., Tzur, R., Heinz, K., Kinzel, M., & Smith, M. S. (2000). Characterizing a perspective underlying the practice of mathematics teachers in transition. *Journal for Research in Mathematics Education*, *31*(5), 579–601. https://doi.org/10.2307/749888

Slavit, D., & Nelson, T. H. (2010). Collaborative teacher inquiry as a tool for building theory on the development and use of rich mathematical tasks. *Journal of Mathematics Teacher Education*, *13*(3), 201–221. https://doi.org/10.1007/s10857-009-9136-x

Smith, M. S. (2001). *Practice-based professional development for teachers of mathematics*.

National Council of Teachers of Mathematics.

Smith, M. S., & Friel, S. N. (2008). Cases in mathematics teacher education. In M. S. Smith, S. N. Friel, & D. R. Thompson (Eds.), *Cases in mathematics teacher education: Tools for developing knowledge needed for teaching* (pp. 1–8). Association of Mathematics Teacher Educators. https://amte.net/sites/default/files/amte_monograph_vol4_ch1.pdf

Smith, M. S., Steele, M. D., & Raith, M. L. (2017). *Taking action: Implementing effective mathematics teaching practices*. National Council of Teachers of Mathematics.

Smith, M. S., Steele, M. D., & Sherin, M. G. (2020). *The 5 practices in practice: Successfully orchestrating mathematics discussions in your high school classroom*. Corwin.

Smith, M. S., & Stein, M. K. (2018). *5 practices for orchestrating productive mathematics discussions* (Issue 15627). National Council of Teachers of Mathematics.

Souto-Manning, M. (2012). Teacher as researcher: Teacher action research in teacher education. *Childhood Education*, *88*(1), 54–56. https://doi.org/10.1080/00094056.2012.643726

Sowder, J. T. (2007). The mathematical education and development of teachers. In F. K. Lester (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 157–223). Information Age Publishing.

Spillane, J. P. (2000). Cognition and policy implementation: District policymakers and the reform of mathematics education. *Cognition and Instruction*, *18*(2), 141–179. https://doi.org/10.1207/S1532690XCI1802_01

Steele, M. D. (2013). Exploring the mathematical knowledge for teaching geometry and measurement through the design and use of rich assessment tasks. *Journal of Mathematics Teacher Education*, *16*(4), 245–268. https://doi.org/10.1007/s10857-012-9230-3

Steele, M. D., & Huhn, C. (2018). *A quiet revolution: One district's story of radical curricular* *change in high school mathematics*. Information Age Publishing.

Steffy, B. E., & Wolfe, M. P. (2001). A life-cycle model for career teachers. *Kappa Delta Pi Record*, *38*(1), 16–19.

Stein, M. K., Grover, B. W., & Henningsen, M. A. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, *33*(2), 455–488. https://doi.org/10.3102/00028312033002455

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project. *Educational Research and Evaluation*, *2*(1), 50–80.

Stein, M. K., Silver, E. A., & Smith, M. S. (1998). Mathematics reform and teacher development: A community of practice perspective. In *Thinking practices in math and science learning* (pp. 17–52). Lawrence Erlbaum Associates.

Stein, M. K., & Smith, M. S. (1998). Mathematical tasks as a framework for reflection: From research to practice. *Mathematics Teaching in the Middle School*, *3*(4), 268–275.

Stein, M. K., Smith, M. S., Henningsen, M. A., & Silver, E. A. (2009). *Implementing standards-based mathematics instruction: A casebook for professional development* (2nd ed.). Teachers College Press.

Stein, M. K., Smith, M. S., & Silver, E. A. (1999). The development of professional developers: Learning to assist teachers in new settings in new ways. *Harvard Educational Review*, *69*(3), 237–269.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education*, *17*(2), 213–

226. https://doi.org/10.1016/S0742-051X(00)00052-4

Stylianides, A. J., & Ball, D. L. (2008). Understanding and describing mathematical knowledge for teaching: Knowledge about proof for engaging students in the activity of proving. *Journal of Mathematics Teacher Education*, *11*(4), 307–332. https://doi.org/10.1007/s10857-008-9077-9

Supovitz, J. A., & Zief, S. G. (2000). Why they stay away. *Journal of Staff Development*, *21*(4), 24–28.

Sztajn, P. (2003). Adapting reform ideas in different mathematics classrooms: Beliefs beyond mathematics. *Journal of Mathematics Teacher Education*, *6*(1), 53–75. https://doi.org/10.1023/A:1022171531285

Thompson, A. G. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In *Handbook of research on mathematics teaching and learning* (pp. 127–146). MacMillan.

Thompson, A. G., Philipp, R. A., Thompson, P. W., & Boyd, B. A. (1994). Calculational and conceptual orientations in teaching mathematics. In D. B. Aichelle & A. F. Coxford (Eds.), *Education* (pp. 79–92). National Council of Teachers of Mathematics.

Thompson, C. L., & Zeuli, J. S. (1999). The frame and the tapestry: Standards-based reform and professional development. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 341–375). Jossey Bass.

TNTP. (2018). *The opportunity myth: What students can show us about how school is letting them down – and how to fix it*. https://opportunitymyth.tntp.org

Tomlinson, C. A. (2018). Help teachers become master learners. *Educational Leadership*, *76*(3), 88–89.

Valencia, R. R. (2010). *Dismantling contemporary deficit thinking: Educational thought and* *practice*. Routledge.

Van Dam, A. (2019). *Teacher strikes made 2018 the biggest year for worker protest in a generation*. The Washington Post. https://www.washingtonpost.com/us-policy/2019/02/14/with-teachers-lead-more-workers-went-strike-than-any-year-since/

Venkat, H., & Adler, J. (2014). Pedagogical content knowledge in mathematics education. In S. Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 477–480). Springer Science+Business Media. https://doi.org/10.1007/978-94-007-4978-8

Wallace, C. S. (2014). Overview of the role of teacher beliefs in science education. In Robert H. Evans, C. M. Czerniak, J. A. Luft, & C. H. Pea (Eds.), *The role of science teachers' beliefs in international classrooms: From teacher actions to student learning* (pp. 17–31). Sense Publishers. https://doi.org/10.1007/978-94-6209-557-1_2

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education*, *18*(4), 375–400. https://doi.org/10.1007/s10857-014-9286-3

Washington, H. A. (2006). *Medical apartheid: The dark history of medical experimentation on Black Americans from colonial times to the present*. Doubleday.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.

Wertz, F. J., Charmaz, K., McMullen, L. M., Josselson, R., Anderson, R., & McSpadden, E. (2011). *Five ways of doing qualitative analysis: Phenomenological psychology, grounded theory, discourse analysis, narrative research, and intuitive inquiry*. The Guilford Press.

Wiggins, G. P., & McTighe, J. (2005). Understanding by design. In *Association for Supervision and Curriculum Development*. ASCD.

Wilhelm, A. G. (2014). Mathematics teachers' enactment of cognitively demanding tasks: Investigating links to teachers' knowledge and conceptions. *Journal for Research in Mathematics Education*, *45*(5), 636–674. https://doi.org/10.5951/jresematheduc.45.5.0636

Wilhelm, A. G., Munter, C., & Jackson, K. (2017). Examining relations between teachers' explanations of sources of students' difficulty in mathematics and students' opportunities to learn. *Elementary School Journal*, *117*(3), 345–370. https://doi.org/10.1086/690113

Wilson, P. H., Mojica, G. F., & Confrey, J. (2013). Learning trajectories in teacher education: Supporting teachers' understandings of students' mathematical thinking. *Journal of Mathematical Behavior*, *32*(2), 103–121. https://doi.org/10.1016/j.jmathb.2012.12.003

Wilson, S. M., Shulman, L. S., & Richert, A. E. (1987). "150 different ways" of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teacher thinking* (pp. 104–124). Cassell Education Limited.

Wisconsin Department of Public Instruction. (2017). *Teacher turnover and attrition brief*. https://dpi.wi.gov/sites/default/files/imce/tepdl/pdf/2016-17_teacher_turnover_attrition_brief.pdf

Wisconsin Department of Public Instruction. (2018). *Teacher turnover and attrition brief*. https://dpi.wi.gov/sites/default/files/imce/tepdl/pdf/2017-18_Teacher_Turnover_Attrition_Brief.pdf

Wisconsin Department of Public Instruction. (2021). *Public staff FTE by ethnicity and gender report*. https://publicstaffreports.dpi.wi.gov/PubStaffReport/Public/PublicReport/StaffByEthnicityAndGenderReport

Wlodowski, R. J. (2008). *Enhancing adult motivation to learn: A comprehensive guide for* *teaching all adults*. Jossey Bass.

Wootton, D. (2015). *The invention of science: A new history of the Scientific Revolution*. HarperCollins Publishers.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). SAGE Publications.

## APPENDICES

### Appendix A Initial MMTP Application[1]

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**A partnership between Lakeside University and Lakeside Public Schools**

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**TEAM APPLICATION**

This application should be completed for all members of a school team. School teams should consist of 3-5 math and/or science teachers who have already earned a master's degree. Each person should complete an individual application, and these should be submitted with one team application.

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Teams should have requested that the principal support their commitment to this **five-year** project. If the team has not spoken with the principal about the MMTP, please do so before completing this application.

Principal support could include partnering with MMTP personnel to publicize and promote teacher work and outcomes, occasional release from afterschool duties, the collection of video and written artifacts from classroom practice (consistent with LPS policy), facilitating the use of building space during non-school time (consistent with LPS policy), and support for attendance at regional professional conferences. Additional support may be needed so that MMTP participants can collaborate as their own Professional Learning Community (PLC), which may occasionally conflict with other building PLC meeting times.

☐**Our Principal has agreed to support our commitment to the Midwest Master Teacher Partnership**

Principal signature (or electronic signature): ____________________________________________

Date: Click here to enter date

School: Click here to enter school name

Teams should be composed of three to five math and/or science teachers. Teams can be either single subject or have members from both subjects.

Team member names and subject(s) taught:

Click here to enter names and subjects

[1] This application and evaluation rubrics were developed collaboratively with input from all members of the MMTP leadership team.

## A partnership between Lakeside University and Lakeside Public Schools

**SMALL SCHOOL APPLICATION**

This application should be completed for all applicants from a small school. Teams will consist of 3-5 math and/or science teachers who have already earned a master's degree, so teachers from small schools will be partnered together to form a team. Each person should complete an individual application, and applicants from the same school should complete one Small School Application.

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Teachers should have requested that the principal support their commitment to this **five-year** project. If the applicant(s) has not spoken with the principal about the MMTP, please do so before completing this application.

Principal support could include partnering with MMTP personnel to publicize and promote teacher work and outcomes, occasional release from afterschool duties, the collection of video and written artifacts from classroom practice (consistent with LPS policy), facilitating the use of building space during non-school time (consistent with LPS policy), and support for attendance at regional professional conferences. Additional support may be needed so that MMTP participants can collaborate as their own Professional Learning Community (PLC), which may occasionally conflict with other building PLC meeting times.

☐**My/Our Principal has agreed to support my/our commitment to the Midwest Master Teacher Partnership**

Principal signature (or electronic signature): ____________________________________________

Date: Click here to enter date

School: Click here to enter school name

Teams should be composed of math and/or science teachers. Teams can be either single subject or have members from both subjects.

Teacher name(s) and subject(s) taught:

Click here to enter names and subjects

## A partnership between Lakeside University and Lakeside Public Schools

**INDIVIDUAL APPLICATION**

This application should be completed for all members of a school team. School teams should consist of 3-5 math and/or science teachers who have already earned a master's degree. Each person should complete an individual application, and these should be submitted with one team application.

---

Name: Click to enter name

Subject (Check all that apply):

☐ Mathematics

☐ Science

Courses you typically teach (in the last five years):

LPS email address: Click to enter LPS email

Summer email address: Click to enter summer email address

Area of master's degree, field of study, and year it was earned:
Click to enter degree: e.g., MS in Education, 1997

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This **five-year** professional development project addresses the need for sustained, content-focused professional development for teams of secondary mathematics and science teachers in five to eight LPS schools through an innovative micro-credentialing program. Specifically, the project brings teachers together to develop their content knowledge for teaching, which includes:

1. Building content knowledge for teaching in focused areas of mathematics and science;
2. Implementing research-based best pedagogical practices to improve student learning; and
3. Developing teams of teacher leaders who design and conduct action research projects that lead to iterative cycles of professional development within LPS.

The earning of microcredentials or "badges" is the primary focus of the MMTP. Teachers will have the opportunity to earn badges in content knowledge areas at three different levels.

☐ **I have read and understand the project goals**

**Individual Acknowledgement of Commitment**

The MMTP project is on schedule for a Fall 2016 launch. This project would require a **five-year commitment** to participate in the professional development and will provide a $10,000 annual stipend for participation.

Activities during the five years will include:

- Learning the foundations of action research and instructional leadership
- Analysis of instructional practices and assessment
- Leadership development and mentoring
- Exploration of math and science topics in small groups, implementation of classroom interventions related to these topics, and evaluation of impacts on student learning using classroom-based action research.
- Summer experiences including content research, curriculum development, and K-8 microteaching

Expected time commitments:

- Initial year: Approximately 6 hours per month for full-cohort meetings and up to 10 hours for each badge.
- Subsequent years: Approximately 10 hours for each badge (for a total of 4 badges per year), 3 hours per month of meeting time, and additional team meetings as needed.
- Summers: Approximately two weeks.

☐ **I have read and agree to the participation requirements.**

☐**I understand that I will be required to repay the annual stipend should I discontinue participation before the end of the five-year commitment.**

Signature:

Date:

**Personal statement**

Please respond to the following:

1. Describe your daily work in teaching science or mathematics.
2. What areas are you interested in learning more about related to mathematics/science content or pedagogy?
3. How do you anticipate the learning from the project will influence your daily work as a teacher?
4. In what ways have you provided (or aspire to provide) mathematics or science leadership for your school, district, and/or state?

(Approximately 1000 words)

Click here to begin typing.

Team/Individual:

MMTP Application Scoring Rubric

| **Focus Area** | **1** | **3** | **5** | **Subtotal/Total** |
|---|---|---|---|---|
| Daily work in teaching science or mathematics | Description does not include any aspect of instruction or its relationship to learning | Description includes **either** aspects of instruction **or** its relationship to learning | Description includes aspects of instruction and its relationship to learning | **/5** |
| Areas are you interested in learning more | Area(s) of interest do not include aspect of instruction or its relationship to learning | Area(s) of interest includes **either** aspects of instruction **or** its relationship to learning | Area(s) of interest include instruction and its relationship to learning | **x 1.5** **/7.5** |
| How learning from the project will influence your daily work | Projected MMTP learning does not address impact on teaching or learning | Projected MMTP learning addresses impact on teaching **or** learning | Projected MMTP learning addresses impact on teaching and learning | **x 2** **/10** |
| Provided/Aspire to provide mathematics or science leadership | Leadership aspirations address less than two of the following: teacher learning, student learning, and system change. | Leadership aspirations address two of the following: teacher learning, student learning, and system change. | Leadership aspirations address all of the following: teacher learning, student learning, and system change. | **x 1.5** **/7.5** |
| | | | **TOTAL** | **/30** |

## A partnership between Lakeside University and Lakeside Public Schools

**STAGE 2 APPLICATION**

This application should be completed for all members of a school team. School teams should consist of 3-5 math and/or science teachers who have already earned a master's degree. Each person should complete these components individually. Your individual submissions should be uploaded to an LPS OneDrive folder which is shared with the other members of your school team (if any) and with the members of the MMTP team. (Directions for sharing your submissions will be provided.)

The second-round application consists of three components:

1. A video clip in which students are engaged (maximum of 10 minutes, continuous). Describe the instructional practices you used to maximize student engagement, your success with that practice, and your challenges with respect to student engagement and student learning. Please include student artifacts from this lesson[*] and a brief description of how these artifacts demonstrate student learning.

2. Write three possible action research questions that you might be interested in answering about your classroom practice. For each question, write a few sentences that explains the data you might collect in your classroom.

3. Provide an instructional task/activity/lab that you have used this year that you would do differently when you teach it next. Include a narrative that describes why you would change this task/activity/lab in ways that illustrate the differences between your learning goals for the lesson and the demonstrated student learning. (You may include student work artifacts related to this task, but it is not strictly required.)

[*] Artifacts do not have to be from the 10-minute video, but from the same lesson. Artifacts can be a picture (.jpg) or PDF (including scans) that represents student work or a brief transcript or paraphrased description of classroom discourse. Student artifacts can be annotated to help reviewers understand the context of the work.

MMTP Application – Part II: Scoring Rubric
Team/Individual:

| Focus Area | 1 | 3 | 5 | Subtotal/Total |
|---|---|---|---|---|
| Part 1. Video Clip Component | Description includes less than three of the following and only portions of each:<br>• Instructional practice and how it maximizes student engagement;<br>• Teacher and student success with the practice;<br>• Challenges in the lesson related to student engagement and learning;<br>• Demonstrated links between student artifacts from lesson and student learning. | Description includes three of the following or some portion of each:<br>• Instructional practice and how it maximizes student engagement;<br>• Teacher and student success with the practice;<br>• Challenges in the lesson related to student engagement and learning;<br>• Demonstrated links between student artifacts from lesson and student learning. | Description includes each of the following:<br>• Instructional practice and how it maximizes student engagement;<br>• Teacher and student success with the practice;<br>• Challenges in the lesson related to student engagement and learning;<br>• Demonstrated links between student artifacts from lesson and student learning. | **x 4**<br><br>**/20** |
| Part II. Action Research Questions | Action Research Questions do not address teacher or student learning<br><br>No explanation of data sources is included. | Action Research Questions address teacher OR student learning<br><br>Explanation includes one's use of only one source of teacher and/or student learning data. | Action Research Questions address teacher and student learning<br><br>Explanation includes one's use of multiple sources of teacher and student learning data. | **x 3**<br><br>**/15** |
| Part III. Instructional Task/Activity/Lab | Instructional Task/Activity/Lab is not provided.<br><br>Explanation of submission does not detail each of the following:<br>• why the project needed a different learning goal;<br>• why the project needed a different demonstration of student learning. | Instructional Task/Activity/Lab is provided.<br><br>Explanation of submission details only one of the following or superficially addresses both:<br>• why the project needed a different learning goal;<br>• why the project needed a different demonstration of student learning. | Instructional Task/Activity/Lab is provided.<br><br>Explanation of submission details each of the following:<br>• why the project needed a different learning goal;<br>• why the project needed a different demonstration of student learning. | **x 3**<br><br>**/15** |
| | | | **TOTAL** | **/50** |

## Appendix B Pre- and Post-Observation Interview Protocol[1]

Before the observation:

1) What are your goals for this lesson?
   a) What do you hope students will learn?

2) What aspects of your learning over the past __ years with MMTP do you think this lesson highlights?[2]

3) How did you plan for this lesson?[3]

After the observation:

1) How do you feel today's lesson went?
   a) What went well?
   b) What didn't go so well?

2) To what extent did you meet your goals for this lesson?
   Note: Press for examples if the teacher does not provide them for how they are evaluating that they met their goals.

Contextual items to note:

- Teacher name
- School
- Date
- Time
- Class period
- Class name
- Grade(s)
- Students present
- Students on the roster
- Others present
- Any issues of note

[1] This protocol was developed by Dr. Michael Steele and Jenny Sagrillo.
[2] This question was not included in the first two years' observations.
[3] This question was occasionally asked after the observation if time did not allow beforehand.

# Appendix C Teaching Practices and Content Survey[22]

Survey Flow

**Standard: Intro (2 Questions)**
**Block: Assessment Practices (4 Questions)**
**Standard: Branching Question (2 Questions)**

**Branch: New Branch**
  **If**
    **If Please specify if you are a Mathematics or Science teacher. Science Is Selected**

  **Block: Teaching Practices (Science Branch) (8 Questions)**

  **Branch: New Branch**
    **If**
      **If Which areas of science do you teach? (Select all that apply) Physical sciences Is Selected**

    **Block: Physical Sciences (4 Questions)**

  **Branch: New Branch**
    **If**
      **If Which areas of science do you teach? (Select all that apply) Life sciences Is Selected**

    **Block: Life Sciences (4 Questions)**

  **Branch: New Branch**
    **If**
      **If Which areas of science do you teach? (Select all that apply) Earth and space sciences Is Selected**

    **Block: Earth and Space Science (3 Questions)**



[22] Survey was developed with input from the members of the MMTP leadership team and based on the Math Teaching Practices Inventory (Huinker & Hedges, 2015), the eight effective mathematics teaching practices (NCTM, 2014), Common Core State Standards for Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), and the Next Generation Science Standards (NGSS Lead States, 2013), .

Branch: New Branch
If
If Please specify if you are a Mathematics or Science teacher. Mathematics/Computer Science Is Selected

Block: Teaching Practices (Mathematics Branch) (16 Questions)

Standard: Aspirations for Instructional Practice (3 Questions)

Start of Block: Intro

Thank you for participating in the survey. The purpose of this survey is to capture your current knowledge and practices related to mathematics and science teaching in your classroom. The survey asks for your name solely so that we can track your responses over the project. Your name will not be known to anyone outside the project personnel, and will not be used in any published product or report of any kind. We ask for your name only so we can track changes to your data over time. If you have questions about confidentiality or the content of this survey, please contact Mike Steele (steelem@uwm.edu).

This survey should take you around 30 minutes to complete. Make sure you give yourself enough time to think about your responses. If you close the survey without finishing and return to it within two weeks on the same computer, you will be able to pick up where you left off.

Your name

________________________________________________________________

End of Block: Intro

Start of Block: Assessment Practices

**Assessment Practices**
In this section, we are interested in learning about your assessment practices and how you monitor student learning. Reflecting on the assessment practices you used during the last school year, please indicate the response that best describes your practice in your science or mathematics classroom.

| | Never | 1-2 times/Year | Monthly | Weekly | Daily |
|---|---|---|---|---|---|
| 1.1 Student assessments were congruent with learning outcomes. | ○ | ○ | ○ | ○ | ○ |
| 1.2 Assessment criteria were shared with students. | ○ | ○ | ○ | ○ | ○ |
| 1.3 Some type of pre-assessment helped determine students' existing knowledge about a concept prior to instruction. | ○ | ○ | ○ | ○ | ○ |
| 1.4 Students self-assessed and monitored their own learning. | ○ | ○ | ○ | ○ | ○ |
| 1.5 Students used assessment feedback to revise and resubmit evidence of their learning. | ○ | ○ | ○ | ○ | ○ |
| 1.6 Students received regular feedback on submitted work, including how each assignment or test affects their overall grade. | ○ | ○ | ○ | ○ | ○ |
| 1.7 Students received assessment feedback during instruction | ○ | ○ | ○ | ○ | ○ |

Please indicate the frequency with which you used each of the following **formative assessments** to monitor student learning during the last school year

| | Never | 1-2 times/Year | Monthly | Weekly | Daily |
|---|---|---|---|---|---|
| 2.1 Exit tickets | ○ | ○ | ○ | ○ | ○ |
| 2.2 Whiteboards | ○ | ○ | ○ | ○ | ○ |
| 2.3 Student Response Board | ○ | ○ | ○ | ○ | ○ |
| 2.4 Thumbs-up | ○ | ○ | ○ | ○ | ○ |
| 2.5 Quizzes | ○ | ○ | ○ | ○ | ○ |
| 2.6 Journals | ○ | ○ | ○ | ○ | ○ |
| 2.7 Choral response | ○ | ○ | ○ | ○ | ○ |
| 2.8 Interactive, whole class discussions | ○ | ○ | ○ | ○ | ○ |
| 2.9 Individualized oral or written feedback | ○ | ○ | ○ | ○ | ○ |
| 2.10 Other, please specify | ○ | ○ | ○ | ○ | ○ |

Please indicate the frequency with which you used each of the following **summative assessments** to monitor student learning during the last school year.

| | Never | 1-2 times/Year | Monthly | Weekly | Daily |
|---|---|---|---|---|---|
| 3.1 Completion Items | ○ | ○ | ○ | ○ | ○ |
| 3.2 Short Answer Items | ○ | ○ | ○ | ○ | ○ |
| 3.3 True/False Items | ○ | ○ | ○ | ○ | ○ |
| 3.4 Multiple-choice exercises | ○ | ○ | ○ | ○ | ○ |
| 3.5 Matching Exercises | ○ | ○ | ○ | ○ | ○ |
| 3.6 Essay Responses | ○ | ○ | ○ | ○ | ○ |
| 3.7 Higher-order Thinking Tasks | ○ | ○ | ○ | ○ | ○ |
| 3.8 Problem Solving Tasks | ○ | ○ | ○ | ○ | ○ |
| 3.9 Critical Thinking Tasks | ○ | ○ | ○ | ○ | ○ |
| 3.10 Performance Assessments (e.g., structured Demonstrations, Experiments, Oral Presentations or Dramatizations) | ○ | ○ | ○ | ○ | ○ |
| 3.11 Long-term Projects | ○ | ○ | ○ | ○ | ○ |
| 3.12 Portfolio Assessments (Best Works/Showcase or Growth/Learning Progress) | ○ | ○ | ○ | ○ | ○ |
| 3.13 Authentic Tasks (e.g., Simulations, Case Studies, Modeling) | ○ | ○ | ○ | ○ | ○ |
| 3.14 Other, please specify | ○ | ○ | ○ | ○ | ○ |

Reflecting on the last school year, indicate the frequency with which you engage in each practice related to assessment data and instructional decisions.

| | Never | 1-2 times/Year | Monthly | Weekly | Daily |
|---|---|---|---|---|---|
| 4.1 Individual student performance data informed your instruction including using more or less time on a unit or deleting a unit entirely. | ○ | ○ | ○ | ○ | ○ |
| 4.2 Evidence of student thinking during a lesson informed your instructional decisions. | ○ | ○ | ○ | ○ | ○ |
| 4.3 Educational research informed your teaching. | ○ | ○ | ○ | ○ | ○ |
| 4.4 Whole class assessment data guided changes in your instruction. | ○ | ○ | ○ | ○ | ○ |
| 4.5 Self-assessment data guided your teaching practices. | ○ | ○ | ○ | ○ | ○ |
| 4.6 Students' language proficiency/heritage language informed your teaching. | ○ | ○ | ○ | ○ | ○ |
| 4.7 Student feedback informed your instruction. | ○ | ○ | ○ | ○ | ○ |
| 4.8 Utilized students' experiences outside of school in your instruction. | ○ | ○ | ○ | ○ | ○ |
| 4.9 Used classroom events to inform your teaching practices. | ○ | ○ | ○ | ○ | ○ |
| 4.10 Information from families was used in your teaching. | ○ | ○ | ○ | ○ | ○ |
| 4.11 New curriculum challenged you to change your teaching practices. | ○ | ○ | ○ | ○ | ○ |

**End of Block: Assessment Practices**

Start of Block: Branching Question

Please specify if you are a Mathematics or Science teacher.

- ○ Mathematics/Computer Science
- ○ Science

*Display This Question:*
*If Please specify if you are a Mathematics or Science teacher. = Science*

Which areas of science do you teach? (Select all that apply)

- ☐ Physical sciences
- ☐ Life sciences
- ☐ Earth and space sciences

End of Block: Branching Question

Start of Block: Teaching Practices (Science Branch)

Choose the classes you taught during the last academic year.

- ☐ Chemistry (standard, AP, or IB)
- ☐ Physics (standard, AP, or IB)
- ☐ Biology (standard, AP, or IB)
- ☐ Physical Science
- ☐ Environmental Science
- ☐ Science - other - list course title________________________________________________
- ☐ Science - other - list course title________________________________________________
- ☐ Science - other - list course title________________________________________________

**Teaching Practices (Science Branch)**

For the items below, please select the choice that best describes your agreement with each statement as it applies to the last academic year.

**Science Goals**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S1.1 I discuss the learning outcomes/lesson goals for each lesson with my students. | ○ | ○ | ○ | ○ | ○ | ○ |
| S1.2 I can identify how the learning goal for each lesson aligns to student learning progression in science. | ○ | ○ | ○ | ○ | ○ | ○ |
| S1.3 I refer to the stated goal throughout each lesson to further focus students on the science concepts they are learning. | ○ | ○ | ○ | ○ | ○ | ○ |
| S1.4 My students know what they are learning in science class. | ○ | ○ | ○ | ○ | ○ | ○ |
| S1.5 My students can tell others the purpose of what they are doing. | ○ | ○ | ○ | ○ | ○ | ○ |
| S1.6 When I plan the goals of a science lesson or unit, I use the Next Generation Science Standards (NGSS) | ○ | ○ | ○ | ○ | ○ | ○ |

**Science Tasks** (geared towards active-learning, see also lab design and assessment)

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S2.1 I engage my students in hands-on laboratory activities or investigations in class. | ○ | ○ | ○ | ○ | ○ | ○ |
| S2.2 I encourage my students to work collaboratively in small groups when doing hands-on activities. | ○ | ○ | ○ | ○ | ○ | ○ |
| S2.3 My students prepare written science reports. | ○ | ○ | ○ | ○ | ○ | ○ |
| S2.4 I place my students in activities that are structured according to the 5 E's model or the Learning Cycle model of instruction. | ○ | ○ | ○ | ○ | ○ | ○ |
| S2.5 I purposefully select activities that allow for a variety of ways to accomplish the task. | ○ | ○ | ○ | ○ | ○ | ○ |
| S2.6 I purposefully select science activities that build on and extend student learning from their previous work. | ○ | ○ | ○ | ○ | ○ | ○ |

**Scientific Representation**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S3.1 I ask students to use models or drawings to solve scientific problems and explain these models to their peers. | ○ | ○ | ○ | ○ | ○ | ○ |
| S3.2 I often ask students to use visual aids such as concept maps to develop or explain their thinking. | ○ | ○ | ○ | ○ | ○ | ○ |
| S3.3 I often ask students to use graphs to explain and justify their reasoning. | ○ | ○ | ○ | ○ | ○ | ○ |
| S3.4 I often ask students to determine how to represent the data gathered from an activity. | ○ | ○ | ○ | ○ | ○ | ○ |
| S3.5 I regularly ask students to prepare short class presentations about their work | ○ | ○ | ○ | ○ | ○ | ○ |

**Science Discourse and Thinking**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S4.1 I structure lessons so that students compare and contrast data and ideas within their group and between small groups. | ○ | ○ | ○ | ○ | ○ | ○ |
| S4.2 I often ask students to use data they gathered to support their thinking and beliefs about a science concept. | ○ | ○ | ○ | ○ | ○ | ○ |
| S4.3 I engage students in whole class discussions in which they must explain and justify their strategies, the data collected, and the conclusions reached. | ○ | ○ | ○ | ○ | ○ | ○ |
| S4.4 I give my students science tasks on a regular basis that require a high level of cognitive demand. | ○ | ○ | ○ | ○ | ○ | ○ |
| S4.5 I often ask students questions in science class requiring them to explain and elaborate on their reasoning. | ○ | ○ | ○ | ○ | ○ | ○ |
| S4.6 I carefully plan key questions to ask students about science content in order to deepen their understanding. | ○ | ○ | ○ | ○ | ○ | ○ |

**Lab Design**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S5.1 I carefully design class activities/experiments to support defined student learning outcomes | ○ | ○ | ○ | ○ | ○ | ○ |
| S5.2 I encourage my students to investigate problem-solving strategies independently. | ○ | ○ | ○ | ○ | ○ | ○ |
| S5.3 I ask students to discuss their problem-solving strategies with each other in pairs or small groups. | ○ | ○ | ○ | ○ | ○ | ○ |
| S5.4 I allow time for students to design and implement their own investigations. | ○ | ○ | ○ | ○ | ○ | ○ |
| S5.5 I ask students to investigate multiple real-world applications relating to in-class experiments. | ○ | ○ | ○ | ○ | ○ | ○ |
| S5.6 How often do you think someone should incorporate lab activities into instruction? | ○ | ○ | ○ | ○ | ○ | ○ |

**Productive Struggle**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| S6.1 I give my students time to struggle productively with science tasks without stepping in to do the work for them. | ○ | ○ | ○ | ○ | ○ | ○ |
| S6.2 My students realize that mistakes are a natural part of learning science. | ○ | ○ | ○ | ○ | ○ | ○ |
| S6.3 My students see mistakes as opportunities to further their understanding of science. | ○ | ○ | ○ | ○ | ○ | ○ |
| S6.4 My students know that breakthroughs in learning science often emerge from confusion and struggle. | ○ | ○ | ○ | ○ | ○ | ○ |
| S6.5 My students persevere in science activities and do not give up. | ○ | ○ | ○ | ○ | ○ | ○ |



End of Block: Teaching Practices (Science Branch)

Start of Block: Physical Sciences

**Physical Sciences Content - Matter and its Interactions**

Each of the topics below is a conceptual category from the current Next Generation Science Standards.

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Matter and its Interactions | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| PS1.1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.5 Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PS1.6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS1.8 Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Physical Sciences Content - Motion and Stability: Forces and Interactions**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate at what confidence level you are teaching this particular concept.

| | Part I: Content Area: Motion and Stability: Forces and Interactions | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| PS2.1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS2.2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS2.3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS2.4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS2.5 Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| PS2.6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Physical Sciences - Energy**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Energy | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| PS3.1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known | | | | | | | | | |
| PS3.2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects) | | | | | | | | | |
| PS3.3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy | | | | | | | | | |
| PS3.4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics) | | | | | | | | | |
| PS3.5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction | | | | | | | | | |

**Physical Sciences Content - Waves and their Applications in Technologies for Information Transfer**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Waves and their Applications in Technologies for Information Transfer | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| PS4.1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media | | | | | | | | | |
| PS4.2 Evaluate questions about the advantages of using a digital transmission and storage of information | | | | | | | | | |
| PS4.3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other | | | | | | | | | |
| PS4.4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter | | | | | | | | | |
| PS4.5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy | | | | | | | | | |

**End of Block: Physical Sciences**

Start of Block: Life Sciences

**Life Sciences Content - Molecules to Organisms: Structures and Processes**
Each of the topics below is a conceptual category from the Next Generation Science Standards.

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.
Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Molecules to Organisms: Structures and Processes | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| LS1.1 Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS1.2 Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS1.3 Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS1.4 Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS1.5 Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LS1.6 Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules | | | | | | | | | |
| LS1.7 Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy | | | | | | | | | |

**Life Science Content - Ecosystems: Interactions, Energy, and Dynamics**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Ecosystems: Interactions, Energy, and Dynamics | | | | Part II Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| LS2.1 Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.2 Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.3 Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.4 Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.5 Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.6 Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LS2.7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS2.8 Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Life Science Content - Heredity: Inheritance and Variation of Traits**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Heredity: Inheritance and Variation of Traits | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| LS3.1 Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS3.2 Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS3.3 Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Life Science Content - Unity and Diversity**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.
Part II: Please indicate at what confidence level you are teaching this particular concept.

| | Content Area: Biological Evolution: Unity and Diversity | | | | Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| LS4.1 Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS4.2 Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS4.3 Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS4.4 Construct an explanation based on evidence for how natural selection leads to adaptation of populations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| LS4.5 Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LS4.6 Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

End of Block: Life Sciences

Start of Block: Earth and Space Science

**Earth and Space Sciences Content - Earth's Place in the Universe**
Each of the topics below is a conceptual category from the Next Generation Science Standards.

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.
Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Earth's Place in the Universe | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| ES1.1 Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES1.2 Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES1.3 Communicate scientific ideas about the way stars, over their life cycle, produce elements | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES1.4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES1.5 Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ES1.6 Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Earth and Space Sciences Content - Earth's Systems**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Earth's Systems | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| ES2.1 Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features | | | | | | | | | |
| ES2.2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems | | | | | | | | | |
| ES2.3 Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection | | | | | | | | | |
| ES3.4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate | | | | | | | | | |
| ES3.5 Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes | | | | | | | | | |
| ES3.6 Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere | | | | | | | | | |
| ES3.7 Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth | | | | | | | | | |

**Earth and Space Sciences Content - Earth and Human Activity**

Part I: For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Content Area: Earth and Human Activity | | | | Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | addressed in several lessons | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| ES4.1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES4.2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES4.3 Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES4.4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES4.5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ES4.6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

End of Block: Earth and Space Science

Start of Block: Teaching Practices (Mathematics Branch)

Choose the classes you taught during the 2018-2019 academic year.

- ☐ Algebra I (1)
- ☐ Algebra II (2)
- ☐ Geometry (3)
- ☐ Calculus (standard, AP, or IB) (4)
- ☐ Statistics (standard, AP, or IB) (5)
- ☐ Pre-Calculus (6)
- ☐ Math - other - list course title (7) ________________________________________________
- ☐ Math - other - list course title (8) ________________________________________________
- ☐ Math - other - list course title (9) ________________________________________________
- ☐ Computer Science - list course title (10) ________________________________________________
- ☐ Computer Science - list course title (11) ________________________________________________
- ☐ Computer Science - list course title (12) ________________________________________________

***Teaching Practices (Mathematics Branch)***

For the items below, please select the choice that best describes your agreement with each statement as it applies to the 2018-2019 academic year.

**Mathematics Goals**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M1.1 I discuss the math learning goal for each lesson with my students. | | | | | | |
| M1.2 I can identify how the math learning goal for each lesson aligns to student learning progressions in mathematics. | | | | | | |
| M1.3 I refer to the stated goal throughout each lesson to further focus students on the math they are learning. | | | | | | |
| M1.4 My students know what they are learning about in math class. | | | | | | |
| M1.5 My students can tell others the purpose of what they are learning in math class. | | | | | | |

**Mathematics Tasks**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M2.1 I encourage my students to use varied approaches and strategies to solve math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M2.2 I regularly give students math tasks that engage them in mathematical reasoning and problem solving. | ○ | ○ | ○ | ○ | ○ | ○ |
| M2.3 I purposefully select math tasks that allow multiple entry points for student learning. | ○ | ○ | ○ | ○ | ○ | ○ |
| M2.4 I purposefully select math tasks that build on and extend student learning from their previous work. | ○ | ○ | ○ | ○ | ○ | ○ |
| M2.5 I give my students math tasks on a regular basis that require a high level of cognitive demand. | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematical Representations**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M3.1 I often allow students to decide which representations they want to use in making sense of math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M3.2 I ask students to make math drawings or use other visual supports to explain and justify their reasoning. | ○ | ○ | ○ | ○ | ○ | ○ |
| M3.3 My students use tools and representations as needed to support their thinking and problem solving in math. | ○ | ○ | ○ | ○ | ○ | ○ |
| M3.4 My students often use diagrams to make sense of math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M3.5 My students make choices about which representations to use as tools for solving math problems. | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematical Discourse**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M4.1 I allow students to work in small groups or pairs to discuss math ideas and solve problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M4.2 I engage students in whole class discussions in which they must explain and justify their strategies for solving math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M4.3 I ask students to analyze and compare the various strategies used by their peers to solve math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M4.4 My students often discuss their ideas for solving math problems with each other in pairs or small groups. | ○ | ○ | ○ | ○ | ○ | ○ |
| M4.5 My students listen carefully to and critique each other's reasoning during whole group discussions in math class. | ○ | ○ | ○ | ○ | ○ | ○ |

**Purposeful Questions**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M5.1 I often ask students questions in math class that go beyond recall of information, definitions, and procedures. | ○ | ○ | ○ | ○ | ○ | ○ |
| M5.2 I often ask students questions in math class requiring them to explain and elaborate on their reasoning. | ○ | ○ | ○ | ○ | ○ | ○ |
| M5.3 I carefully plan key questions to ask students about the math content in order to deepen their understanding. | ○ | ○ | ○ | ○ | ○ | ○ |
| M5.4 I carefully plan questions to ask students that require them to justify their decisions in solving math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M5.5 My students expect to be asked to explain, clarify, and elaborate on their answers in math class. | ○ | ○ | ○ | ○ | ○ | ○ |

**Fluency and Understanding**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M6.1 I always make sure students understand why the math procedures and formulas they are using work. | ○ | ○ | ○ | ○ | ○ | ○ |
| M6.2 I regularly have students discuss why specific procedures seem to work well to solve particular math problems. | ○ | ○ | ○ | ○ | ○ | ○ |
| M6.3 I carefully help students move from using inefficient to more efficient procedures without sacrificing the connection to their conceptual understanding. | ○ | ○ | ○ | ○ | ○ | ○ |
| M6.4 My students understand and can explain the mathematical basis for the procedures that they are using. | ○ | ○ | ○ | ○ | ○ | ○ |
| M6.5 My students demonstrate flexible use of strategies and methods for solving math problems. | ○ | ○ | ○ | ○ | ○ | ○ |

**Productive Struggle**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M7.1 I give students time to struggle productively with math tasks without stepping in to do the work for them. | ○ | ○ | ○ | ○ | ○ | ○ |
| M7.2 My students realize that mistakes are a natural part of learning mathematics. | ○ | ○ | ○ | ○ | ○ | ○ |
| M7.3 My students see mistakes as opportunities to further their understanding of mathematics. | ○ | ○ | ○ | ○ | ○ | ○ |
| M7.4 My students know that breakthroughs in learning math often emerge from confusion and struggle. | ○ | ○ | ○ | ○ | ○ | ○ |
| M7.5 My students persevere in solving math problems and do not give up. | ○ | ○ | ○ | ○ | ○ | ○ |

**Evidence of Student Thinking**

| | Strongly Disagree | Moderately Disagree | Slightly Disagree | Slightly Agree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|---|
| M8.1 I am clear on what counts as evidence of student progress toward the math learning goal of each lesson. | ○ | ○ | ○ | ○ | ○ | ○ |
| M8.2 I carefully plan for ways to elicit and gather evidence of student math understanding at strategic points during a lesson. | ○ | ○ | ○ | ○ | ○ | ○ |
| M8.3 I use evidence of student thinking to make instructional decisions during each math lesson. | ○ | ○ | ○ | ○ | ○ | ○ |
| M8.4 I use evidence of student learning to inform my planning and preparation for subsequent math lessons. | ○ | ○ | ○ | ○ | ○ | ○ |
| M8.5 I often provide my students with ways to monitor their own progress toward our mathematics learning goals. | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematics Content - Number and Quantity**

Each of the topics below is a conceptual category from the current Wisconsin State Standards for Mathematics.

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.
Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Number and Quantity | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC1.1 Extend the properties of exponents to rational exponents | | | | | | | | | |
| MC1.2 Use properties of rational and irrational numbers | | | | | | | | | |
| MC1.3 Reason quantitatively and use units to solve problems | | | | | | | | | |
| MC1.4 Perform arithmetic operations with complex numbers | | | | | | | | | |
| MC1.5 Represent complex numbers and their operations on the complex plane | | | | | | | | | |
| MC1.6 Represent complex numbers and their operations on the complex plane | | | | | | | | | |
| MC1.7 Represent and model with vector quantities | | | | | | | | | |
| MC1.8 Perform operations on vectors | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MC1.9 Perform operations on matrices and use matrices in applications | | | | | | | | | |
| MC1.10 Know that there are numbers that are not rational, and approximate them by rational numbers | | | | | | | | | |
| MC1.11 Work with radicals and integer exponents | | | | | | | | | |

**Mathematics Content - Algebra**

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I : Content Area: Algebra | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC2.1 Interpret the structure of expressions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.2 Write expressions in equivalent forms to solve problems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.3 Perform arithmetic operations on polynomials | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.4 Understand the relationship between zeros and factors of polynomials | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.5 Use polynomial identities to solve problems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.6 Rewrite rational expressions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.7 Create equations that describe numbers or relationships | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.8 Understand solving equations as a process of reasoning and explain the reasoning | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.9 Solve equations and inequalities in one variable | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MC2.10 Solve systems of equations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.11 Represent and solve equations and inequalities graphically | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.12 Understand the connections between proportional relationships, lines, and linear equation | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC2.13 Analyze and solve linear equations and pairs of simultaneous linear equations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematics Content - Functions**

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Functions | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC3.1 Understand the concept of a function and use function notation | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.2 Interpret functions that arise in applications in terms of the context | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.3 Analyze functions using different representations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.4 Build a function that models a relationship between two quantities | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.5 Build new functions from existing functions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.6 Construct and compare linear, quadratic, and exponential models and solve problems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.7 Interpret expressions for functions in terms of the situation they model | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.8 Define, evaluate, and compare function | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC3.9 Use functions to model relationships between quantities | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematics Content - Modeling**

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Modeling | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC4.1 Choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematics Content - Geometry**

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Geometry | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC5.1 Experiment with transformations in the plane | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.2 Understand congruence in terms of rigid motions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.3 Prove geometric theorems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.4 Make geometric constructions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.5 Understand similarity in terms of similarity transformations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.6 Prove theorems involving similarity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.7 Define trigonometric ratios and solve problems involving right triangles | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.8 Apply trigonometry to general triangles | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.9 Understand and apply theorems about circles | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MC5.10 Find arc lengths and areas of sectors of circles | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.11 Translate between the geometric description and the equation for a conic section | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.12 Use coordinates to prove simple geometric theorems algebraically | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.13 Explain volume formulas and use them to solve problems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.14 Visualize relationships between two-dimensional and three-dimensional objects | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.15 Apply geometric concepts in modeling situations | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.16 Understand congruence and similarity using physical models, transparencies, or geometry software | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.17 Understand and apply the Pythagorean Theorem | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC5.18 Solve real-world and mathematical problems involving volume of cylinders, cones, and spheres | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Mathematics Content - Statistics and Probability**

Part I : For the topics listed in each category, please indicate how often you address the topic in your teaching.

Part II: Please indicate your confidence level for teaching the concept.

| | Part I: Content Area: Statistics and Probability | | | | Part II: Confidence Level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | not addressed | minimally addressed (1-2 lessons) | returning subject (3-5 lessons) | a key topic (addressed extensively) | not at all confident in teaching this topic | somewhat confident in teaching this topic | confident in teaching this topic | extremely confident in teaching this topic | not addressed |
| MC6.1 Summarize, represent, and interpret data on a single count or measurement variable | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.2 Summarize, represent, and interpret data on two categorical and quantitative variables | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.3 Interpret linear models | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.4 Understand and evaluate random processes underlying statistical experiments | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.5 Make inferences and justify conclusions from sample surveys, experiments, and observational studies | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.6 Understand independence and conditional probability and use them to interpret data | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.7 Use the rules of probability to compute probabilities of compound events | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.8 Calculate expected values and use them to solve problems | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| MC6.9 Use probability to evaluate outcomes of decisions | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MC6.10 Investigate patterns of association in bivariate data | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

End of Block: Teaching Practices (Mathematics Branch)

Start of Block: Aspirations for Instructional Practice

**Aspirations for Instructional Practice**

5.1 What would you want to do more of in your classroom that you are not doing now, or do not feel like you can do?

5.2 What is the biggest challenge you face when implementing lessons, units and a classroom that reflects the ultimate desired state of learning?

5.3 What assistance do you need to achieve the desired state of learning in your classroom?

End of Block: Aspirations for Instructional Practice

## Appendix D Chronicles of Learning and Development Episodes (CLADE) Templates[1]

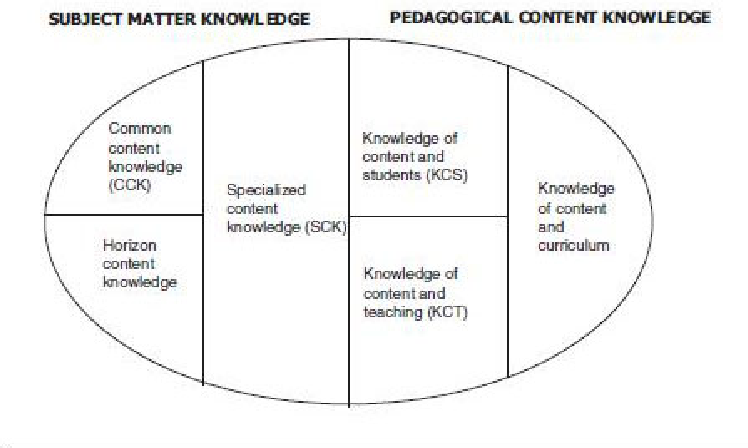
| MMTP Year II: September 2017 - May 2018 | | | | |
|---|---|---|---|---|
| **MMTP Readiness** | *Discuss your summer MMTP-related activities and musings* | | | |
| **Badge Completion**<br>1. *Identify each badge you completed;* | **Year II – Badge #1** | **Year II – Badge #2** | **Year II – Badge #3** | **Year II – Badge #4** |
| 2. *Describe three (3) key concepts you learned.* | | | | |
| 3. *Provide an example of student learning that depicts how what you have learned affected your classroom practice.* | | | | |
| 4. *Identify if this badge developed your understanding of:*<br>*a. Common Content Knowledge (CCK);*<br>*b. Specialized Content Knowledge (SCK);*<br>*c. Knowledge of Content and Students (KCS);*<br>*d. Knowledge of Content and Teaching (KCT);*<br>*e. Knowledge of Content and Curriculum (KCC); and or*<br>*f. Horizontal Curriculum Knowledge (HCK)* | | | | |
| **Year II Reflections**: Knowledge of Content, Pedagogy, Students, and Curricular Growth | *Post your Year II closing reflections.*<br>*Identify any growth you experienced related to Content, Pedagogy, Students, and Curriculum.*<br>*Document any resulting changes in classroom practice.*<br>*Offer evidence of your growth.* | | | |
| **Year III Goal and Badge Projections** | *Reflect on what you have documented thus far then generate a series of MMTP Year III goals and potential badges.* | | | |

[1] The CLADE was developed by Dr. Barbara Bales with input from the members of the MMTP leadership team and based on the model of Mathematical Knowledge for Teaching (Ball et al., 2008)

| MMTP Year III: September 2018 - May 2019 | | | | |
|---|---|---|---|---|
| **MMTP Readiness** | *Discuss your summer MMTP-related activities and musings* | | | |
| **Badge Completion**<br>1. *Identify each badge you completed;* | **Year III – Badge #1** | **Year III – Badge #2** | **Year III – Badge #3** | **Year III – Badge #4** |
| 2. *Describe three (3) key concepts you learned.* | | | | |
| 3. *Provide an example of student learning that depicts how what you have learned affected your classroom practice.* | | | | |
| 4. *Identify if this badge developed your understanding* of:*<br>*a. Common Content Knowledge (CCK);*<br>*b. Specialized Content Knowledge (SCK);*<br>*c. Knowledge of Content and Students (KCS);*<br>*d. Knowledge of Content and Teaching (KCT);*<br>*e. Knowledge of Content and Curriculum (KCC); and or*<br>*f. Horizontal Curriculum Knowledge (HCK)*<br><br>***Definitions on Next Page** | | | | |
| **Year III Reflections**: Knowledge of Content, Pedagogy, Students, and Curricular Growth | *Post your Year III closing reflections.*<br>*Identify any growth you experienced related to Content, Pedagogy, Students, and Curriculum.*<br>*Document any resulting changes in classroom practice.*<br>*Offer evidence of your growth.* | | | |
| **Year IV Goal and Badge Projections** | *Reflect on what you have documented thus far then generate a series of MMTP Year IV goals and potential badges.* | | | |

**KNOWLEDGE DOMAINS FOR TEACHING**

**Figure 5**
**Domains of Mathematical Knowledge for Teaching**




Ball et al. / Content Knowledge for Teaching (2008, p.403)

**SUBJECT MATTER KNOWLEDGE ARENAS:**

- **Common Content Knowledge (CCK):** The mathematical or science knowledge and skill used in settings other than teaching (e.g., Simply calculating an answer or, more generally, correctly solving mathematics/science problems.
- **Specialized Content Knowledge (SCK):** The mathematical or science knowledge and skill unique to teaching (e.g., looking for patterns in student errors or in sizing up whether a nonstandard approach would work in general. This teacher-specific work involves an uncanny kind of unpacking of mathematics/science that is not needed—or even desirable—in settings other than teaching. Many of the everyday tasks of teaching are distinctive to this special work.
- **Horizon Content Knowledge (HCK)**: is an awareness of how mathematical or science topics are related over the span of mathematics/science included in the curriculum. First-grade teachers, for example, may need to know how the mathematics/science they teach is related to the mathematics/science students will learn in third grade to be able to set the mathematical/science foundation for what will come later.

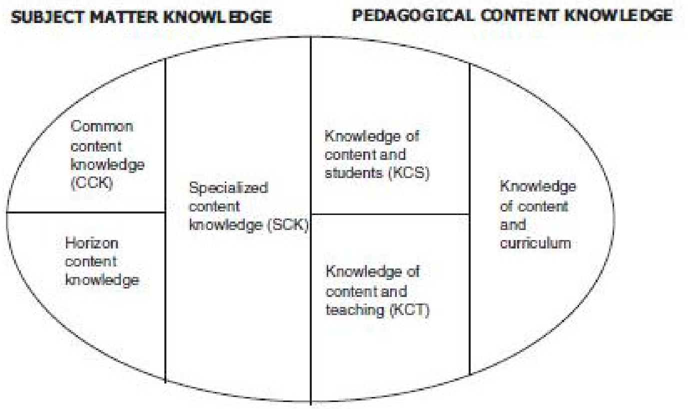
**PEDAGOGICAL CONTENT KNOWLEDGE ARENAS:**

- **Knowledge of Content and Students (KCS)**: The knowledge that combines knowing about students and knowing about mathematics or science. KCS acknowledges the special knowledge associated with the interaction between specific mathematical understanding and familiarity with students and their mathematical/scientific thinking.
- **Knowledge of Content and Teaching (KCT):** This knowledge arena combines knowing about teaching and knowing about mathematics or science. Teachers sequence particular content for instruction. They choose which examples to start with and which examples to use to take students deeper into the content.
- **Knowledge of Content and Curriculum (KCC):** Knowledge of content and curriculum implies a knowledge of the curricular materials that will support student learning. Curricular knowledge is "represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances" (p. 10). Shulman also pointed to two other dimensions of curricular knowledge that are important for teaching, aspects that he labeled lateral curriculum knowledge and vertical curriculum knowledge. Lateral knowledge relates knowledge of the curriculum being taught to the curriculum that students are learning in other classes (in other subject areas). Vertical knowledge includes "familiarity with the topics and issues that have been and will be taught in the same subject area during the preceding and later years in school, and the materials that embody them" (Shulman, 1986, p. 10).

| MMTP Year IV: September 2019 - May 2020 | | | | |
|---|---|---|---|---|
| **MMTP Readiness** | *Discuss your summer MMTP-related activities and musings* | | | |
| **Badge Completion**<br>1. *Identify each badge you completed;* | **Year IV – Badge #1** | **Year IV – Badge #2** | **Year IV – Badge #3** | **Year IV – Badge #4** |
| 2. *Describe three (3) key concepts you learned.* | | | | |
| 3. *Provide an example of student learning that depicts how what you have learned affected your classroom practice.* | | | | |
| 4. *Identify if this badge developed your understanding* of:*<br>*a. Common Content Knowledge (CCK);*<br>*b. Specialized Content Knowledge (SCK);*<br>*c. Knowledge of Content and Students (KCS);*<br>*d. Knowledge of Content and Teaching (KCT);*<br>*e. Knowledge of Content and Curriculum (KCC); and or*<br>*f. Horizontal Curriculum Knowledge (HCK)*<br><br>***Definitions on Next Page** | | | | |
| **Year IV Reflections**: Knowledge of Content, Pedagogy, Students, and Curricular Growth | *Post your Year IV closing reflections.*<br>*Identify any growth you experienced related to Content, Pedagogy, Students, and Curriculum.*<br>*Document any resulting changes in classroom practice.*<br>*Offer evidence of your growth.* | | | |
| **Year V Goal and Badge Projections** | *Reflect on what you have documented thus far then generate a series of MMTP Year V goals and potential badges.* | | | |

**KNOWLEDGE DOMAINS FOR TEACHING**

**Figure 5**
**Domains of Mathematical Knowledge for Teaching**




Ball et al. / Content Knowledge for Teaching (2008, p.403)

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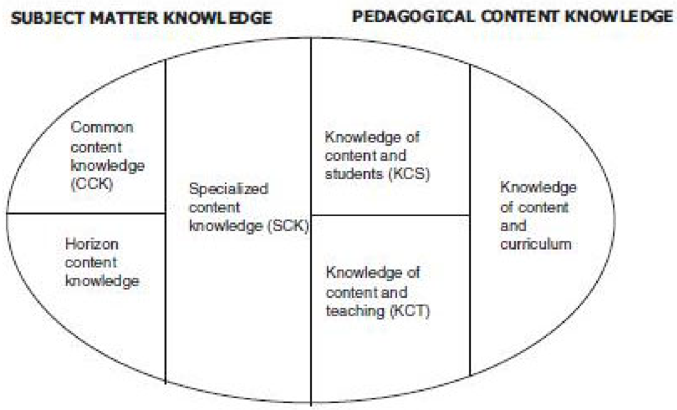
| MMTP Year V: August 2020 – June 2021 | | | | |
|---|---|---|---|---|
| **Summer 2020 reflections** | **Activities:**<br>*List any professional learning activities in which you took part in the summer of 2020. How, if at all, did these activities extend your learning from MMTP in 2019-2020 and/or help prepare you for your MMTP experiences in 2020-2021?* | | | |
| **Badge Completion**<br>1. *Identify each badge you completed;* | **Year V – Badge #1** | **Year V – Badge #2** | **Year V – Badge #3** | **Year V – Badge #4** |
| 2. *Describe three (3) key concepts you learned.* | | | | |
| 3. *Provide an example of student learning that depicts how what you have learned affected your classroom practice.* | | | | |
| 4. *Identify if this badge developed your understanding* of:*<br>*a. Common Content Knowledge (CCK);*<br>*b. Specialized Content Knowledge (SCK);*<br>*c. Knowledge of Content and Students (KCS);*<br>*d. Knowledge of Content and Teaching (KCT);*<br>*e. Knowledge of Content and Curriculum (KCC); and or*<br>*f. Horizontal Curriculum Knowledge (HCK)*<br>***Definitions on Next Page** | | | | |
| **Year V Reflections**: Knowledge of Content, Pedagogy, Students, and Curricular Growth | *Post your Year V closing reflections.*<br>*Identify any growth you experienced related to Content, Pedagogy, Students, and Curriculum.*<br>*Document any resulting changes in classroom practice.*<br>*Offer evidence of your growth.* | | | |

**KNOWLEDGE DOMAINS FOR TEACHING**

**Figure 5**
**Domains of Mathematical Knowledge for Teaching**




Ball et al. / Content Knowledge for Teaching (2008, p.403)

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- **Knowledge of Content and Teaching (KCT):** This knowledge arena combines knowing about teaching and knowing about mathematics or science. Teachers sequence particular content for instruction. They choose which examples to start with and which examples to use to take students deeper into the content.
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## Appendix E  Protocol for Final Interview

Opening: Thanks for letting me talk with you today. I hope you don't mind if I'm recording this. It helps if I can focus on what you're saying and not have to worry about writing everything down. If there's any questions that you're not comfortable answering, just let me know.

I'll be focusing on your work with MMTP and the work you've done over the last five years. I want to get your take on any changes you've noticed in your teaching over the course of the project.

1) Now that the main five years of the project has wrapped up, how do you think it went?
    - Do you think you got what you wanted to out of MMTP?
2) What were some of your big successes?
3) What were some of your big challenges/frustrations/disappointments?
4) How did MMTP compare with other PD you've done?
    - Encourage them to think across the gamut of professional learning, including school-level, district-level, work done independently, conferences, university courses.

Here's the list of micro-credentials that you worked on over the course of the project.

5) What are some of the micro-credentials (MCs) that have most influenced your teaching?
6) Which MCs didn't have much of an impact on your teaching?
7) How do you think your teaching has changed over the last five years?
8) Are there practices that you used to use that you don't do anymore?
    - Can you describe these for me?
9) Are there practices you started using because of work on one of the MCs that you are still doing?

- Can you describe these for me?

10) What are some practices that haven't really changed since MMTP started?

I want to zoom out and think more broadly about your work as a teacher.

11) Are there aspects of your work as a teacher that feel more important or valuable to you now than they did at the start of the project?
12) As part of your initial application, you wrote some possible action research questions that you might like to look into. They were about [list the topics of the teacher's original three action research questions].
    - What kinds of opportunities have you had to investigate these questions?
    - What kinds of questions are you interested in now?
13) Also as part of your initial application, you shared a lesson that you would do differently. Here's the lesson you described. [Share their description of the activity they would change, but not what they said they'd do different.] How do you think you'd do this lesson now?
14) The last part of your initial application was that you were asked to share a 10-minute video showing students engaged. Share what you're thinking as you watch yourself from Spring of 2016. [Offer teachers the option to read a transcript instead?]
    - What do you think about the student engagement you see in the video?
    - What other aspects of your teaching or of the student work jumped out as you watched?

I want to you to think back over your whole time with MMTP.

15) When you think about everything you did with MMTP, do you think we met your professional learning needs at the point where you are in your career?

- Probe for details about how MMTP did or did not meet their needs.

16) Why did you stay for the whole time?

17) How do you think it went overall?

    - What aspects of MMTP should we continue if we do this again?
    - What aspects of MMTP should we discontinue if we do this again?
    - What else do you wish you had gotten the chance to do through MMTP?
    - What else do you wish had been part of the project? (Either by the leadership team or by you as a participant.)
    - What do you wish had been done differently? (Either by the leadership team or by you as a participant.)

## Appendix F MMTP Classroom Observation Tool[24]

# MMTP Classroom Observation Tool

Teacher:
School:
Date of Observation:

| Rubric Name | Score |
|---|---|
| **TP1: Establish STEM goals to focus learning**<br>***Effective STEM teaching establishes clear goals for the science, technology, engineering, and mathematics that students are learning, situates goals within learning progressions, and uses the goals to guide instructional decisions.*** | |
| **TP2: Implement tasks the promote reasoning, problem solving, experimentation, and explanation.**<br>***Effective STEM teaching engages students in solving and discussing tasks that promote reasoning and problem solving, engage students in meaningful simulations and experiments, press for disciplinary explanations, and allow multiple entry points and varied solution strategies.*** | |
| **TP3: Use and connect representations as analytical tools.**<br>***Effective STEM teaching of engages students in making connections among representations to deepen understanding of disciplinary concepts and procedures and as tools for problem solving and analysis*** | |
| **TP4: Facilitate meaningful disciplinary discourse.**<br>***Effective STEM teaching facilitates discourse among students to build shared understanding of disciplinary ideas by analyzing and comparing student approaches and arguments.*** | |
| **TP5: Pose purposeful questions**<br>***Effective STEM teaching uses purposeful questions to assess and advance students' reasoning and sense making about important disciplinary ideas and relationships.*** | |
| **TP6: Build procedural fluency from conceptual understanding through meaningful application and lab design.**<br>***Effective STEM teaching builds fluency with procedures on a foundation of conceptual understanding so that students, over time, become skillful in using procedures flexibly as they solve contextual problems, and makes use of laboratory and application experiences as opportunities for concept development rather than procedural practice.*** | |
| **TP7: Support productive struggle in STEM learning.**<br>***Effective STEM teaching consistently provides students, individually and collectively, with opportunities and supports to engage in productive struggle as they grapple with disciplinary ideas and relationships.*** | |
| **TP8: Elicit and use evidence of student thinking.**<br>***Effective STEM teaching uses evidence of student thinking to assess progress towards conceptual understanding of STEM disciplinary topics to adjust instruction continually in ways that support and extend learning.*** | |

[24] These rubrics were developed collaboratively by all members of the MMTP leadership team, using the eight effective mathematics teaching practices (NCTM, 2014), the Instructional Quality Assessment (Boston, 2012), the Mathematics Classroom Observation Protocol for Practices (Gleason et al., 2015), and the Reformed Teaching Observation Protocol (Piburn et al., 2000) as references.

# Rubric TP1

## Establish STEM goals to focus learning

| Score Point | Description |
|---|---|
| **4** | Teacher's plans for instruction build on each other to support students to do one or more of the following:<br>• learn science concepts,<br>• investigate a phenomenon by engaging in scientific practices through inquiry and mathematical reasoning and/or problem-solving skills<br>• explore a non-routine mathematics problem<br>AND<br>• engage in both the content and practice of science and mathematics<br>• construct and evaluate evidence-based explanations of the phenomenon or support predictions with patterns in evidence and/or data<br><br>The learning goals are connected to the standards, clearly communicated, and anticipate possible student misunderstanding. The learning goals allow students to make clear and consistent connections linked to the larger curriculum context. The goals connect clearly to prior knowledge and learning. |
| **3** | Teacher's plans for instruction build on each other to support students to<br>• learn science concepts,<br>• investigate a phenomenon by engaging in scientific practices through inquiry and mathematical reasoning and/or problem-solving skills<br>• explore a non-routine mathematics problem<br>AND<br>• engage in both the content and practice of science and mathematics<br>• construct and evaluate evidence-based explanations of the phenomenon or support predictions with patterns in evidence and/or data<br><br>The goals, however, do not rise to a 4 because there is not an explicit connection to prior knowledge and/or learning. |
| **2** | Teacher's plans for instruction build on each other to support students to<br>• learn science concepts,<br>• investigate a phenomenon by engaging in scientific practices through inquiry and mathematical reasoning and/or problem-solving skills<br>• explore a non-routine mathematics problem<br>The lesson focuses either on the content or the practice of science or mathematics, but not both, in the same lesson.<br><br>The learning goals are clear and connected to the standards. |
| **1** | Teacher's plans for instruction support student learning of facts and procedures with few opportunities for students to engage in scientific practices through inquiry OR mathematical reasoning and/or problem-solving skills.<br>**AND/OR** The learning goals are unclear and not aligned to the standards and/or the teacher makes serious content errors that may affect student understanding. |
| **0** | Teacher's plans for instruction focus solely on memorization and following prescribed procedures for an "inquiry" with no opportunities for students to engage in scientific practices through inquiry OR mathematical reasoning and/or problem-solving skills. |

| | |
|---|---|
| | No evidence of explicit student learning goals. |
| **Not observed** | Teacher and students were not engaged in mathematical nor science instructions that were aligned to grade level standards. |

Notes:

Use Score Point 1 under two possibly distinct conditions:

a. The teacher has clear instructional goals, but those goals are procedural and don't provide opportunities for science inquiry or mathematical reasoning or problem solving
b. The teacher has unclear instructional goals that aren't aligned to standards or there are serious content errors

# Rubric TP2

## Implement tasks that promote reasoning, problem solving, experimentation, and explanation

<table>
<tr><th>Score Point</th><th>Description</th></tr>
<tr><td>4</td><td>Students engaged in complex thinking or in creating meaning for mathematical concepts, procedures, and/or relationships, such as:<ul><li>Doing mathematics/science: using complex and non-algorithmic thinking (i.e., there is not a predictable, well-rehearsed approach or pathway explicitly suggested by the task, task instructions, or a worked-out example); OR</li><li>Procedures with connections: applying a broad general procedure that remains closely connected to mathematical concepts.</li></ul>There is explicit evidence of students' reasoning and understanding. For example, students may have:<ul><li>solved a genuine, challenging problem for which students' reasoning is evident in their work on the task;</li><li>developed an explanation for why formulas, procedures, or a given scientific process work;</li><li>identified patterns, formed, and justified generalizations based on these patterns, including inductive reasoning about a scientific phenomenon;</li><li>made conjectures and supported conclusions with mathematical or scientific evidence;</li><li>made explicit connections between representations, strategies, or mathematical/scientific concepts and procedures.</li><li>followed a prescribed procedure in order to explain/illustrate a mathematical/scientific concept, process, or relationship.</li></ul></td></tr>
<tr><td>3</td><td>Students engaged in complex thinking or in creating meaning for mathematical concepts, procedures, and/or relationships. However, the implementation does not warrant a "4" because:<ul><li>there is no explicit evidence of students' reasoning and understanding.</li><li>students engaged in doing mathematics/science or procedures with connections to mathematical/scientific meaning, but the underlying mathematics or science in the task was not appropriate for the specific group of students (i.e., too easy or too hard to sustain engagement with high-level cognitive demands);</li><li>students identified patterns but did not form or justify generalizations;</li><li>students used multiple strategies or representations but connections between different strategies/representations were not explicitly evident;</li><li>students made conjectures but did not provide evidence or explanations to support conclusions</li></ul></td></tr>
<tr><td>2</td><td>Students engaged in using a procedure that was either specifically called for or its use was evident based on prior instruction, experience, or placement of the task. There was little ambiguity about what needed to be done and how to do it. Students did not connections to the concepts or meaning underlying the procedure being used. Focus of the implementation appears to be on producing correct answers or results (in the case of a lab) rather than developing mathematical or scientific understanding (e.g., applying a specific problem-solving strategy, practicing a computational</td></tr>
</table>

| | |
|---|---|
| | algorithm, performing a prescribed laboratory procedure without engaging in explanation or meaning making).<br>OR<br>There is evidence that the mathematical or scientific content of the task is at least 2 grade-levels below the grade of the students in the class. |
| **1** | Students engage in memorizing or reproducing facts, rules, formulae, or definitions. Students do not make connections to the concepts or meaning that underlie the facts, rules, formulae, or definitions being memorized or reproduced. |
| **0** | Students did not engage in mathematical or scientific activity. |
| **Not observed** | Students did not have the opportunity to engage with a mathematical or scientific task. |

Notes:

If the entire class time was taken up with a lecture, where students were expected only to take notes, listen, and/or answer brief fill-in-the-blank questions, this is considered not having the opportunity to engage with a mathematical or scientific task and should be coded as Not Observed.

If the lecture was buttressed with some sort of small group or individual practice, or synthesized ideas that students had explored earlier in the class period through some sort of mathematical or scientific engagement, it should be coded using one of the numeric score points.

## Rubric TP3

### Use and connect representations as analytical tools

| Score Point | Description |
|---|---|
| **4** | The lesson provided students with opportunities to create multiple distinct types of representations or meaningfully different representations within a single type. Connections were made between the representations by the students or teacher to highlight the relationship between the different representations and the underlying disciplinary content. |
| **3** | The lesson provided students with opportunities to create multiple distinct types of representations or meaningfully different representations within a single type. Connections between representations (either by teacher or students) were minimal to modest, with more discussion focused on the construction and meaning of each representation.<br>OR<br>The mathematics or science content did not reasonably lend itself to multiple representational types, but the mathematical or scientific features of a single representations were unpacked (e.g., explaining how the math or science concepts are visible in the representation). |
| **2** | The lesson asked students to generate a single type of representation, and the majority of representations generated were the same. Few meaningful opportunities existed to make connections between representations due to similarity. |
| **1** | Representations used in this lesson were mostly or entirely generated by the teacher. Little opportunity existed for students to create a representation. |
| **0** | There was no meaningful effort to generate multiple representations beyond the routine work of communicating between teacher and student about the lesson (e.g., verbal instructions, written notes, lecture). |
| **Not observed** | Teacher and students were not engaged in mathematical nor science instruction that made any representations public (e.g., engaged in private written or computer work). |

Defining representation:

A mathematical or scientific representation includes written, spoken, illustrated, or gestural descriptions of a math or science concept. Representations are *distinct types* when they make use of a different physical or verbal form. Multiple representations of the *same type* exist when a single form is used (such as a table of values) but the contents of that form are substantially different and could afford different reasoning opportunities.

Examples of representations in mathematics include symbolic, tabular, graphical, visual/diagrammatic, contextual, gestural, and verbal. Examples of representations in science include diagrammatic, symbolic, contextual, verbal, tabular, graphical, and physical (modeled). Diagrams can be considered distinct types of representations if the diagrams represent significantly different interpretations of the mathematical or scientific idea (e.g., a Bohr model as compared to a Schrödinger model of an atom).

## Rubric TP4

### Facilitate meaningful disciplinary discourse (Teacher Scale)

| Score Point | Description |
|---|---|
| **4** | The discourse in this lesson focuses both on procedures (what and how) and the conceptual meanings behind the procedures. Students are asked to explain their reasoning and make connections to deeper mathematical or scientific understandings. Students are asked to justify their answers and their decisions using mathematical and scientific terminology as appropriate.<br><br>Students are consistently held accountable for engaging in these explanations; the teacher rarely takes over the thinking for the students. The teacher may contribute mathematical or scientific ideas, but does so less than half the time as compared to the student body. |
| **3** | The discourse in this lesson focuses both on procedures (what and how) and the conceptual meanings behind the procedures. Students are asked to explain their reasoning and make connections to deeper mathematical or scientific understandings. They are asked to justify their answers and their decisions using mathematical and scientific terminology as appropriate.<br><br>The lesson, however, **does not merit a 4** because 50% or more of the explanations of meaning come from the teacher rather than the students. The students are asked and contribute some conceptual ideas, but the teacher contributes more than half of the meaning-making talk and work. |
| **2** | The discourse in this lesson focuses mostly on students providing brief answers and explanations of the procedures they enacted. The discussion focuses on the what and the how rather than the why related to the mathematics or science concepts being taught. There may be some interchanges in which students explain their reasoning more deeply, but most of the discourse is framed by the teacher as relating to procedures or processes without deeper explanation. |
| **1** | The dominant discourse pattern is Initiate Respond Evaluate (IRE), in which the teacher invites responses that are procedural in nature, students respond, and the teacher evaluates correctness. This pattern is evident in most of the opportunities for discourse. |
| **0** | There was no discussion of the task. |
| **Not observed** | |

Facilitate meaningful disciplinary discourse (Student Scale; adapted from IQA)

| Score Point | Description |
|---|---|
| **4** | Students show/describe written work for solving a task and/or engage in a discussion of the important mathematical/scientific ideas in the task. During the discussion, students provide complete and thorough explanations of why their strategy, idea, or procedure is valid; students explain why their strategy works and/or is appropriate for the problem; students make connections to the underlying mathematical or scientific ideas (e.g., "I divided because we needed equal groups," "the principles of the carbon cycle suggest that less plant biomass will reduce the amount of soil carbon available").<br>OR<br>Students show/discuss more than one strategy or representation for solving the task, provide explanations of why/how the different strategies/representations were used to solve the task, *and/or make connections between strategies or representations.*<br>*[Thorough presentation and discussion across strategies or representation]* |
| **3** | Students show/describe written work for solving a task and/or engage in a discussion of the important mathematical/scientific ideas in the task. During the discussion, students provide explanations of why their strategy, idea, or procedure is valid and/or students begin to make connections BUT the explanations and connections are not complete and thorough (e.g., student responses often require extended press from the teacher, are incomplete, lack precision, or fall short making explicit connections).<br>OR<br>Students show/discuss more than one strategy, representation, or model for solving the task, and provide explanations of why/how the individual strategies/representations/models were used to solve the task *but do not make connections between different strategies, representations, or models.*<br>*[Thorough presentation and/or discussion of individual strategies, representations, or models (no crosstalk)]* |
| **2** | Students show/describe written work for solving the task (e.g., the steps for a multiplication problem, finding an average, or solving an equation; what they did first, second, etc.) but do not engage in a discussion of why their strategies, procedures, or models work*; do not make connections to mathematical or scientific concepts.*<br>*[Procedural explanations only]*<br>OR<br>Students show/discuss only one strategy, representation, or model for solving the task. |
| **1** | Students provide brief or one-word answers (e.g., fill in blanks);<br>OR<br>Student's responses are non-mathematical or non-scientific. |
| **0** | There was no discussion of the task. |
| **Not observed** | |

# Rubric TP5

## Pose purposeful questions

| Score Point | Description |
|---|---|
| **4** | The questions asked by the teacher (and students, as applicable) included questions that prompted a high level of mathematical or scientific thinking. Questioning regularly pressed students to explain their thinking making use of underlying mathematical or scientific constructs. |
| **3** | The questions asked by the teacher (and students, as applicable) included questions that prompted a high level of mathematical or scientific thinking. Questioning regularly pressed students to explain their thinking making use of underlying mathematical or scientific constructs.<br>However, the lesson did not merit a 4 because the questions asked directed student thinking towards a particular way of thinking about the mathematics or science topic,<br>**OR**<br>The teacher asks questions that prompt a high level of mathematical or scientific thinking but acts as the primary evaluator of whether responses to those questions are correct. |
| **2** | The questions asked by the teacher are a mix of questions that prompt a high level of mathematical or scientific thinking and questions that are procedural or engender single-word answers. The balance of high-level questions in the lesson is 50% or less. |
| **1** | The teacher's questions are almost exclusively questions with single-word or brief answers that do not represent high-level thinking. Answering these questions fully includes recounting steps of a procedure or memorized facts only. |
| **0** | Students are not asked questions during the lesson. |
| **Not observed** | The format of the lesson was such that questioning was not applicable or visible (e.g., students worked independently on computers or worked collaboratively on a lab investigation in pairs the entire observed lesson). |

Characteristics of high-level questions:

- The teacher's questions triggered divergent modes of thinking. (RTOP/ACEPT)
- Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence (RTOP/ACEPT)
- Intellectual rigor, constructive criticism, and the challenging of ideas were valued. (RTOP/ACEPT)
- Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so. (RTOP/ACEPT)
- Questions probe student thinking, asking students to "explain, elaborate, or clarify their thinking, including articulating the steps in solution methods or the completion of a task" (NCTM 2014, p. 36)
- Questions make mathematical/scientific ideas visible, asking students to "discuss mathematical [or scientific] structures and make connections among mathematical [or scientific] ideas and relationships" (NCTM 2014, p. 37)
- Questions encourage reflections and justification, "reveal[ing] deeper understanding of their reasoning and actions, including making an argument for the validity of their work" (NCTM 2014, p. 37)

# Rubric TP6

## Build procedural fluency from conceptual understanding through meaningful application and lab design

| Score Point | Description |
|---|---|
| **4** | The lesson was focused on conceptual understanding as a precursor to procedural fluency. Conceptual understanding was prioritized in the lesson **or** had been a part of a previous lesson and was explicitly activated as prior knowledge. Procedural fluency was connected to conceptual understanding in the lesson **or** was clearly previewed as a next step following the conceptual work. |
| **3** | The lesson was focused on conceptual understanding as a precursor to procedural fluency in either of the conditions listed in Score Point 4.<br>However, the lesson does merit a 4 because:<br>-If the lesson was focused on procedural fluency, conceptual understanding was not explicitly activated as prior knowledge **or**<br>-If the lesson was focused on conceptual understanding, there was no connection made forward by students or the teacher to future procedural fluency work. |
| **2** | The lesson was focused primarily on learning and/or rehearsing specific mathematical or scientific procedures. The teacher notes that work on conceptual understanding, such as the application of the procedures in contextual situations or an authentic lab- or exploration-based learning experience, will take place in the future. |
| **1** | The lesson was focused primarily on learning and/or rehearsing specific mathematical or scientific procedures. There is no communicated expectation that the procedural work will be linked to a conceptual understanding as a part of future learning. |
| **0** | It is not clear whether students are working on procedural fluency or conceptual understanding based on the observed lesson. |
| **Not observed** | No new instruction occurred related to procedures or concepts (e.g., students worked on a task with no new learning component). |

Note: The teacher's description of how the lesson situates in a multi-lesson progression related to procedural fluency or conceptual understanding can come from a pre- or post-lesson interview. It does not have to be publicly stated during class time. If a lesson is observed related to conceptual understanding, the connections to procedures/procedural fluency do not have to be extant in the lesson; a 3 or 4 score can be awarded if it is clear from talk during the lesson or pre- or post-lesson interviews that students will be engaged in procedural work in the future. Similarly, if the work is focused on procedures and it is clear that work on concepts preceded the observed lesson, a score of 3 or 4 can be awarded.

## Rubric TP7

### Support productive struggle in STEM learning

| Score Point | Description |
|---|---|
| **4** | Students are engaged in productive struggle, and the teacher supports that productive struggle *most often* using **affordance**.<br>Affordance involves asking the student to articulate what they have done, encouraging continued effort with limited intervention, allowing students time to work. |
| **3** | Students are engaged in productive struggle, and the teacher supports productive struggle *most often* using **probing guidance**.<br>Probing guidance involves determining what the student is thinking, encouraging self-reflection, and offering ideas based on student thinking. |
| **2** | Students show some evidence of productive struggle, but that struggle is not supported. The teacher most often responds to struggle using **directed guidance**.<br>Directed guidance involves redirecting students to another strategy consistent with the teacher's thinking. |
| **1** | Students show some evidence of productive struggle, but that struggle is not supported. The teacher most often responds to struggle using **telling**.<br>Telling involves supplying students with information that removes the struggle. |
| **0** | The task students were given provided opportunities for productive struggle, but students did not show evidence of engaging in that struggle. **Or**<br>Teacher guidance was **unfocused or vague** and did not necessarily support or inhibit the productive struggle (e.g., read the problem again and think about it). |
| **Not observed** | The task did not provide meaningful opportunities for productive struggle. |

This is adapted from the work of Warshauer (2015) as expanded by Smith, Steele, & Raith (2017).

# Rubric TP8

## Elicit and use evidence of student thinking

| Score Point | Description |
|---|---|
| **4** | Teacher regularly **elicits** student thinking through inviting student contributions (explicitly or implicitly).<br>Student thinking contributions are used and **frequently linked** to one another and to the teacher's comments.<br>Student thinking contributions are **closely connected** to the instructional goals of the lesson and advance the mathematical or scientific discourse towards those goals.<br>Student thinking that contains **mathematical or scientific inaccuracies are identified and discussed**; the teacher plays a clear role in identifying and supporting discussion of inaccuracies or misconceptions. |
| **3** | Teacher regularly **elicits** student thinking through inviting student contributions (explicitly or implicitly).<br>Student thinking contributions are used and **linked** to the teacher's comments but may not consistently be linked to one another.<br>Student thinking contributions are **closely connected** to the instructional goals of the lesson and advance the mathematical or scientific discourse towards those goals.<br>Student thinking that contains **mathematical or scientific inaccuracies are identified and discussed**; the discussion of inaccuracies or misconceptions may be incidental (driven by student contributions) rather than intentionally driven by the teacher. |
| **2** | Teacher occasionally **elicits** student thinking through inviting student contributions (explicitly or implicitly); there are some parts of the lesson where student input is not welcomed or invited.<br>Student thinking contributions are used and **occasionally linked** to the teacher's comments.<br>Student thinking contributions are **connected** to the instructional goals of the lesson and advance the mathematical or scientific discourse towards those goals.<br>Student thinking that contains **mathematical or scientific inaccuracies are not discussed**; this may be through explicit dismissal of inaccuracies, teacher correction, or an absence of such discussion. |
| **1** | Teacher occasionally **elicits** student thinking through inviting student contributions (explicitly or implicitly); for some portions of the lesson, student input is not welcomed or invited.<br>Student thinking contributions are used and **rarely linked** to the teacher's comments or the instructional goals (e.g., student thinking is elicited but not used). |
| **0** | No student thinking is elicited or used during the lesson. |
| **Not observed** | Students were not engaged in a mathematical or scientific task. |

Notes:

Teacher evaluating correctness of student contributions does not count as linking.

Score points 3 and 4 represent eliciting <u>and</u> using student thinking including inaccuracies; score point 2 represents eliciting <u>and</u> using student thinking that does not include inaccuracies and is a bit less consistent; score point 1 represents eliciting but not using. Score point 0 represents neither eliciting nor using.

## Appendix G Emailed Invitation to Attend Focus Groups

LPS Mathematics and Science Teachers:

Thank you to everyone who participated in the two needs assessment surveys this winter for the Midwest Master Teacher Project (MMTP), a joint project between Lakeside University and Lakeside Public Schools funded by the National Science Foundation. The MMTP project is on schedule for a Fall 2016 launch of a professional development program for high school mathematics and science teachers holding Masters degrees. This project would require a five-year commitment to participate in the professional development and will provide a $10,000 annual stipend for participation.

The MMTP team will be holding focus groups in April to provide more information about the project and to further understand your professional development needs and interests. Dates, times, and locations for the meetings are shown below.
Please use the Doodle link below to RSVP for one of the sessions. Attending the focus group does not commit you to the project, but is an important next step in learning more and making sure the project fits your professional learning needs.
If you have additional questions regarding the focus groups or the project, please visit the MMTP website at xxx.edu/xxxx or contact Dr. S in the LU Department of Curriculum and Instruction at xxx@xxx.edu. We look forward to seeing you at one of the focus group meetings next month!

-The MMTP Team

Link to RSVP: <<link included>>

Dates:
Wednesday, 6 April 2016, 4:30-5:30pm Cedar High School
Wednesday, 13 April 2016, 4:30-5:30pm Hawthorne High School
Thursday, 21 April 2016, 4:30-5:30pm, Hickory High School
Saturday, 23 April 2016, 10-11am, Sycamore High School

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LPS Mathematics and Science Teachers:

A reminder that we will be holding focus groups starting this week to gauge interest in participation in the Midwest Master Teacher Project (MMTP), a joint project between Lakeside University and Lakeside Public Schools funded by the National Science Foundation. The MMTP project is on schedule for a Fall 2016 launch of a professional development program for high school mathematics and science teachers holding Masters degrees. This project would require a five-year commitment to participate in the professional development and will provide a $10,000 annual stipend for participation.

The goal of the focus groups is to provide more information about the project and to further understand your professional development needs and interests. An RSVP link is included below. If you have already RSVP'd, thank you - a confirmation will be sent out the day before your selected session. Please encourage other colleagues to come along to the session, even if they have not registered in advance.

**We know your time is valuable! All teachers attending the session will be eligible for a $50 stipend for their time.**

If you have additional questions regarding the focus groups or the project, please visit the MMTP website at xxx.edu/xxx or contact Dr. S in the LU Department of Curriculum and Instruction at xxxx@xxx.edu. We look forward to seeing you at one of the focus group meetings starting this week!

## Appendix H Focus Group Protocol

The goals of the focus group with teachers are for the project team to better understand teacher professional development needs related to content and pedagogy, the ways in which they might think about a balance of content and pedagogy across the PD, to provide a brief overview of the grant and an in-depth look at one or more badges, and to get preliminary ideas about logistics for the group. Our role as facilitators of the focus group is to listen more than we talk, but also to keep the conversation focused on the topics that we wish to learn more about. Questions to ask exactly as worded appear in regular font. Notes to the focus group interviewers appear in *blue italics*.

---

### Part 1: Project Overview (10 minutes)

*Start the audio recording now.*

*Present the project overview using slides or handout developed by the team.*

Applications for teams to participate in the project will be available at the end of April. We will share these via email and on the MMTP project site, xxx.edu/xxxx. We'll look at the specifics of a badge and discuss the logistics of the project meetings at the end of our session today. Are there any questions on the content or requirements of the project at this time?

*Allow time for questions.*

---

### Part 2: Discussion of Content Learning (15 minutes)

*Display on a handout or slides the topics that were most prominent areas for content learning using Survey 1 data.*

The first part of our focus group will concentrate on the mathematics and science content that might be learned during the 5-year MMTP project.

*Show content themes.*

This slide/handout shows the content area themes that arose in the first survey as possible focus areas for the MMTP professional development. These are areas where teachers had a lower confidence their own abilities as well as areas that showed inconsistency in implementation.

*Teachers may need clarification on the meaning of some of the themes shown.*

First, are there areas that you don't see on this list that you believe are important to include in the design of the professional development?

*Allow time for responses; record ideas publicly if possible for reference.*

Considering the list of topics we have here, which specific focus areas would you participate?

*When ideas run out or the allotted time ends, move on to the next topic.*

---

### Part 3: Discussion of Pedagogical Learning (15 minutes)

*Display on a handout or slides the topics that were most prominent areas for pedagogical learning using Survey 2 data.*

The next part of our focus group will concentrate on teaching practices that might be learned during the 5-year MMTP project.

*Show pedagogical themes that are going well.*

The first set of themes are instructional practices that seem to be strong among respondents to the second survey. Do you have any comments related to these themes?
*If needed, probe with the following:* Are these things you believe are going well in your school? Or do you believe the identified areas could be improved?
*Show pedagogical themes that are focus areas for the PD.*
This slide/handout shows the instructional practice themes that arose in the second survey. These are potential focus areas for the MMTP professional development modules.
Are there teaching practices missing from this list that you believe are important and should be included in the MMTP design?
*Allow time for responses; record ideas publicly if possible for reference.*
Considering this list of identified teaching practices, which specific focus areas would you want to participate?
*Allow time for responses.*
Thinking about building a collaborative, active group of teacher participants across the five-year project, what features do you think we should consider to ensure that the professional development is effective over time?
*When ideas run out or the allotted time ends, move on to the next topic.*

---

## Part 4: Obstacles to engaging in meaningful PD/changing practice (5 minutes)

MMTP will be a five-year project and require productive collaborations over time. We'd like to talk for a few minutes about the challenges related to engaging in sustained professional development and changing teaching practices.

Thinking about your past professional development experiences, what obstacles prevented you from engaging in meaningful professional development? Along those same lines, when you learned something new, what might have prevented you from implementing new practices into your teaching?
What types of previous professional development been you found most useful in your career? What specific problems have you had with professional development in the past? What types of professional development help you translate new ideas into your classroom practices?

*When ideas run out or the allotted time ends, move on to the next topic.*

---

## Part 5: Considering a Badge Example (10 minutes)

*Provide one or more badge examples for the group to consider.*
The badge design reflects a cycle of learning about a topic, designing a classroom intervention related to that topic, collecting some data on the teaching and learning from the intervention, and providing teacher and student reflections to assess effectiveness.
We are currently anticipating that all teachers will complete at least four badges per year as a part of the project together in small groups with the support of MMTP facilitators. *Give teachers a few moments to read through the example.*
What questions and comments do you have about this structure?
*When ideas run out or the allotted time ends, move on to the next topic.*

## Part 6: Logistics (5 minutes)

As we think toward the MMTP project's Fall 2016 start, we have a brief electronic poll for you to take which help us with schedule specific days and times that would fit best with your schedule.

*Provide the URL for the poll.*

*Thank participants for their time.*

**Appendix I Micro-credential Template**

# [Partner Organization Logo]

# Title

*The title is associated with the Competency. Creative names encouraged!*

## Competency

The **Competency** section identifies and describes the research-backed skill or practice the educator will be demonstrating.

| |
|---|
| [add competency description here] |

## Key Method

This section identifies the specific (but widely applicable) research-backed **Method** of achieving this competency. By employing this Method, the educator can demonstrate the research-backed skill or competency

| |
|---|
| [add key methodology description here] |

## Method Components

The **Method Components** section elaborates upon the **Key Method,** including a description of the **Key Method** and/or actionable steps or strategies for demonstrating the competency. This is the basis for the artifact submission that is later assessed according to the evaluation criteria.

| |
|---|
| [add method components here] |

## Supporting Rationale and Research

**Research** citations substantiate the effectiveness of the **Competency** and **Key Method** and must be put in MLA format. Optionally, this section can include a brief summary of the research to provide the earner with the general **Rationale** for why successful demonstration of the **Competency** can be achieved through the selected **Key Method**.

**Citation Example (MLA or APA format)**

**MLA Example**

Harris, Alma. "Distributed leadership: According to the evidence." Journal of educational administration 46.2 (2008): 172-188 http://www.emeraldinsight.com/doi/abs/10.1108/09578230810863253

**APA Example**
Harris, A. (2008). Distributed leadership: According to the evidence. Journal of educational administration, 46(2), 172-188.
http://www.emeraldinsight.com/doi/abs/10.1108/09578230810863253

| |
|---|
| [add supporting rationale and research here] |

# Resources (optional)

This optional section can include any resources that might aid or support the teacher as they build the particular competency associated with this micro-credential.

| |
|---|
| [add resources here] |

# Submission Guidelines & Evaluation Criteria

*This section can have multiple parts - one part for each section of the submission process.*

| |
|---|
| [After you have specified each part of the submission, please describe the scores necessary for each part to earn the micro-credential.]<br><br>*Example*: "*To earn the micro-credential, you must receive a passing evaluation for Parts 1, 3, and 4 and a "Yes" for Part 2."* |

## Part 1. Overview Questions (Provides Context)

Often, Part 1 allows earners to provide context for the evidence they are submitting for this micro credential.

*Educators from many educational settings complete micro-credentials, so it's important to craft these overview questions carefully to give the assessor a good idea of the classroom environment.*

Each of the overview questions is complemented with passing criteria for assessors. The passing criteria also give earners an idea of how they will be assessed.

| |
|---|
| [add overview questions here in bullet form, with sub-bullets describing what a passing response would include] |

## Part 2. Work Examples/Artifacts/Evidence

Part 2 describes the artifacts potential earners must submit as evidence towards demonstrating competency for this micro-credential. Each artifact is assessed according to a rubric defined by the micro-credential developer. Rubrics can have a wide range of columns and rows. Artifacts can be video, photographic, textual, or any other appropriate medium for demonstrating competence.

[add a description of the artifact that you would like educators to submit.]
(this can be a video, audio, plan, etc)

Example: Please submit a link to a video that shows two distinct CFU sequences, along with text analyzing each clip according to the questions below (200-word limit for each clip).

**Part 2. Scoring Guide (Example)**

*Your artifact submission will be assessed based on the following rubric. You must earn a "Yes" score on this portion of the total submission in order to earn the micro-credential.*

| "Yes" | "Almost" | "Not Yet" |
|---|---|---|
| Describe an artifact that completely satisfies the requirements necessary to demonstrate competency | Describe an artifact that almost meets the requirements necessary to demonstrate competency | Describe an artifact that does not meet the requirements necessary to demonstrate competency |

## Part 3 Reflection (optional)

Part 3 might ask the earner to reflect on what they've learned while completing the micro-credential, how the incorporation of the competency has affected their current practice, or how the attained competency might impact their practice in the future. Part 3 could also include student reflections on a specific lesson or activity. Similarly, Part 3 could provide additional context for the artifacts submitted by the earner in the evidence/artifacts section (part 2).

[add reflection or other types of additional assessment here. Each question/component should be accompanied by the passing criteria (like part 1).]

**Appendix J  Example of a Content-focused Micro-credential**

# Teaching Math with Technology A: Focus on Rates of Change in Algebra

## Competency

The **Competency** section identifies and describes the research-backed skill or practice the educator will be demonstrating.

| |
|---|
| Educator uses technological tools to plan and execute a secondary mathematics lesson focused on representing change/rates of change. |

## Key Method

This section identifies the specific (but widely applicable) research-backed **Method** of achieving this competency. By employing this Method, the educator can demonstrate the research-backed skill or competency

| |
|---|
| The educator uses technologies such as Desmos or TI-84+ graphing calculators to plan, teach, and reflect on a lesson in secondary mathematics focused on representing change and/or rates of change. |

## Method Components

The **Method Components** section elaborates upon the **Key Method,** including a description of the **Key Method** and/or actionable steps or strategies for demonstrating the competency. This is the basis for the artifact submission that is later assessed according to the evaluation criteria.

1. Complete the Technology in Algebra self-assessment (bit.ly/MMTPmta). Discuss your self-assessment with a math colleague and/or your technology coordinator in your school or district.
2. Explore the following tasks related to representing change and rate of change using Desmos (see links in Resources section):
   Polygraph: Distance-Time Graphs
   Marbleslides
   You're So Fined
   Choosing an Appropriate Growth Model
3. Read *Catalyzing Change* (pp. 37-43, 45-55, and More4U Examples)
   - Identify a topic related to the NCTM Essential Concept from Catalyzing Change: "*expressions can be rewritten in equivalent forms using algebraic properties, including properties of addition, multiplication, and exponentiation, to make different characteristics or features visible.*"
4. After experiencing the activities and reading the excerpt from Catalyzing Change related to the Essential Concept, consider the following:
   - What did you need to know to get started on each of the activities?

- What did this help you see or understand that you would not have understood about the mathematics that kids need to know with a more traditional sort of activity?
- How can a technology like this remove barriers to entry for students in learning the mathematics concepts highlighted in Catalyzing Change?
- What are hallmarks of a good task which uses technology?

5. Design a lesson that makes use of similar technology to teach a lesson related to the Essential Concept appropriate for your grade level. Specify the ways in which the use of technology in the lesson provides students with unique engagement in the mathematics that a pencil-and-paper activity would not provide.
6. Teach the lesson. Video record the lesson and use at least two methods of assessing student thinking related to the Essential Concept. Collect student voice data about the use of technology in the lesson.
7. Analyze your data and reflect on the lesson. Write up and submit your reflection, including a video clip that exemplifies student engagement in the mathematics.

# Supporting Rationale and Research

National Council of Teachers of Mathematics (2018). Catalyzing change in high school mathematics: Initiating critical conversations. Reston, VA: NCTM.
National Council of Teachers of Mathematics (2018). Catalyzing Change: More4U Examples for Essential Concepts in Algebra and Functions. Retrieved from https://www.nctm.org/uploadedFiles/Publications/More4U/Catalyzing_Change_in_High_School_Mathematics_Initiating_Critical_Conversations/Essential%20Concepts%20in%20Algebra%20and%20Functions%20Additoinal%20Examples.pdf

# Resources

**Desmos tasks related to rate of change**
Graphing Stories
https://teacher.desmos.com/activitybuilder/custom/58797d35d81a612605304b1f
Polygraph: Distance-time graphs
https://teacher.desmos.com/polygraph/custom/560ad68f7701c303063305f5

Linear Bundle – a series of 7 activities leading students through understandings of linear rates of change
https://teacher.desmos.com/linear
Included activities:
*Polygraph: Lines
https://teacher.desmos.com/polygraph-lines
Polygraph: Lines Part 2
https://teacher.desmos.com/activitybuilder/custom/5755ed8c0d942e9b07b65b98
Put the point on the line
https://teacher.desmos.com/activitybuilder/custom/57f3dd9dcf3c849008d81007
Match My Line
https://teacher.desmos.com/activitybuilder/custom/5605bb5f00701ed10fb09314
Land the Plane

https://teacher.desmos.com/activitybuilder/custom/582b81f4bf3030840aacf265
Card Sort: Linear Functions
https://teacher.desmos.com/activitybuilder/custom/5785081e72fcab925a4ef95f
*Marbleslides: Line (includes domain restrictions but allows for play. The later problems get challenging)
https://teacher.desmos.com/activitybuilder/custom/566b31734e38e1e21a10aac8
Lego Prices (fitting a line to data, works with a 3-act task)
https://teacher.desmos.com/activitybuilder/custom/57e563aa072703f509160cc2

Investigating rate of change from an equation
https://teacher.desmos.com/activitybuilder/custom/5673095054bf1351078e195d
Investigating rate of change
https://teacher.desmos.com/activitybuilder/custom/584f275271adce170c8d13f4

Which is steepest? -- Investigates the concept of "steepness" for nonnegative slopes (This is below high-school grade level)
https://teacher.desmos.com/activitybuilder/custom/56b8d8ec6fb01b1648653477

Exponential Bundle – 7 activities dealing with exponential rates
https://teacher.desmos.com/exponential
Included activities:
Avi and Benita's Repair Shop
https://teacher.desmos.com/activitybuilder/custom/56c7457e11c7724106e683b1
Polygraph: Exponentials
https://teacher.desmos.com/polygraph/custom/56c3947ce3a0912c0a942de0
What comes next?
https://teacher.desmos.com/activitybuilder/custom/56c7458cb289584109c2d337
Marbleslides: Exponentials
https://teacher.desmos.com/activitybuilder/custom/566b317b4e38e1e21a10aafb
Card sort: Exponentials
https://teacher.desmos.com/activitybuilder/custom/579bd9fe3037419e171c207d
Predicting movie ticket prices
https://teacher.desmos.com/activitybuilder/custom/581394efa64518b3069b6de7
Game, Set, Flat
https://teacher.desmos.com/activitybuilder/custom/57ee9583d2f184680755ac5d

**Technology-enhanced tasks**
These tasks can (and probably should) be done using technology. This can be Desmos or a graphing calculator, but they are greatly enhanced using technology rather than being done by hand.
Laptop Battery Charge 2 (linear)
https://www.illustrativemathematics.org/content-standards/tasks/1559
Used Subaru Foresters 1 (linear)
https://www.illustrativemathematics.org/content-standards/tasks/941
Boiling Water (linear-ish)
https://www.illustrativemathematics.org/content-standards/tasks/1592
Decaying Dice (exponential)
https://www.illustrativemathematics.org/content-standards/tasks/2130
Identifying Exponential Functions (exponential)

https://www.illustrativemathematics.org/content-standards/tasks/2115
Basketball Rebounds (exponential)
https://www.illustrativemathematics.org/content-standards/tasks/347
Comparing Exponentials (exponential)
https://www.illustrativemathematics.org/content-standards/tasks/213
Folding Paper (exponential)
https://www.illustrativemathematics.org/content-standards/tasks/2114
*Choosing an Appropriate Growth Model (linear, quadratic, exponential)
https://www.illustrativemathematics.org/content-standards/tasks/1594

Domino Effect (linear, grade 8)
http://mathalicious.com/lessons/domino-effect
Green Acres (linear and exponential)
http://mathalicious.com/lessons/green-acres
*You're So Fined (linear)
http://mathalicious.com/lessons/you-re-so-fined
Carpe Donut (nonlinear)
http://www.mathalicious.com/lessons/carpe-donut

**Templates**
5 Practices lesson planning template for mathematics
https://www.nctm.org/uploadedFiles/Publications/More4U/5_Practices_for_Orchestrating_Productive_Mathematics_Discussion,_2nd_Edition/Lesson%20Planning%20Protocol%20Chart.pdf
Sample monitoring chart template
https://www.nctm.org/uploadedFiles/Publications/More4U/5_Practices_for_Orchestrating_Productive_Mathematics_Discussion,_2nd_Edition/Monitoring%20Chart.pdf

# Submission Guidelines & Evaluation Criteria

*This section can have multiple parts - one part for each section of the submission process.*

*To earn this micro-credential, you must receive a passing evaluation for Parts 1 and 3, and a "Yes" for each component in Part 2.*

## Part 1. Overview Questions (Provides Context)

After your engagement in the Desmos tasks and reading of the Essential Concept, write a narrative that addresses the following:

- What did you need to know to get started on each of the activities?
- What did this help you see or understand that you would not have understood about the mathematics that kids need to know with a more traditional sort of activity?
- How can a technology like this remove barriers to entry for students in learning the mathematics concepts highlighted in Catalyzing Change?

**Passing:** Narrative connects features of the activity with mathematical ideas represented in the Essential Concept. Reasonable intellectual barriers are identified that can be removed by the technology. A clear sense of what the technology affords over traditional activity is present.

## Part 2. Work Examples/Artifacts/Evidence

To earn this micro-credential, submit the following:

- A lesson plan based on a technological task related to rate of change.
- Analysis of artifacts from your implemented lesson (video, student work, transcripts, teacher and student reflections) from the lesson, including at least two modes of assessment. Describe what students learned through their engagement in the lesson.

### Part 2. Scoring Guide

| | "Yes" | "Almost" | "Not Yet" |
|---|---|---|---|
| Task | Task makes use of technology in an integral way<br><br>Technological task directly addresses an aspect of rate of change | Task makes use of technology in an integral way<br><br>May not be directly evident how the task addresses an aspect of rate of change | Task is not technological<br><br>OR<br><br>Task does not represent appropriate grade-level material for the teacher's classroom. |
| Lesson Plan | Lesson plan justifies the use of the technological task in supporting learning related to the essential concept identified<br><br>Lesson plan contains clear support for implementing the task in ways that support rich student thinking<br><br>Lesson plan provides multiple forms of assessment that includes measuring conceptual understanding of big mathematical ideas | Lesson plan justifies the use of the technological task in supporting learning related to the essential concept identified<br><br>Aspects of instructional enactment and/or assessment may not be clear | Lesson plan is underdeveloped or only supports the development of procedural understandings |
| Analysis | Analysis of the lesson shows evidence of student learning related to the mathematics<br><br>Analysis of the lesson identifies ways in which the technology supported student learning<br><br>Analysis includes multiple types of artifacts as evidence | Analysis includes only 2 out of the three criteria under the 'yes' section | Analysis includes 1 or fewer of the criteria in the 'yes' section |

## Part 3 Reflection

Submit the following reflections on engaging with this competency:

- A reflection on the implementation of the technology and how it supported student thinking during the lesson
- Identifying changes the teacher would make to this task OR principles to guide the selection of future tasks related to technology
- A description of how planning, teaching, and assessing the lesson helped the teacher better understand the essential mathematics concept and how students learn rate of change

**Passing**: Reflection discusses implementation, student learning, changes to the lesson or principles for future technology use, and how the teacher better understands the essential concept related to rate of change

## Part 4 Time Accounting and Micro-credential Feedback

Please indicate the amount of time you spent on the micro-credential and the major activities in the micro-credential. Provide any feedback for how the micro-credential might be changed to better meet your needs as a teacher in the future.

**Passing**: Educator provides sufficient information on the time they spent working on the micro-credential, as well as provides feedback on the content of the micro-credential.

**Appendix K Example of a Pedagogy-focused Micro-credential**

# Developing Conceptual Understanding Through Task Selection in Math and Science

## Competency

Educator investigates a framework for selecting and implementing high cognitive demand tasks in mathematics and science, examines factors which support or inhibit the maintenance of a high level of cognitive demand during implementation, then plans and analyzes a lesson related to such that improves professional practice and student learning outcomes.

## Key Method

Using the Math or Science Tasks Framework, the educator examines the cognitive demand of science or mathematics tasks used in their classroom over a sequence of lessons. The educator chooses an instructional factor to focus on that supports or inhibits the cognitive demand in order to adopt routines which support maintenance of cognitive demand.

## Method Components

1. Pre-assessment: factors that support or inhibit the cognitive demand, and identifying your focal factor for the micro-credential
2. Sort tasks in math and science by cognitive demand
3. Review the Task Analysis Guide for Math and Science and the Mathematics or Science Task Framework that discusses implementation of tasks
4. Select a factor related to cognitive demand to serve as the focus for task selection and implementation
5. Explore strategies to modify tasks to increase the cognitive demand

a. Choose a task from their instructional resources, classify it by cognitive demand, and modify it as needed to enhance the cognitive demand

6. Collect data from 5-10 lessons that includes the following:
    a. The mathematics or science task you used for that lesson, classified by cognitive demand
    b. The factors that support or inhibit cognitive demand that were evident in your reflection on the lesson
    c. For one lesson early in the sequence and one task late in the sequence, four pieces of student work, two of which represent high-level performance and two of which represent low-level performance
    d. Student reflections at the end of the sequence of instruction related to your focal factor

# Supporting Rationale and Research

Arbaugh, F. & Brown, C. A. (2005). Analyzing Mathematical Tasks: A Catalyst for Change? *Journal of Mathematics Teacher Education, 8*, 499-536. https://link.springer.com/article/10.1007%2Fs10857-006-6585-3?LI=true

Boston, M. & Smith, M. P. (2009). Transforming Secondary Mathematics Teaching: Increasing the Cognitive Demands of Instructional Tasks Used in Teachers' Classrooms. *Journal for Research in Mathematics Education, 40*(2), 119-156. http://www.jstor.org/stable/40539329?seq=1#page_scan_tab_contents

Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, Launching, and Implementing High Quality Learning Opportunities for Students That Advance Scientific Thinking. *Journal of Research in Science Teaching, 53*(9), 1316-1340. http://escholarship.org/uc/item/5qw3675d.pdf

Stein, M. K. & Lane, S. (1996). Instructional Tasks and the Development of Student Capacity to Think and Reason: An Analysis of the Relationship between Teaching and Learning in a Reform Mathematics Project. *Educational Research and Evaluation, 2*(1), 50-80.

Tekkumru Kisa, M. & Stein, M. K. (2015). Learning to See Teaching in New Ways: A Foundation for Maintaining Cognitive Demand. *American Educational Research Journal, 52*(1), 105-136. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.846.7266&rep=rep1&type=pdf

Tekkumru-Kisa, M., Stein, M. K., & Schunn, C. (2015). A Framework for Analyzing Cognitive Demand and Content-Practices Integration: Task Analysis Guide in Science. *Journal of Research in Science Teaching, 52*(5), 659-685. http://www.lrdc.pitt.edu/schunn/research/papers/Tekkumru-Kisa_et_al-2015-Journal_of_Research_in_Science_Teaching.pdf

# Resources (optional)

Carter, J. L., Smith, M. S., Stein, M. K., & Ross, D. K. (2013). *5 Practices for Orchestrating Productive Task-Based Discussions in Science*. Reston, VA: National Council of Teachers of Mathematics.

Smith, M. S. & Stein, M. K. (2011). *5 Practices for Orchestrating Productive Mathematics Discussions*. Reston, VA: National Council of Teachers of Mathematics.

# Submission Guidelines & Evaluation Criteria

*This section can have multiple parts - one part for each section of the submission process.*

To earn this micro-credential, you must receive a passing evaluation on Parts 1 and, 3 and a "yes" on Part 2.

## Part 1. Overview Questions (Provides Context)

Identify a factor related to cognitive demand in math or science that you intend to focus on in your instruction for this badge. Describe how your teaching currently embodies (or doesn't embody) this factor, and why you want to change this factor in your practice. Include your thinking about how attending to this factor will support stronger student outcomes.

Passing: Educator identifies of a factor from the list of factors that support or inhibit cognitive demand, connections to current practice, and connections to student outcomes.

## Part 2. Work Examples/Artifacts/Evidence

- Submit tasks from 5-10 lessons representing a stretch of consecutive days of instruction while you have been working on this micro-credential.
  - For each task, identify the cognitive demand of the task using the math or science Task Analysis Guide as appropriate.
  - Write a brief narrative (about a paragraph) describing how your focal factor did or did not come into play with each tasks.
- Write a brief (1-2 page) reflection across the set of tasks.
  - What did you notice about the cognitive demand of the tasks you chose?
  - How did your thinking about your focal factor change over time?
  - What was the impact on student learning?

**Part 2. Scoring Guide (Example)**

*Your artifact submission will be assessed based on the following rubric. You must earn a "Yes" score on this portion of the total submission in order to earn the micro-credential.*

| "Yes" | "Almost" | "Not Yet" |
|---|---|---|
| 5-10 tasks are included and classified by cognitive demand<br><br>The brief paragraphs following each task make a substantive connection between the focal factor, the task, and the task's implementation<br><br>A trajectory of progress over time with task demand and implementation of the factor is evident in the individual and overarching narrative | 5-10 tasks are included and classified by cognitive demand, with some being inaccurate<br><br>The brief paragraphs following each task make a substantive connection between the focal factor and the task, but details about implementation are thin<br><br>A trajectory of progress over time with task demand and implementation of the factor is evident in the individual and overarching narrative | Less than 5 tasks are included or the tasks are largely classified inaccurately with respect to cognitive demand<br><br>Connections to the factor are superficial or absent |

## Part 3 Reflection

Provide a summary of student feedback about this set of lessons. This could be in the form of aggregating individual lesson feedback or a survey or discussion held at the end of the sequence of instruction.

Passing: Student voices are represented in excerpted or aggregated data and explicit connections are made to the focal factor for the project.

## Part 4 Time Accounting and Badge Feedback

Please indicate the amount of time you spent on the badge and the major activities in the badge. Provide any feedback for how the badge might be changed to better meet your needs as a teacher in the future.

**Appendix L  Example of a Leadership-focused Micro-credential (Year 2)**

# Designing and Supporting Teacher Learning - I

## Competency

Educator utilizes research to understand the theoretical underpinnings of teacher learning, professional development, and leadership as it relates to their analysis of school-based learning data and gaps among high-need student subgroups, and analysis of student learning data.

## Key Method

The educator researches the theoretical underpinnings of teacher learning, change, and development. The educator next investigates strategies that promote a range of professional learning and organizational development outcomes and determines teases apart, recognizes, and addresses factors that promote or hinder teacher learning and professional development within the multiple and embedded contexts of urban schools. The educator analyzes multiple sources of data to identify and isolate learning gaps among high-need student subgroups and explores how great leaders inspire action.

## Method Components

**Components of Teacher Leadership to Improve Instructional Practices**

- Research the theoretical underpinnings of teacher learning, change, and development.
- Investigate strategies that promote a range of professional learning and organizational development outcomes.
- Distinguish, recognize, and address factors that promote or hinder teacher learning and professional development within the multiple and embedded contexts of urban schools.
- Analyze multiple sources of data to identify and isolate learning gaps among high-need student subgroups.
- Explore how great leaders inspire action.

**Suggested Implementation**

It is suggested that the work be completed in a small learning community to accomplish and discuss the learning activities.

1. Examine various teacher learning and development theories.
2. Map teacher leadership research to experiences.
3. Engage in a critical exploration of the alignment between and among learning data, students' opportunities to learn, and teachers' current instructional practice.

4. Investigate the foundational tenets of leadership so you may develop your own.

This learning grounds the professional development project you will orchestrate in the micro-credential **Designing and Supporting Teacher Leadership - Part II.**

# Supporting Rationale and Research

Today, national and nationally initiated state education policies tie the standards of student success expected at each grade level to teacher effectiveness. The theory of action in these efforts is to improve teachers' practices and elevate student achievement levels, particularly for learners historically underserved by local public schools (e.g., Bales, 2006; Daly, Moolenaar, Der-Martirosian, & Liou, 2014; Desimone, Smith, & Phillips, 2013; Hamilton, Stecher, & Yuan, 2008). Classroom teachers sit at the confluence of these policies, making instructional decisions about how to best support students' academic growth. At the same time, they must be cognizant of their own learning so they stay current with new content knowledge and pedagogical practices, while paying close attention to the accountability mechanisms that measure their performance. Teachers, as instructional leaders, can facilitate this required new learning (e.g., Amore, Hoeflich, & Pennington, 2015; Bond, 2015; Ronfeldt, Farmer, McQueen, & Grissom, 2015). This badge examines the current research on teacher learning, professional development, and teacher leaders. In doing so, traditional understandings of a teacher leader's development as the acquisition of a finite package of knowledge and skills is replaced with a vision of professional practice that is intersubjective, dynamic, and pluralistic in nature (Dall'Alba & Sandberg, 2006; Wenner & Campbell, 2017).


- Amore, A., Hoeflich, N., & Pennington, K. (2015). Teacher leadership: The pathway to Common Core success. https://cdn.americanprogress.org/wp-content/uploads/2015/04/CCTeacherVoiceFinal.pdf
- Borko, H. (2004). Professional development and teacher learning: Mapping the Terrain. Educational Researcher, 33(8), 3-15. https://journals.sagepub.com/doi/pdf/10.3102/0013189X033008003
- Center for American Progress (Producer). (2013). Teacher Learning Through Assessment: How Student-Performance Assessments Can Support Teacher Learning. http://www.americanprogress.org/events/2013/09/06/73638/teacher-learning-through-assessment/
- Center for Strengthening the Teaching Profession. (2015). Teacher Leader Self-Assessment. Retrieved from http://cstp-wa.org/cstp2013/wp-content/uploads/2013/11/CSTP_self_assessment.pdf
- Dall'Alba, G., & Sandberg, J. (2006). Unveiling professional development: A Critical review of stage models. Review of Educational Research, 76(3), 383-412. https://journals.sagepub.com/doi/pdf/10.3102/00346543076003383

- Daly, A. J., Moolenaar, N. M., Der-Martirosian, C., & Liou, Y. (2014). Accessing capital resources: Investigating the effects of teacher human and social capital on student achievement. Teachers College Record, 116(7). https://www.tcrecord.org/Content.asp?ContentId=17486
- Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). Effective Teacher Professional Development. Palo Alto, CA: Learning Policy Institute. https://learningpolicyinstitute.org/sites/default/files/product-files/Effective_Teacher_Professional_Development_REPORT.pdf
- Desimone, L., Smith, T., & Phillips, K. (2013). Linking Student Achievement Growth to Professional Development Participation and Changes in Instruction: A Longitudinal Study of Elementary Students and Teachers in Title I Schools. Teachers College Record, 115(5). http://www.tcrecord.org/content.asp?contentid=16963
- Fishman, B., Konstantopoulos, S., Kubitskey, B., Vath, R., Park, G., Johnson, H., & Edelson, D. (2013). Comparing the Impact of Online and Face-to-Face Professional Development in the Context of Curriculum Implementation. Journal of Teacher Education, 64(5), 426-438. https://journals.sagepub.com/doi/pdf/10.1177/0022487113494413
- Garrett, R., & Steinberg, M. (2015). Examining teacher effectiveness using classroom observation scores: Evidence from the randomization of teachers to students. Educational Evaluation and Policy Analysis, 37(2), 224-242. https://journals.sagepub.com/doi/pdf/10.3102/0162373714537551
- Hill, H., Beisiege, M., & Jacob, R. (2013). Professional Development Research: Consensus, Crossroads, and Challenges. Educational Researcher, 42(9), 476-487. https://journals.sagepub.com/doi/pdf/10.3102/0013189X13512674
- Institute for Educational Sciences. (2017). What Works Clearinghouse. https://ies.ed.gov/ncee/wwc/
  Kennedy, M. M. (2016). How does professional development improve teaching? Review of Educational Research, 86(4), 945-980. https://journals.sagepub.com/doi/pdf/10.3102/0034654315626800
- Kintz, T., Lane, J., Gotwals, A., & Cisterna, D. (2015). Professional development at the local level: Necessary and sufficient conditions for critical colleagueship. Teaching and Teacher Education, 51, 121-136. https://www.sciencedirect.com/science/article/pii/S0742051X15001018
- Kyndt, E., Gijbels, D., Grosemans, I., & Donche, V. (2016). Teachers' everyday professional development: mapping informal learning activities, antecedents, and learning outcomes. Review of Educational Research, 86(4), 1111-1150. https://journals.sagepub.com/doi/pdf/10.3102/0034654315627864
- Linn, M. C., Gerard, L., Matuk, C., & McElhaney, K. W. (2016). Science Education: From Separation to Integration. Review of Research in Education, 40(1), 529-587. https://journals.sagepub.com/doi/pdf/10.3102/0091732X16680788

- Loucks-Horsley, S., Stiles, K., Mundry, S., Love, N., & Hewson, P. (2009). Designing Professional Development for Teachers of Science and Mathematics (3rd ed.). Thousand Oaks, CA: Corwin Press: 17-50.
- Loucks-Horsley, S., N. Love, et al. (2009). Strategies for Professional Learning. Designing professional development for teachers of science and mathematics education (3rd ed.). Thousand Oaks, CA, Corwin Press: 157-271.
- Murphy, P. K., & Knight, S. L. (2016). Exploring a Century of Advancements in the Science of Learning. Review of Research in Education, 40(1), 402-456. https://journals.sagepub.com/doi/pdf/10.3102/0091732X16677020
- Pullin, D. (2015). Performance measures for teachers and teacher education: Corporate education reform opens the door to new legal issues. Education Policy Analysis Archives, 23(81). https://eric.ed.gov/?id=EJ1084088
- Ronfeldt, M., Farmer, S. O., McQueen, K., & Grissom, J. A. (2015). Teacher collaboration in instructional teams and student achievement. American Educational Research Journal, 52(3), 475-514. https://journals.sagepub.com/doi/pdf/10.3102/0002831215585562
- Schoenfeld, A. H. (2016). Research in mathematics education. Review of Research in Education, 40(1), 497-528. https://journals.sagepub.com/doi/pdf/10.3102/0091732X16658650
- Spillane, J. P. (2002). Local theories of teacher change: The pedagogy of district policies and programs. Teachers College Record, 104(3), 377-420. http://bit.ly/35TG7Sq
- Tam, A. C. F. (2015). The role of a professional learning community in teacher change: a perspective from beliefs and practices. Teachers and Teaching, 21(1), 22-43. https://www.tandfonline.com/doi/abs/10.1080/13540602.2014.928122
- Wenner, J. A., & Campbell, T. (2017). The theoretical and empirical basis of teacher leadership: A review of the literature. Review of Educational Research, 87(1), 134-171. https://journals.sagepub.com/doi/pdf/10.3102/0034654316653478


# Resources

Teacher Learning through Assessment:
https://www.americanprogress.org/events/2013/09/06/73638/teacher-learning-through-assessment/
Start with why: How great leaders inspire action:
https://youtu.be/u4ZoJKF_VuA
Teacher Leader Self-Assessment:
http://cstp-wa.org/cstp2013/wp-content/uploads/2013/11/CSTP_self_assessment.pdf

# Learning Opportunities

It is suggested that the work be completed in a small learning community to accomplish and discuss the learning activities.

- **Research** theoretical underpinnings of teacher learning, change, and development. **Read**: Borko (2004); Kennedy (2016); and Dall'Alba (2016).
- **Investigate** strategies that promote a range of professional learning and organizational development outcomes. **Watch**: Teacher Learning through Assessment.
- **Read**: Darling-Hammond, et. al. (2017); Loucks-Horsley, et. al., (2010) and any two (2) models of professional development specific to your discipline.
- **Tease apart** factors that promote or hinder teacher learning and professional development within the multiple and embedded contexts of urban schools. **Read and write an abstract** on any two of the following: Amore, et. al., (2015); Desimone, et. al., (2013), Garret & Steinberg (2015); Kintz, et. al., (2015); or Pullin (2015). **Discuss common themes across the readings**.
- **Analyze** multiple sources of data to identify and isolate learning gaps among high-need student subgroups. **Read**: Desimone, Emith, & Phillips (2013) and Daly, et. al., (2014).
- **Explore** the tenets of leadership generally, and teacher leadership specifically. **Read** Wenner & Campbell (2017). **View the Video**: "Start with why: How great leaders inspire action" (link in Resources above)
- Complete the Teacher Leader Self-Assessment (link in Resources above)

# Submission Guidelines & Evaluation Criteria

To earn the Designing and Supporting Teacher Leadership micro-credential, you must receive a "passing" on Part 1 and a "Yes" evaluation on Part 2.

## Part 1: Overview

Please submit the Graphic Organizer of Teacher Learning and Development Theories and two (2) Professional Development Models used in the teaching and learning of mathematics and science.

Passing: Educator offers a Graphic Organizer illustrating the relationships among the teacher learning and development theories shared in the readings. The organizer provides a brief description of the theories, describes the theories of action with one (1) supporting quote, and includes a complete citation for each quote.

## Part 2: Work Examples/Artifacts

To earn this micro-credential, your submission must include each of the following items:

- An artifact (video, PowerPoint, narrative) that maps the factors that promote teacher learning and professional development to your own teacher leadership experiences. It includes a robust discussion of the following:
- Compares how the factors that promote teacher learning and professional development map to your own teacher leadership experience(s).

- Shares what was learned, with examples.
- Identifies areas for further investigation.
- A packet that includes department-, school-, and/or district-based student and/or teacher learning data illustrating differences among student subgroups.
- A representation of your leadership style, with an accompanying explanatory narrative illustrating the interactions among teacher learning, professional development, and instructional leadership research, with identified areas of strength and needed growth. For example, there may be an animal or metaphor that depicts your leadership style.
- A cogent argument that directs changes in practice through reflection, literature provided, and other self-identified research.

**Part 2. Scoring Guide (Example)**

*Your artifact submission will be assessed based on the following rubric. You must earn a "Yes" score on this portion of the total submission in order to earn the micro-credential.*

| Area of Focus | Yes | Almost | Not Yet |
|---|---|---|---|
| **Teacher Learning and Professional Development Graphic Organizer** | Organizer offers each of the following:<br>• Provides a brief description of the theory.<br>• Describes its theory of action with one (1) supporting quote.<br>• Offers a complete citation for each quote. | Organizer offers two (2) of the following or moderately addresses each:<br>• Provides a brief description of the theory.<br>• Describes its theory of action with one (1) supporting quote.<br>• Offers a complete citation for each quote | Organizer offers one (1) of the following or superficially addresses each:<br>• Provides a brief description of the theory.<br>• Describes its theory of action with one (1) supporting quote.<br>• Offers a complete citation for each quote. |
| **Mapping Research on to your Teacher Leadership Experiences (Video, PowerPoint, or Narrative Paper)** | Mapping includes a robust discussion of the following:<br>• Compares how the factors that promote teacher learning and professional development map to your own teacher leadership experience.<br>• Shares what was learned, with examples.<br>• Identifies areas for further investigation. | Mapping includes two (2) of the following or modestly addresses each:<br>• Compares how the factors that promote teacher learning and professional development map to your own teacher leadership experience.<br>• Shares what was learned, with examples.<br>• Identifies areas for further investigation. | Mapping includes only one (1) of the following or tenuously addresses each:<br>• Compares how the factors that promote teacher learning and professional development map to your own teacher leadership experience.<br>• Shares what was learned, with examples.<br>• Identifies areas for further investigation. |
| **Department, School, and/or District Data Packet *(High Fidelity Simulation)*** | Packet includes each of the following four (4) items:<br>• School Improvement Plan or equivalent.<br>• Previous year's classroom-, department-, or school-level data (or the equivalent) illustrating differences among student subgroups.<br>• Two (2) instructional goals isolated from the data. | Packet includes three (3) of the following items:<br>• School Improvement Plan or equivalent.<br>• Previous year's classroom, department, or school-level data (or the equivalent) illustrating differences among student subgroups.<br>• Two (2) instructional goals isolated from the data. | Packet includes fewer than three (3) of the following items:<br>• School Improvement Plan or equivalent.<br>• Previous year's classroom-, department-, or school-level data (or the equivalent) illustrating differences among student subgroups.<br>• Two (2) instructional goals isolated from the data. |

| | | | |
|---|---|---|---|
| | • Department, school, or district professional development goals. | • Department, school, or district professional development goals. | • Department, school, or district professional development goals. |
| **Representation of leadership style *(On the Job Transfer)*** | Representation of leadership style includes an accompanying explanatory narrative illustrating the following:<br>• Interactions among teacher learning, professional development, and instructional leadership research.<br>• Identified areas of strength and needed growth. | Representation of leadership style includes an accompanying explanatory narrative illustrating one (1) of the following:<br>• Interactions among teacher learning, professional development, and instructional leadership research.<br>• Identified areas of strength and needed growth. | Representation of leadership style includes an accompanying explanatory narrative that superficially addresses or omits discussion of the following:<br>• Interactions among teacher learning, professional development, and instructional leadership research.<br>• Identified areas of strength and needed growth |
| **Use of Supporting Research** | Submission includes a cogent argument that directs changes in practice through reflection, literature provided, and other self-identified research. | Submission includes a plan for changes in practice through reflection and literature provided. It does not include other self-identified research. | Submission includes a superficial plan for changes in practice, but argument does not draw on reflection or the literature. |

**Appendix M Example of a Leadership-focused Micro-credential (Year 4)**

# Planning to Lead Instructional Change in Mathematics and Science

## Competency

Educator identifies design principles for leading educational change, and links them to specific features of teacher professional development and/or curriculum design to be enacted in a forthcoming instructional change initiative.

## Key Method

The educator uses the tenets of research-based effective professional development and curriculum design in mathematics and science to plan a series of activities to support instructional change.

## Method Components

**Identify Practices and Strategies**

Identify your strengths regarding key teaching practices and powerful strategies related to micro-credential work you have completed in the first four years of this project. Identify your top five strengths related to teaching and learning and how you know that you could provide some leadership and guidance for others in need of such strengths. What have you learned in your work with the Midwest Master Teacher Partnership? What evidence do you have for changes to your practice that would demonstrate the strengths? What aspects of those strengths would you like to share with others and mentor others accordingly?

**Change Initiative**

Identify the type of change you'd like to lead in the next school year. This will be a year-long initiative that will likely involve a mix of leadership activities, data collection, and data analysis. Your change initiative should fit into one of the following categories:

- mentoring PreK-8, or 6-12 teachers,
- mentoring beginning teachers,
- strengthening research-based instructional practices
- curriculum development and implementation, or
- other initiative related to teacher change, within a school or cross-school

Describe how your proposed change initiative relates to, as appropriate:

1. Lakeside Public Schools (LPS) Science Needs Assessment, LPS Mathematics Needs Assessment, LPS Professional Development Rubric (High-Quality Professional Learning Strategy) and
2. What you consider to be your strengths when providing PD for needs.

### Review Research

Review the provided research literature related to instructional change and best practices as appropriate. Your MMTP facilitator might have additional resources for you depending on your intended change initiative. Discuss how the ideas in the research literature might influence the design of the change initiative you'd like to lead.

### Outline the Intervention

Begin with a set of design principles based on the research literature. Describe the timeline of tasks, who the participants will be in the work (leaders and subjects), and describe the data you will collect and how that data assesses the effectiveness of the change initiative. Your assessment is likely to include multiple data sources that help to determine the impact of the change initiative on teachers and teaching, student learning, and systemic conditions. The plan should extend through the 2020-21 school year. Review this plan with your MMTP facilitator and/or appropriate LPS leaders.

### Formalize with Stakeholders

Bring to district stakeholders to formalize the plan. The following elements help with this formalization:

- If you are mentoring teachers and working with a different school or schools: Have a planning meeting with the target school officials – school support teacher and Principal for input and approval. Each school has an induction plan that must be filed for each school by September 1 of the school year. If you are going to work with teachers within a school and provide professional development, you must have the conversation with the school support teacher and Principal before the end of the school year in order to be part of the induction plan for 20-21. Therefore, as part of the development of your leadership plan for year 5, the plan must be in place and approved before the end of the 19-20 school year, or it will not be filed on time, and you will not be able to implement the intended professional development.
- If you are mentoring other teachers in your department or within your school, *m*eet with your administrative team and discuss how common planning time could be used for these purposes, where appropriate.
- If you are developing a new course or curriculum development, *b*ecome familiar with the process of getting a new course approved. LPS curriculum specialists can help you with this process.
- If you are planning external conference presentations as a part of your work, *c*onsult with MMTP staff and make sure you're aware of the deadlines.

# Supporting Rationale and Research

- National Council of Supervisors of Mathematics (NCSM). (2008). The PRIME Leadership Framework: Principles and Indicators for Mathematics Education Leaders. https://www.mathedleadership.org/resources/shop.html
  Executive Summary:
  https://www.mathedleadership.org/docs/resources/prime/NCSM_PRIME_Text_55-59.pdf
- NCSM. (2020). NCSM Essential Actions: Framework for Leadership in Mathematics Education.
  https://www.mathedleadership.org/resources/shop.html
  Executive Summary:
  https://www.ns2.mathedleadership.org/docs/resources/essentials/EssentialActions-ExecSummary.pdf
- Hill, Heather C. (2020). Teacher PD Gets a Bad Rap. But Two Approaches Do Work. *Education Week.* Available online at:
  https://www.edweek.org/ew/articles/2020/02/24/teacher-pd-gets-a-bad-rap-but.html
- Smith, M. S. (2001). Practice-based professional development for teachers of mathematics. National Council of Teachers of Mathematics.
- Hochberg, E. D., & Desimone, L. M. (2010). Professional development in the accountability context: Building capacity to achieve standards. *Educational psychologist*, *45*(2), 89-106.
  https://doi.org/10.1080/00461521003703052


# Resources

The following resources are available on the MMTP SharePoint site.

**Resources (General)**

- Lakeside Public Schools Professional Development Rubric

**Resources (Mathematics)**

- Lakeside Public Schools Mathematics Needs Assessment

**Resources (Science)**

- Lakeside Public Schools Science Needs Assessment

# Submission Guidelines & Evaluation Criteria

To earn this micro-credential, you must receive a passing evaluation for Parts 1, 3, and 4, and "Yes" for part 2.

## Part 1: Overview

Identify strengths that correspond with school district needs, and share your answers to the following prompts.

- What are your top five strengths related to teaching and learning? Identify and describe how you know you could provide leadership and guidance for others in need of such strengths.

- Describe and define the match between LPS Science Needs Assessment, LPS Mathematics Needs Assessment, LPS Professional Development Rubric (High-Quality Professional Learning Strategy) and what you consider to be your strengths when providing PD.
- Review the provided research literature related to instructional change as appropriate and provide a summary of the design principles for your project.

**Passing:** Educator provides a narrative that fully addresses each of the three points above. Educator provides a narrative that identifies strengths of teaching and learning and connects those strengths to opportunities to teach other educators. Educator identifies an area of need within the department, school, district, or other entity, supporting the need as it's identified in district documents. Educator provides a narrative of the design principles of the project and supports these design principles with literature related to instructional change.

## Part 2: Work Examples / Artifacts

To complete the micro-credential, please submit the following evidence for your implementation plan regarding the activities, formative and summative assessment of the impact of professional development, and your pilot project.

**Intervention Outline**: share an outline of the intervention that includes: frequency of tasks, timeline, and participants.

*Note: it should be specific enough if someone with the same set of skills and expertise as you could implement the plan*.

- **Professional Development Induction Plan:** upload artifacts representing the PD you will provide in the targeted school's induction plan with a justification for how you think the PD will affect teaching and learning regarding the target audience.
- **Assessment Data for Impact**: upload a narrative that describes when, what, and how you will collect formative and summative assessment data to help you determine the impact of providing PD.
- **Professional Development Alignment**: upload a narrative that describes how your efforts are synergistic with the other PD that is occurring with the target teachers or school, and the receptivity of the school leadership toward your intended contribution.

## Part 2. Scoring Guide

| | Yes | Almost | Not Yet |
|---|---|---|---|
| Intervention Outline | The outline of intended PD activities is specific and thorough. Includes frequency of tasks, timeline, and participants | The outline of intended PD activities needs some improvement; includes only two of the three elements. | The outline of the intended PD is not specific or thorough; includes one or no essential elements. |

| | | | |
|---|---|---|---|
| Professional Development Induction Plan | Artifacts represent the PD that will be provided, and the justification is specific and comprehensive. | Artifacts represent some of the PD, but not all that will be provided. The justification is not specific. | Artifacts and justification were not uploaded. |
| Assessment Data for Impact | Description of the formative and summative assessment plans are present and consistent with measures of intended impact. Method by which the assessments are collected is clearly explained. | Description of formative and summative assessment plans are present, but not consistent with the measures of intended impact. Method by which the assessments are collected is nonspecific. | Description of formative and summative assessment plans are not present. Method by which the assessments are collected are not present or inconsistent. |
| Professional Development Alignment | Description includes how the plan works with other PD that is happening with target teachers or school, and is specific in how receptive school leadership is with the plan. | Description includes only one of the following:<br>• how the plan works with other PD that is happening with target teachers or school<br>• how receptive school leadership is with the plan<br>• both descriptions of how the plan works and how receptive school leadership is, but descriptions are nonspecific to determine alignment or receptivity | Descriptions were not uploaded. |

## Part 3: Reflection

Reflect on the activities you experienced when preparing the plan for your change initiative. Be sure to address the following:

- How has your prior micro-credential work and four years of involvement in MMTP placed you in a good position to lead change for teachers and schools?
- What challenges did you face when planning for your initiative? What skills or experience did you need to be better positioned to lead change with other teachers?
- Provide a sense of what you anticipate in terms of impact of the change initiative when working in partnership with the leadership of the target teachers and school. What do you think will go well? What might be some potential difficulties to overcome to reach the goals?
- What recommendations do you have for others if they were thinking about planning for and leading change with teachers and schools?

**Passing:**

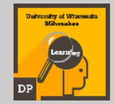
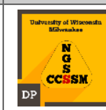
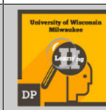
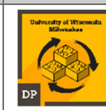
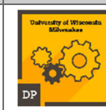
Reflection connects to educator experiences with past micro-credentials, outlines challenges to planning and personal needs for making the project successful, describes anticipated successes and challenges, and provides recommendations.

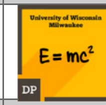
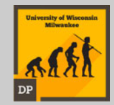
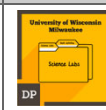
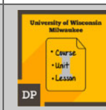
## Part 4: Time Accounting and Micro-credential Feedback

Please indicate the amount of time you spent on the micro-credential and the major activities in the micro-credential. Provide any feedback for how the micro-credential might be changed to better meet your needs as a teacher in the future.

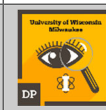
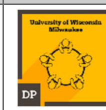
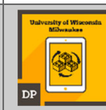
**Passing**: Educator provides sufficient information on the time they spent working on the micro-credential, as well as provides feedback on the content of the micro-credential.

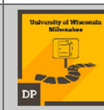
# Appendix N Project Micro-credentials

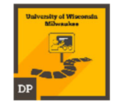
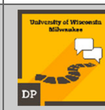
| *Year first offered* | *Micro-credential Title* | *Description (paraphrased from Competency and Key Method)* | *Image* | *Type* | *Primary Author(s) (alphabetical)* |
|---|---|---|---|---|---|
| 1 | Using Action Research to Improve Teaching and Learning | Participants identified an area of inquiry within their practice, wrote a question that could be answered through action research, conducted a review of the literature, and designed a study intended to answer the question. |  | Foundations | Dr. B |
| 1 | NGSS and CCSSM in Action | Participants unpacked the content knowledge of a set of math or science standards, designed an assessment to measure student progress toward those standards, and analyzed the data from the assessment. |  | Pedagogy | Dr. A, Dr. C, Dr. S |
| 1 | Using Action Research to Improve Teaching and Learning II | Participants conducted the action research study designed in Part 1, collected classroom data, analyzed the data, drew conclusions, and shared their results. |  | Foundations | Dr. B |
| 1 | Models and Modeling - Mathematics | Participants examined mathematical modeling as presented in the CCSSM and GAIMME Report, examined several sample modeling tasks, and planned, taught, and reflected on a lesson that used mathematical modeling. |  | Pedagogy | Dr. A, Dr. C, Dr. S |
| 1 | Models and Modeling - Science | Participants examined scientific models and the use of scientific models in instruction, different types of scientific models, and planned, taught, and reflected on a lesson that used scientific modeling. |  | Pedagogy | Dr. A, Dr. C, Dr. S |
| 2 | Student Engagement and Motivation in STEM Education | Participants examined their own motivations, learned about motivation for students, and designed, taught, and reflected on a lesson designed to promote high student engagement. |  | Pedagogy | Dr. C, Dr. S |
| 2 | Designing and Supporting Teacher Learning I | Participants investigated theories of and strategies for teacher learning, examined their own leadership experiences and style, and identified potential areas for future leadership and teacher learning. |  | Leadership | Dr. B |

| ***Year first offered*** | ***Micro-credential Title*** | ***Description (paraphrased from Competency and Key Method)*** | ***Image*** | ***Type*** | ***Primary Author(s) (alphabetical)*** |
|---|---|---|---|---|---|
| 2 | Models and Modeling II Mathematics | Participants identified student understandings and misconceptions from a recent lesson, and designed, taught, and reflected on a lesson that used mathematical modeling to address the misconceptions. |  | Pedagogy | Dr. A, Dr. S |
| 2 | Models and Modeling II Science | Participants identified student understandings and misconceptions from a recent lesson, and designed, taught, and reflected on a lesson that used science modeling to address the misconceptions. |  | Pedagogy | Dr. A, Dr. S |
| 2 | Matter and Energy | Participants planned, taught, and analyzed a lesson around the crosscutting concept of matter and energy. |  | Content | Dr. A |
| 2 | Evolution in Action | Participants examined their own and student understandings of evolution, and designed, taught, and reflected on a unit on evolution. |  | Content | Dr. C |
| 2 | Developing Conceptual Understanding Through Task Selection in Math & Science | Participants identified a factor that supports or inhibits maintenance of cognitive demand that they want to improve upon and examined the cognitive demand of the tasks they used over a period of 1-2 weeks. |  | Pedagogy | GRA, Dr. S |
| 2 | Instructional Design Part 1: Developing a Course Curriculum | Participants use backward design to design a plan for a new course by identifying the key ideas and acceptable evidence and designing learning experiences. |  | Pedagogy | GRA, Dr. S |
| 2 | Supporting Productive Struggle | Participants defined productive struggle, identified ways teachers can support students struggle, and planned, taught, and reflected on a lesson designed for students to encounter and work through struggle. |  | Pedagogy | Dr. S |
| 2 | Designing and Supporting Teacher Learning II | Participants identified learning gaps in their schools and designed, presented, and reflected on a professional development initiative to address the learning gaps. |  | Leadership | Dr. B |

| *Year first offered* | *Micro-credential Title* | *Description (paraphrased from Competency and Key Method)* | *Image* | *Type* | *Primary Author(s) (alphabetical)* |
|---|---|---|---|---|---|
| 2 | Instructional Design Part 2: Developing and Piloting Units and Lessons | Participants planned in detail a unit from the previously designed new course, using backward design, piloted the unit or part of the unit, and made revisions based on the pilot results. | | Pedagogy | Dr. S |
| 2 | Questioning and Discourse in Math and Science: Analyzing Types of Teacher Questions | Participants planned and taught lessons designed to feature meaningful discussion and analyzed their questioning patterns in those lessons. | | Pedagogy | Dr. C, Dr. S |
| 3 | Five Practices for Orchestrating Productive Mathematics and Science Discussions I | Participants planned, taught, and reflected on a lesson designed to engage students in discussions using the 5 practices of anticipating student responses, monitoring small-group work, selecting and sequencing responses to be shared, and connecting student responses to key math or science ideas through whole-class discussion. | | Pedagogy | Dr. S |
| 3 | Planning and Implementing Open Inquiry in Science I | Participants investigated the purposes of open in quiry in science and planned, taught, and reflected on a science lesson that incorporated open inquiry. | | Pedagogy | Dr. A, Dr. C |
| 3 | Collaborative Coaching | Participants learned about collaborative coaching practices, engaged in collaborative coaching with a colleague, and reflected on the experience. | | Leadership | Kentucky Valley Educational Cooperative |
| 3 | Teaching Math with Technology A: Focus on Rates of Change in Algebra | Participants explored technologies for teaching mathematics, explored the essential concept of Algebra and Functions from Catalyzing Change, and designed, taught, and reflected on a lesson on rates of change that incorporated technology as an essential part of the learning experience. | | Content | GRA, Dr. S |
| 3 | Facilitating Productive STEM Discourse: Press Students for Evidence Based Explanations | Participants identified a learning objective, anticipated possible student explanations and possible questions for students, conducted the lesson, and reflected on student opportunities to provide evidence-based explanations. | | Pedagogy | Trellis Education |

| *Year first offered* | *Micro-credential Title* | *Description (paraphrased from Competency and Key Method)* | *Image* | *Type* | *Primary Author(s) (alphabetical)* |
|---|---|---|---|---|---|
| 3 | Classroom-based Assessments to Improve Teaching and Learning I | Participants investigated curricular coherence and foundations of assessment, and created or upgraded an assessment to improve curricular coherence, reliability, and validity. |  | Pedagogy | Dr. B |
| 3 | Five Practices for Orchestrating Productive Mathematics and Science Discussions II | Participants examined their practices around planning, teaching, and reflecting on lessons, identified potential productive changes in those practices, planned and taught two 5 Practices lessons, and examined the impact of changes on student learning. |  | Pedagogy | Dr. S |
| 3 | Planning and Implementing Open Inquiry in Science II | Participants investigated Process Oriented Guided Inquiry Learning (POGIL) and planned, taught, and reflected on a POGIL lesson. |  | Pedagogy | Dr. A, Dr. C |
| 3 | Productive Small Group Work | Participants used cooperative learning in a lesson or series of lessons and analyzed the impact of cooperative learning on students and student learning. |  | Pedagogy | Dr. C |
| 3 | Designing and Supporting Teacher Learning III | Participants examined the National Teacher Leaders Standards and research on effective PD and upgraded or redesigned an existing PDI to improve instructional capacity and students' opportunities to learn. |  | Leadership | Dr. B |
| 3 | Environmental Education and Education for Sustainability | Participants learned about environmental education and education for sustainability and designed a sustainability project for their classroom, school, or community. |  | Content | Dr. B, Dr. C, Ms. Z |
| 3 | Teaching Math with Technology B: Focus on Mathematical Modeling | Participants explored technologies for teaching modeling in mathematics or physics, reviewed the GAIMME report and high school modeling standard, and designed, taught, and reflected on a modeling lesson that incorporated technology as an essential part of the learning experience. |  | Content | GRA, Dr. S |

| *Year first offered* | *Micro-credential Title* | *Description (paraphrased from Competency and Key Method)* | *Image* | *Type* | *Primary Author(s) (alphabetical)* |
|---|---|---|---|---|---|
| 3 | Classroom-based Assessments to Improve Teaching and Learning II | Participants investigated assessment using higher-order thinking, problem-solving, critical thinking, performance, and portfolios, and created or upgraded an assessment to include one of these assessment types and to improve curricular coherence, reliability, and validity. |  | Pedagogy | Dr. B |
| 4 | Analysis of Classroom Instruction I | Participants learned to use the SeeMeTeach observation tool as a way to use both qualitative and quantitative data to examine student engagement in their classrooms. |  | Leadership | Dr. C |
| 4 | Analysis of Classroom Instruction II | Participants used SeeMeTeach with a colleague to analyze teaching for equity and inclusion. |  | Leadership | Dr. C |
| 4 | Culturally Relevant Pedagogy | Participants learned about the framework for culturally relevant pedagogy and analyzed their current practices with respect to the CRP framework. |  | Pedagogy | Dr. A, Dr. L, Ms. R |
| 4 | Planning to Lead Instructional Change in Mathematics and Science | Participants designed an initiative intended to produce instructional change in their departments, schools, or districts. *Note: Although participants completed these plans, they were significantly changed in implementation due to COVID-19. |  | Leadership | Dr. S |
| 5 | Leading Instructional Change in Mathematics and Science: Curriculum Development and Implementation | Participants designed a unit of curriculum, implemented the unit, collected data on the implementation, and reflected on the success of the unit. Part of a series of interconnected MCs focusing on leading change in mathematics and science education. |  | Leadership | GRA, Dr. S |
| 5 | Leading Instructional Change in Mathematics and Science: Professional Development Design & Implementation | Participants designed a PD session, implemented the PD, collected data on the implementation, and reflected on the success of the PD. Part of a series of interconnected MCs focusing on leading change in mathematics and science education. |  | Leadership | Dr. S |

| *Year first offered* | *Micro-credential Title* | *Description (paraphrased from Competency and Key Method)* | *Image* | *Type* | *Primary Author(s) (alphabetical)* |
|---|---|---|---|---|---|
| 5 | Leading Instructional Change in Mathematics and Science: Data Collection and Analysis | Participants chose a construct of interest to study, chose or designed a measurement tool, and analyzed the resulting data. Part of a series of interconnected MCs focusing on leading change in mathematics and science education. |   | Leadership | Dr. S |
| 5 | Leading Instructional Change in Mathematics and Science: Developing as a STEM Teacher Leader | Participants reflected on their growth as a teacher leader as a result of leading a project intended to produce instructional change in their departments, schools, or districts. Part of a series of interconnected MCs focusing on leading change in mathematics and science education. |   | Leadership | Dr. S |
| 5 | Leading Instructional Change in Mathematics and Science: Sharing Outcomes and Reflections | Participants shared the outcomes of their year-long instructional-change initiative. The culminating MC focusing on leading change in mathematics and science education. |   | Leadership | Dr. S |

## Appendix O Codebook

| Code | Description | Examples |
|---|---|---|
| **PD characteristics** | Codes are used when the teacher makes reference to valuing elements in my framework for teacher learning (Figure 4) as valuable to their learning or as part of their leadership of others. | No examples. This is used as an umbrella for the five components of my framework for teacher learning. |
| Assessment | Teacher references valuing being assessed, sharing assessment, and/or using student formative/summative assessment results as part of their learning process or as part of their leadership of others. Teacher references means of assessing their learning as part of MC expectations. Does not include explicit references to feedback, which is coded separately. | "Whether the word is 'monitoring' or 'evaluating', there were many moments that caused me to realize that the quality control aspects of our implementation of math education are not as solid as they should be." |
| Opportunity to get feedback | Teacher explicitly references feedback from MMTP facilitators, mentors, and/or peers as helpful in their learning process or as part of their leadership of others | "I hated it because I was always behind but I like the peer feedback about the badges but I was always behind but I really did appreciate the flexibility." |
| Community | Teacher makes explicit reference to the learning community or other communities they are part of as being valuable to their learning process or to their leadership of others. This does not include items already coded to checking in with peers and facilitators, shared vision, or sharing knowledge with the community. | "Teachers at all grade levels need time to collaborate with grade level teams, special education teachers, and same mathematics content teachers." |
| Checking in with peers and facilitators | Teacher explicitly references valuing community check-ins with peers and/or facilitators as being valuable in their learning process. | "And it was like that immersion into it because we always kind of brought along with it, we would have professors at our…you know, would be able to contact them when we needed them for help or ideas." |

| Code | Description | Examples |
|---|---|---|
| Shared Vision | Teacher explicitly references valuing a shared community vision as part of their learning process or as part of their leadership of others. | “We worked to define and develop a shared vision for high quality mathematics teaching and learning.” |
| Sharing knowledge with the community | Teacher explicitly references being able to share their knowledge with the learning community, with their school colleagues outside of MMTP, or with the larger mathematics teacher community as being valuable to their learning process or to their leadership of others. | “If there is truly one thing I am looking forward to, it is the opportunity to work collaboratively with other teachers to identify and approach ideas as a team.” |
| Context | Teacher notes elements of their context as being valuable to their learning process or to their leadership of others. This does not include references to experiential learning or the length of time, which use the Context sub-codes. | “This proposal aims to supplement / restructure existing math lessons through use of the following resources: (1) Our district has adopted the tenets from Catalyzing Change - Key Recommendation: High school mathematics empowers students to understand and critique the world: Students should be able to identify, interpret, evaluate, and critique the mathematics embedded in social, scientific, commercial, and political systems and experience wonder, joy, and beauty.” |
| Experiential | Teacher explicitly references having learning based in their ongoing work of teaching as valuable to their learning process or to their leadership of others. | “I grasped those concepts because we really worked hard and we were immersed in the culture.” |
| Long periods of time | Teacher references the length of time of MMTP or the length of time involved in completing a microcredential as valuable to their learning process or to their leadership of others. | “The only reason I feel even close to able to do this work is because of 5-6 years of work done leading up to it. I also would recommend taking your time because nothing is worse than when an initiative is put in motion just for the reason of putting it in place.” |
| Knowledge | Teacher stated that attention to their MKT and development of elements of their MKT were valuable to their learning process or to their leadership of others. This includes times when the teacher reflected | “Knowledge of Content and Curriculum (KCC): especially the ‘connecting’ stage allowed a deeper dive into the content. Many discussions within the algebra |

| Code | Description | Examples |
|---|---|---|
| | upon their own MKT growth, but does not include statements relating to sub-codes cognitive dissonance or coherence, or the development of teachers' general mathematical knowledge. | team and within the math department resulting from this dive into student understanding of the concepts." |
| Cognitive dissonance and discomfort | Teacher notes that they encountered cognitive dissonance, or cognitive dissonance can be inferred from their statements. | "I am learning how important this discomfort is for growth; more discomfort, more growth." |
| Coherence | Teachers stated that the coherence of the learning across all of MMTP was valuable to their learning process or to their leadership of others. | "The progression of the badges I think really met my needs. I felt like there was a progression there." |
| Mathematical Knowledge | Teacher stated that developing their mathematical knowledge as part of developing MKT was valuable to their learning process or to their leadership of others. This is distinguished from knowledge in general by referencing general mathematical knowledge. | "For example, if we are going to be asking teachers to reflect on how to implement a certain task, then we should probably start by asking the teachers to work through that task for themselves." |
| Teacher-centered | Teacher stated that themselves being the central consideration of the learning experiences in MMTP was valuable to their learning process or to their leadership of others. | "Something I saw the value in, you know, I never felt like I was asked to do something that wasn't benefiting me." |
| Agency in learning | Teachers stated that being able to choose their learning path and topics was valuable to their learning process or to their leadership of others. | "And I enjoyed the research stuff at the beginning, but I really enjoyed, appreciated, and was kind of pleasantly… gifted with the direction it then turned into with the different topics that we had to pick from and essentially areas of learning and the materials that were then provided to like learn and collaborate around all the different badges." |
| Motivation | Teacher stated that attention to building motivation for learning or their existing motivation for learning was | "Other PD's I took were good but also seemed to be missing the 'why'. The only other PD I really enjoyed other than the current MMTP would be Link Crew |

| Code | Description | Examples |
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| | valuable to their learning process or to their leadership of others. | training. The 'why' was well addressed as well as 'active learning strategies' and goals." |
| Paying teachers for their time | Teacher referenced being compensated for their time spent on professional learning as being valuable to their learning process or to their leadership of others. | "I mean, obviously the money helped to make me want to run through the finish line, 'cause there were definitely times where it was, you know, this is a lot on me right now." |
| Recognition of accomplishments | Teacher noted that external recognition of accomplishments was valuable to their learning process or to their leadership of others. | "They lent a lot of credibility to what you were doing beyond just, like, this is nice for me. And I felt like it made me feel like more of a professional and more of a master of what I was doing beyond just like nobody carrying in my building." |
| Supporting individual learning needs | Teacher stated that consideration of their own individual needs as experienced teachers was valuable to their learning process or to their leadership of others. | "The struggle is real right now, but I always knew that after the fact, when the dust settled, all of these things that I had done were going to make me better. And so it's just, like, drive through it and you'll be able to appreciate this a lot more on the back end. It will make you better at your job." |
| **Research** | This is a grouping of all codes related to teacher statements about research and the research process. | No examples. This is used as an umbrella for all codes relating to teachers' experiences as researchers. |
| Awareness of bias and assumptions | Teacher explained the importance of being aware of one's own bias and assumptions while conducting research. | "I feel like I have covered many different areas of study but I worry that it will clearly portray the success of the circle. I included the word success because I will also admit my bias to my study, another challenge." |
| Care for those being studied | Teacher expressed the necessity to have consideration and care for those being studied, including adherence to ethical guidelines. | "I personally feel that there is a slight ethical dilemma involved in [controlled experimental design] type of study, specifically when prior research points toward a benefit in one style of instruction." |

| Code | Description | Examples |
|---|---|---|
| Causation | Teacher used causal language when describing results of research. | "The purpose of the project being to identify if providing students options for homework assignments will lead to improved results on assessment." |
| Confidence as a researcher | Teacher expresses that confidence at being a researcher is important to them. | "My biggest struggle has been feeling confident in my strategies for collecting data. I feel like I have covered many different areas of study but I worry that it will clearly portray the success of the circle." |
| Correlation | Teacher used correlational language when describing results of research. | "The purpose of this research is to determine the connection between the use of technology and student learning." |
| Positivism | Teacher expresses value in viewing research from a scientific, single Truth lens. | "As an educator, we are involved in a scientific field based in the study of (ideally) specified actions and the responses they elicit. Those responses are observed and their result informs on how to proceed from there." |
| Qualitative | Teacher expresses value in analysis of qualitative data as valid for research and drawing conclusions about teaching and learning. | "Main themes from student included that Desmos allowed them to make an easier visualization of what was happening with each city's population trend." |
| Quantitative | Teacher expresses value in analysis of quantitative data as valid for research and drawing conclusions about teaching and learning. | "Try different methods of formative assessment that include self-monitoring and self-assessment within one class. Compare their test scores with test scores of a class that used more standard methods of formative assessment." |
| **Teaching Practices** | The eight teaching practices identified in Principles to Actions (NCTM, 2014). | No examples. This is used as an umbrella for all codes relating to the eight effective teaching practices. |
| Establish goals to focus learning | Teacher makes direct reference to lesson goals or discusses using goals to direct learning. | "The final student learning goal was for students to gain more familiarity with starting value, rate of |

| Code | Description | Examples |
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| | | change and the connection between graphs and equations.” |
| Implement tasks that promote reasoning and problem solving | Teacher makes reference to classroom task as being high cognitive demand. Teacher includes actual high-demand classroom task. The tasks fall into the categories of Procedures with connections or Doing Mathematics. Use of modelling tasks is included in this code. | “Students were given an opening task to find the number of possible outcomes for a four digit pin without repeating. Students are given time to think/share/compare on outcomes then given notes.” |
| Use and connect representations | The teacher shows they value having students use different representations and make conceptual connections between the representations. The teacher articulates a plan for students to use different mathematical representations, that they have encouraged the students to use multiple representations during class, that they have encouraged students to make conceptual connections between different representations, and/or representations are used/connected during whole-class discussions. | “The S-Pattern Task, seen in Figure 1 below, is a nice task because it aims at getting students to provide multiple representations of the relationships they observe, such as written descriptions, geometric representations and functions that describe terms in the pattern.” |
| Facilitate meaningful discourse | The teacher makes explicit reference to purposeful orchestration of whole-class and/or small-group discourse. This includes explicit references to using the 5 Practices or to teacher discourse moves. This code does not include instances of classroom discussion that were not purposefully planned, which are coded as "student discussion of mathematics" | “I would have other students repeat or check in to make sure everyone understood the comment made. I would attempt to do this even in ‘normal times’ with the goal of including the reluctant to speak participants.” |
| Pose purposeful questions | Teacher references purposeful questions that assess or advance student thinking. These include higher-order thinking questions but not questions that gather information or require a yes/no response. Teacher values pre-planning questions. | “Here is where the assessing questions become incredibly helpful. To have students explain their understanding, identify what it is that they are confused about with the task, and provide a small |

| Code | Description | Examples |
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| | | piece of insight that might allow them to understand the concept better.” |
| Build procedural fluency from conceptual understanding | Teacher makes reference to building students' conceptual understanding of mathematics as a precursor to or in conjunction with building students' procedural competency. Specifically includes references to both conceptual understanding and procedural fluency. Statements that included only one are coded separately. | “Really trying to bring in more conceptual first and then hitting the you know procedural after. And just really making that a focus. It makes my room look totally different in that just how I pitch a lesson. I still get pushback on that. My co-teacher in the one class says, ‘well, I think you should just tell him how to do it all first and then you can play with this other stuff later.’ So, it's an interesting push, pull. And I will even say to the co-teacher, I'll say, ‘Yeah, I hear what you're saying, and I'm not convinced my way is gonna work. But I know this other way is not working.’ And so that's kind of where we're at with that. |
| Support productive struggle | Teacher references students struggling productively. Teacher discusses strategies used or planned to support student struggle. | “I expect to improve the way I engage my students by using different questioning methods. My goal is to improve student learning and engagement by being less directive and more guiding in working with student mathematical thinking.” |
| Elicit and use evidence of student thinking | Teacher references purposeful elicitation of student thinking. Teacher references use of student thinking to move the understanding of the class forward. | “One way I supported students in this task was by stopping them once I saw all students had reached a critical slide in the Desmos task, and then asking questions to the whole group, as well as sharing some student responses. It allowed me to help students who had drawn incorrect conclusions to adjust their thinking, so students who had drawn incorrect conclusions to adjust their thinking, so that they could move forward with a better understanding. Being able to see all of their responses allowed me to have that shared work, appropriate questions and even students selected to share their thinking all ready to go. |

| Code | Description | Examples |
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| Values in teaching | | No examples. This is used as an umbrella for all codes relating to teachers' values about teaching and learning. |
| Agency in teaching | Teacher references valuing having the freedom to choose instructional materials and methods as they see fit, including feeling like they are able to adapt instruction with minimal interference from the outside. This also includes the teacher referencing feeling constrained by various outside requirements, such as the textbook, curriculum guides, pacing guides, standardized tests, and standards. | "I look to follow the book as much as possible, but do not hesitate supplementing with lessons that promote the desired student goals."<br><br>"Although the selection of content, tasks and activities may not be as learner driven as it should be, due to constraints such as national and district standards, time and large numbers of diverse learners." |
| Alignment to CCSSM | Teacher references the CCSSM standards (including specific CCSSM standards in lesson plans) or the importance of teaching to standards that are at grade level. | "When students have gaps in their learning, we address them, but our curriculum and pacing are directly tied to high school content standards… When planning lessons, I always start with the CCSS content standards."<br><br>"The properties of exponents, because that's a middle school standard, so we don't teach that." |
| Assessment of students | Teacher references assessment of student knowledge, understanding, and/or procedural fluency. This includes a range of assessment, including formative, summative, and standardized tests. | "The proficiency level on the exit ticket and unit assessment are higher than normal, and the percent of students who were at the minimal level is significantly smaller."<br><br>"I also use homework in order to know if the lesson was effective."<br><br>"I like to have students go to the board to explain to help me formatively assess understanding." |

| Code | Description | Examples |
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| Asset-based thinking | Teacher references students' assets as they exist and/or as a means of moving student thinking forward. This includes the teacher referencing their own belief that all students can learn mathematics. | "I believe all students will learn and know I have had success with many students with low scores and little confidence."<br><br>"Because of my strong relationships, I am able to see the whole child better and learn about the assets they bring to our learning relationship." |
| Building a positive math identity | Teacher references creating a culture to help students build a positive math identity. | "My goals with Restorative Practices to be cognitive of the relationships is my classroom and use these practices to proactively and, if needed, relatively cultivate these relationships. By relationships, I mean student to student, student to teacher and student to mathematics. Identifying and attending to these as well as making sure discourse is fair, students can feel more connected and included in their math experience. This meets another goal of my school; a positive math identity." |
| Building community and relationships | Teacher references building the classroom community and/or building relationships with students and/or having students build relationships with each other. | "Because I wanted students to connect to each other before attempting the problem and get a chance to share whatever level of connection they had with baseball as a way to also connect and see their opinions on the task valued, I chose to start with restorative circles in small groups." |
| Categorizing students | Teacher references categorizing students by ability, referring to students using achievement labels, underestimating what students are capable of, and other instances of deficit thinking. | "Students worked in teams of 3. Assignments were as followings: 1 group of 'high fliers', 2 groups of 'lowest', remaining groups mixed ability."<br><br>"I aim to utilize this more in my teaching, especially with students who aren't the strongest students. I am much more prone to holding someone who struggles' hand." |

| Code | Description | Examples |
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| Efficient use of time | The teacher references making use of all available time, both in and out of class, to maximize learning, making sure time in class is well-spent, and/or covering as much content as possible in a given day, week, unit, or school year. | “The great strength that this method provides is its efficiency; we can cover material faster” |
| Student Agency | Teacher references students having agency in their learning to choose representations, pursue different solution paths and strategies, enter into the problem using their own understanding, self-monitor their solution, and so on. | “Some used DESMOS, others wanted to plot points on a paper version.”<br><br>“Most students try multiple dimension approaches to finding the maximum surface area but it is important that they keep track of the dimensions they have tried in an organized fashion, looking for any patterns or indications on how to maximize the surface area. Students who cannot self-monitor their work often end up trying many different options without any idea if they are getting close to knowing the largest possible surface area within the constructs of the problem.” |
| Student as owner of math ideas | Teacher references students as being mathematical authorities or students as being able to present their work as their own. This is the opposite of a teacher presenting students’ ideas to the whole class. | “Charlie, want to come up front and talk about your picture here a little bit? Just explain what you drew. Talk about your drawing real quick Charlie. My other sharer is Jerry. Jerry, you want to come on up? When you get up there, I want you to talk about your picture, right? And also where we see our learning intention today, right? I think you guys have a good idea of where we have similar triangles, right? Cool.” |
| Students being motivated to learn | Teacher references student motivation (or lack of motivation) for learning or students having an intrinsic motivation to learn. (This was sometimes double-coded with deficit thinking.) | “Common motivations for students’ participation in the flip were to be prepared for class, grades and the ability to re-watch the videos until they understood the content.” |

| Code | Description | Examples |
|---|---|---|
| Student beliefs | Teacher references student beliefs about mathematics, learning, learning mathematics, and their own efficacy. | “Through conversations with a mentor, it came to be beliefs and attitudes and also increased math discourse. For beliefs and attitudes, I feel restorative circles can “restore” a student’s relationship with math or at least a measurable amount.” |
| Student collaboration | Teacher references students working together in pairs or small groups to solve mathematics problems. This covers the entire spectrum of students working together, from discussing answers and procedures to collaborative problem solving. | “Allowing students to work collaboratively has always been a focus of mine. I would like to develop new and more creative ways for students to critique each other’s work and provide feedback.”<br><br>“After individual work time students partner with a group and share answers and procedures for each problem.” |
| Students being prepared for the future | Teacher references preparing students for future high school courses and for college. This includes prepping students for IB tests, AP tests, the ACT, and other high-stakes/standardized tests. | “It also did not have multiple types of assessment formats. I also did not expose them enough to multiple answer question format, the format used on the Early Math Placement Test and what I am using as a guide for this class. In this case, I was not ‘using assessment procedures as teaching tools’ (Ch 6, pg 107.)” |
| Student confidence | Teacher references students having confidence in their own thinking and/or having confidence in their mathematical thinking and/or their confidence as learners. | "But when I prodded them to consider the elements of the lesson presented and the elements of the task they were able to make comments. While there were only 10 students in the class, five of the students said they felt successful/comfortable with the topic due in part to its graphical nature.” |
| Students connecting mathematical ideas | Teacher references having students make connections between mathematical topics, other than connecting representations (which is coded above as “use and connect representations). Includes references to students comparing and contrasting elements within the same task as well as comparing and contrasting | “Again, really emphasizing that and how it connects with some of the quadratic work that we had done previously with solving quadratics. And then I hope that students learn exponential properties and how they connect with radicals.” |

| Code | Description | Examples |
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| | across different solutions (as used in the Connecting practice of the 5 Practices). | |
| Students developing conceptual understanding | Teacher references the development of students' mathematical conceptual understanding. This includes student understanding beyond procedural and students making sense of mathematics. Reference to procedures is not included. | "The S-Pattern Task, seen in Figure 1 below, is a nice task because it aims at getting students to provide multiple representations of the relationships they observe, such as written descriptions, geometric representations and functions that describe terms in the pattern. It also asks them a question examining the question in the opposite direction (if given a number of tiles, what figure number is it?) as well as a question about the presence of a linear relationship between each figure (which many students feel confidently there is not, and which provides an opportunity to discuss why there actually is)." |
| Students developing and practicing procedures and skills | Teacher references the development of students' procedural skills or students practicing using procedures. This does not include references that explicitly link to students' conceptual understanding; those were coded as "Building procedural fluency from conceptual understanding." | "Students were given the equation and asked to find the roots using factoring and solve by taking the square root." |
| Student engagement and participation | Teacher references students participating in doing mathematical work in some form (individual, cooperative, on paper, verbally, on a vertical surface, online, and so on). This participation may or may not include deep mathematical thinking about the task. | "The use of high cognitive demand tasks resulted in greater creativity and problem solving by students. The students became inquisitive, and more engaged. I reworked most of my lessons because I wanted a greater focus on conceptual learning and problem solving." |
| Student enjoyment of mathematics | Teacher references student enjoyment or interest in mathematics and/or the work of the class. | "At the end of the sequence of five lessons I had, and the students had as well, come to really enjoy the doing mathematics tasks." |

| Code | Description | Examples |
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| Student exploration of mathematical concepts | The teacher references having students explore mathematical ideas through guided investigations that provide appropriate scaffolding. This is the opposite of the teacher telling students about mathematics, having students complete investigations that include precise directions, or having students complete procedures to obtain correct answers. This includes students engaging in inquiry and students being able to use different methods to explore mathematics. | "I liked the students were discovering it on their own instead of me telling them with the properties that we were discovering." "The characteristic of this type of task not having and obvious solution and requiring students to develop their own systems of investigation will help students develop a sense of different ways to possible explore a math concept." |
| Students getting feedback from the teacher | Teacher references giving feedback to students to help them move their learning forward. | "By adding a rubric, students know what is expected of them and it becomes a tool for feedback and future conversation." |
| Students developing a growth mindset | Teacher references students viewing mistakes as opportunities to learn and being willing to share their mathematical struggles. | "Estimation 180 also does this by asking for guess too high and too low, many correct answers with none more right than another and then what they think is a good estimation, with most of the class being wrong. Failure can be seen in a different light." |
| Students having mathematical discussions | Teacher references student discussion of mathematical ideas. This differs from "facilitate meaningful mathematical discussions" in that the discussions are occurring in small groups or pairs and not necessarily directly facilitated or orchestrated by the teacher. | "This activity is designed to allow students a chance to not only practice math in a safe, formative environment but also to receive and give constructive feedback on their work. Giving feedback not only helps the person receiving a suggestion but also challenges the student giving the feedback to identify ways work could improve even if it looks identical to their own. In general, a wonderful activity to help students practice and reflect on math as well as foster a positive classroom discourse around peer's work." |
| Students' individual thinking | Teacher references students working alone. This includes individual think time and working through the | "The majority of this modelling process was done individually by students. They were forced to take this process as far as they could individually, which I believe to be very important in furthering |

| Code | Description | Examples |
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| | problems alone (without a group or other collaboration). | mathematical understanding. If students aren't forced to wrestle with the concepts in a task individually, then there are less anchors in place to connect things that your classmates and teachers can help you with." |
| Students justifying thinking and reasoning | Teacher references having students justifying their thinking, explaining thought processes, or showing their work. | "One of the things that I am trying to do with my teaching and task selection is to try and improve problem solving abilities of students by making them explicitly show the process they went through to reach their final solution and then having them reflect on that." |
| Student learning over time | Teacher references student understanding as a long-term process of growth over time. Rather than within a single lesson, the teacher shows value in learning concepts over time. | "I will now start the school year next year with a better approach of more modelling for each lesson with a progression of the modelling. I am thinking that we could start a model problem as a launch with a large group discussion and then come back to the problem after more "tools" for the problem were given, a nod to Montessori three period lessons. " |
| Student learning styles | The teacher references student learning styles (visual, verbal, kinesthetic, etc.) and/or the role learning styles play in their classroom. | "The general consensus was that students tend to perform better in flipped environments due in part to the number of learning styles that it incorporates (problem-based, active, cooperative, collaborative and peer-tutored) and the opportunity to present rich and authentic learning tasks within a supported environment." |
| Student perseverance leading to sense-making | The teacher references students engaging in struggle without giving up and students persevering in solving problems. This includes making sense of problems so as to be able to get started in solving. | "I think I got the thing I wanted the most, which was that sense of [being] overwhelmed, that sense of this is going to be a lot. I think that in terms of getting going, I didn't have anybody give up, which was great. There was no, 'I'm not doing this.' It seemed like everybody at least pursued some avenue, maybe to varying |

| Code | Description | Examples |
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| | | degrees of success, but there wasn't any throwing in the towel.” |
| Student preparedness for learning | Teacher references students being prepared or not prepared for the day’s learning. This includes background knowledge and/or completion of preparatory work, including homework from the previous day. | “This situation leads to students not having the appropriate background knowledge to complete application tasks with success and understanding.”<br><br>“As commonly known, when assigned work for practice outside of class, many students are not routinely completing their work. This situation leads to difficulty participating in lessons and poor performance on assessments.” |
| Student respect for the learning environment | Teacher references student behavior, discipline, disruptions, and/or respect/lack of respect for the teacher or other students. | “The class selected for this research is one where disruptive behavior has been a chronic issue. Students have been disrespectful towards the teacher and other students. A few students have openly challenged the teaching methods within the classroom.” |
| Students’ retention of knowledge | Teacher references students’ day-to-day retention of knowledge from previous days or other days within the same unit or course. | “Often times I will have a lesson that by all indicators seems to have been successful. High student participation, solid discourse, high quality in class work, and even success on exit slip questions. Yet the next time we meet it sometimes feels like we never covered the prior material at all.” |
| Student success | Teacher references students’ quality of work, students getting good grades, and/or students being successful at completing a problem or task. | “The students met my expectations of success for the most part, although I would have liked them to do a bit better job with communicating their understanding.” |
| Students self-evaluating and reflecting | Teacher asks students to self-evaluate their knowledge and/or confidence with the content, or teacher asks students to reflect on their learning or learning process. | “Self-assessments from 29 students from this initial lesson indicated 63% ‘got this’; 27% ‘starting to understand – need some practice’; and 10% ‘don’t understand’ or ‘did not try’.” |

| Code | Description | Examples |
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| | | "I have recently also begun assigning homework that asks student to reflect on how they thought. These 'How did you work' homework's have allowed me to see if the lesson is effective in a much different manner from can they get math problems correct. The homework's that have students reflect on their work allows me to see to what level student thinking got from the lesson." |
| Students' use of math practices | Teacher references students using one or more of the Standards for Mathematical Practice, or teacher references the Standards for Mathematical Practice in their plan. | "I will specifically 'call out' standard for math practice #3 - Construct viable arguments and critique the reasoning of others in an effort to maintain the high - level cognitive demand of the task in order to promote group and class discussion." |
| Students viewing math as useful | Teacher references having students use contexts to help them make sense of mathematics and understand why mathematics is important. This includes using mathematics to model the world as well as using applications of math content that may not rise to the level of modeling. | "In the future, I would bring in a more tangible, real-world example prior to this to help develop more mastery of work with variables."<br><br>"From there, I utilize a number of other very big numbers found around us, including the distance from the Earth to the Moon, the distance from the Earth to the Sun and Beyoncé's net worth. I ask students to estimate these before I give them the actual numbers, which helps to engage students." |
| Teacher adapting instruction for different needs and interests | Teacher references instances of changing their plan based on the works that students have done, adapting their plans based on student interests, or adapting their plan based on students' previous understandings. This includes differentiation, scaffolding problems for different students and/or offering multiple modes of assessment. | "I thought it would be easier for them, but it was a challenge. I mean, it's still appropriate. I gave them longer to do this. Once I went through the warm up, I was going to have this due Friday, as per conversation to you. I changed that to Tuesday because I didn't want to stress them out because I saw how much work already the first page would be. I thought the first page would kind of be a fly-through. It wasn't, and that's good to know. So I did extend that to be due Tuesday |

| Code | Description | Examples |
| --- | --- | --- |
| | | so I think that was a good choice, right? That way, then I wasn't stressing them for the level of work that they have."<br><br>"Depending on the class and the method of teaching the material the book may use, I will sometimes develop my own curriculum to aid my student's grasp of the material." |
| Teacher as advocate | Teacher references advocating for students beyond their classroom, including at department, building, and district levels, and beyond. | "The culturally responsive teaching for year four, that was really above and beyond, and that really lit a fire under me. Because then after that, I actually took it back to my building and did professional development on culturally responsive teaching. And that actually changed the way I talked to my students." |
| Teacher as arbiter of what's right | Teacher references directing student thinking in a particular direction or directing students to use a particular procedure. This includes use of funneling questions that direct student thinking, use of directed guidance as a means of helping students work through struggle, and/or revealing the "correct" answer at the end. | "So maybe we could draw this light so that it's actually showing like it would be going and going and going and then he's what's causing to be blocked out right? Yeah, so maybe redraw how we're seeing that."<br><br>"We also ran out of time within the lesson for every group to present their solutions, so I hand-picked a couple of groups with solid approaches to present to the class, then we had a discussion about which seemed the most realistic, and then I revealed the actual answer to the class." |
| Teacher as collaborator | Teacher references collaborating with other math teachers in the planning, teaching, and reflecting process; collaborating with teachers in other content areas; collaborating with teachers at other schools; and/or participating in professional learning communities. | "With regard to anticipating, I utilized both colleagues and my badge mentor to brainstorm different ways that students might approach this task."<br><br>"We share resources with one another, share student work and our reflections on tasks that we have |

| Code | Description | Examples |
|---|---|---|
| | | implemented, and we work together to help new teachers to our department.” |
| Teacher as dispenser of knowledge | Teacher references “telling kids math” in a lecture, demonstration or explanation of procedures, or direct instruction. This is the opposite of students exploring mathematical ideas. | “Within that statement is the reflection that specifies something they do not know, and hopefully that causes them to pay more attention to the explanation given on future problems that detail exponential equations.”<br><br>“I felt like it was very, you know, I kind of showed them how to do it, got a little bit kind of back and forth, but really ultimately it was me up in the front showing them how to do it.” |
| Teacher as facilitator or orchestrator | Teacher references allowing students to explore mathematical concepts in a semi-structured or less-structured manner. The teacher acts as a facilitator to learning rather than guiding students. This code includes specific reference to and mindful use of the 5 Practices. This also includes use of specific talk moves to facilitate discussions. This code differs from “Student exploration of mathematical concepts” in that it is from the perspective of what the teacher is doing rather than what the student is doing. | “The modeling task really tested my ability to ask students the right question to guide their work while still leaving the modeling task open ended. I did not want to push them in any direction or cause them to make any assumptions based on what I said. I tried my best to not give them specifics when answering questions.”<br><br>“I planned on having to mediate the group discussions when students were presenting their methods. I anticipated having to help groups settle disputes over whether they should choose to assume the tree is a cylinder or a cone.”<br><br>“Appropriate levels of wait time encouraged student response.” |
| Teacher as leader of other teachers | Teacher references leadership of others. This includes both formal leadership (such as leading a department, mentoring in-service and/or pre-service teachers, leading professional development, or membership on a school or district committee) and informal leadership | “Informally, I am talking with other algebra teachers and encouraging them to adopt some of these strategies.” |

| Code | Description | Examples |
| --- | --- | --- |
| | (such as sharing knowledge with others in order to impact others' practice). | "Not only is it a best practice for me personally to engage in but will also serve as a concept for working with other certified and pre-service teachers." |
| Teacher as learner | Teacher references their own learning and/or learning experiences, including using learning as a means to improve practice. | "Through that experience I developed knowledge about different devices (temperature sensors and distance/speed sensors), as well as different websites simulating authentic math experiments. Not only has that given me the awareness of these technologies, but also experiences with them that can help me guide my colleagues." |
| Teacher confidence | Teacher references their own confidence as a teacher. | "I felt more confident as a teacher in my classroom which I think benefits students." |
| Teacher control | Teacher references having or wanting to have control over the pace, flow, and/or thinking of the class. | "There is probably also a sense of control I want to think I have in my classroom but realizing I can only control my responses is something to also practice." |
| Teacher feeling intellectually challenged | Teacher references valuing feeling intellectually challenged and valuing using challenges to grow as a teacher. | "The continued cycle of being challenged and growing in this process has also given me a lot of confidence in myself to be the leader I know I want to be." |
| Teacher getting feedback from peers and administrators | Teacher references feedback from non-MMTP peers and/or administrators as helpful in their learning process. | "The evidence for changes to my practice that would demonstrate the strengths include feedback from administrators and colleagues in my high school building. I actively seek feedback from anyone who observes my class or who teaches with me." |
| Teacher getting feedback from students | Teacher references getting and/or using feedback from students as valuable for the teacher's learning process and/or in improving their teaching. | "In addition, I gave a survey to students at the completion of the two day activity. A couple of the questions helped me identify the perceived learning from the students' perspective." |

| Code | Description | Examples |
|---|---|---|
| Teachers having high expectations for students | Teacher references having high expectations for students' mathematical understanding, student performance, and/or student products. | "It is important for teachers to have a high standard for themselves and their students because it will allow their students to aim higher and achieve more than they would have otherwise." |
| Teacher having strong content knowledge | Teacher references their own mathematics content knowledge as being strong. | "I have developed good questioning ability by way of strong content knowledge, adequate reflection and general stubbornness to have students reach understanding on their own." |
| Teacher planning | Teacher references their lesson plan, planning process, and/or aspects of planning, including anticipating how students will work through a task and planning specific questions to ask students. | "I would like to be more planned. I know that sounds vague but the readings really inspired and justified why I should vs. winging it because I can after many years of teaching something. I would like to backwards plan at least the concepts in the order I want to cover them, the key activities I want to complete and a launch of the unit (often a 5 practice task) that is also planned." |
| Teacher respect for students | Teacher references moves that demonstrate respect for students. This includes acknowledging student contributions, student thinking, and students who are volunteering but not being called on. This also includes affirming students' identities. | "I would often repeat their question to the group to show importance of the question or thank them for asking. The same happened when students responded to a question of mine." |
| Teacher self-evaluation and reflection | Teacher references valuing self-evaluation or reflection, and/or teacher makes statements that are self-evaluative or self-reflective of their knowledge and practices. | "I need to improve my formative assessment skills to make better decisions for teaching strategies and behaviors."<br><br>"During our MMTP session 3 meeting we explored the mathematical modeling process. It was not until then that I realized I had never followed the process in its entirety. At best, I have introduced my classes to rich |

| Code | Description | Examples |
|---|---|---|
| | | application problems and emphasized the 'formulating, performing operations, and interpreting results' steps." |
| Teacher setting expectations for students | Teacher references setting expectations for student performance and/or products, including holding students accountable for their work and learning. | "I alerted the students that while this task would not be assessed for a course grade, it would be serving as a prelude to skills necessary in our upcoming unit."<br><br>"Prior to the self-assessment being distributed, I talked to students about why it was being introduced and how I expected students to use the form." |
| Teachers' trust of students | Teacher references trusting students to engage in the intellectual work required for learning. | "Essentially, you rely on the students in a modeling task."<br><br>"I think I used to do a lot of leading, like taking a pencil away from a kid and being, like, here you go, let me show. You want to put a dot here on the graph paper, and you want to put it out here. I mean, I wouldn't dream of doing that anymore, so rarely do I do that anymore. And so it fundamentally changed what I viewed as the point of my classes and then how I teach them." |
| Teachers' understanding of student thinking | Teacher references valuing making sense of emergent student thinking, including informal formative assessment to understand thinking pathways that students follow during instruction and misconceptions that arise during instruction. | "I value picking tasks and activities that help me gather information on student's thinking, prior learning, and developmental differences."<br><br>"Once the groups begin the activity, I must listen carefully and respond specifically to each group."<br><br>"The disproportionality in their drawing leads them having improperly sized triangles and no concept of what the length of the shadows would be. It is clear that their misconception had limited their work as they |

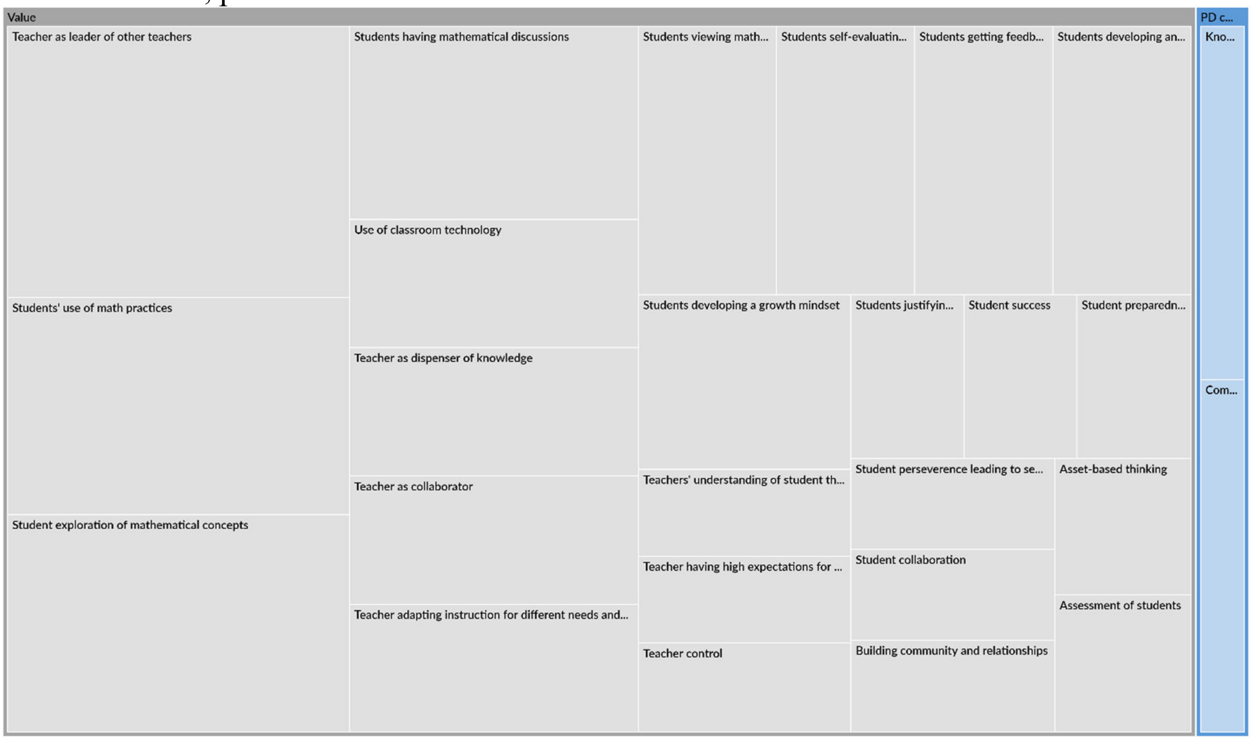
| Code | Description | Examples |
| --- | --- | --- |
| | | fail to make a statement about the overall question regarding the combined length of the shadows." |
| Teacher uses classroom data | Teacher references using classroom data to improve teaching and learning. | "Although I had suspensions about what would be shown through this work, it was very important to put data to it. This allows for progress monitoring of the issue and to put into data what I was feeling in my teaching this year." |
| Teacher uses student thinking to drive instruction | Teacher references using students' mathematical thinking as a means to move the understanding of the class (or individual students) forward. Includes the use of focusing questions, the use of the practices of selecting and sequencing, and using student interests and prior knowledge. | "These students had physically drawn out the 59 dots for the question on the hand out. In order to see if they understood how to work the machine without having to physically draw every scenario asked them this question." |
| Teacher views education as a community effort | Teacher references student learning as being the responsibility of a community that includes the teacher, the student, peers, the school community, parents, and/or the larger city community | "But being supported by other students' learning around you helps to provide insight. With that communal information gathering, a very challenging task becomes possible. This provides greater depth of learning for students." |
| Use of equitable teaching practices | Teacher references using practices that ensure all students learn and all students are heard. This includes using culturally responsive practices, practices to ensure students with special needs are learning, and differentiation. | "Working with students I was able to understand that what they valued was feeling that work they were doing was 'worth' something. The cultural concepts around 'why' we should do something were different from my own held beliefs. Where I valued doing something for the learning experience and chance to increase conceptual understanding, the students valued work that they felt was working towards a reward. I believe that this difference is cultural and allowed me to better understand why some students may be struggling with keeping up in the course." |

| Code | Description | Examples |
|---|---|---|
| Use of restorative practices or circles | Teacher references using restorative practices and/or restorative circles. | “By bringing Math Discourse and Restorative Circles together, I hope to provide trust and community to engage all learners.” |
| Use of classroom technology | Teacher references students using technology in the classroom. This includes the teacher mindfully planning for the use of technology in teaching mathematics. This does not include references made to the necessity of using Google Meet or other conferencing software during COVID-19. | “The technology allowed students the ability to ‘play’ with the graphing calculator and sketching software and connect those graphics to linear equations and the slope and starting values. Aside from the ability to explore the concepts and build on their prior knowledge, the technology allowed students the quick ability to check their conjectures and adjust their understanding as they moved throughout the task.” |

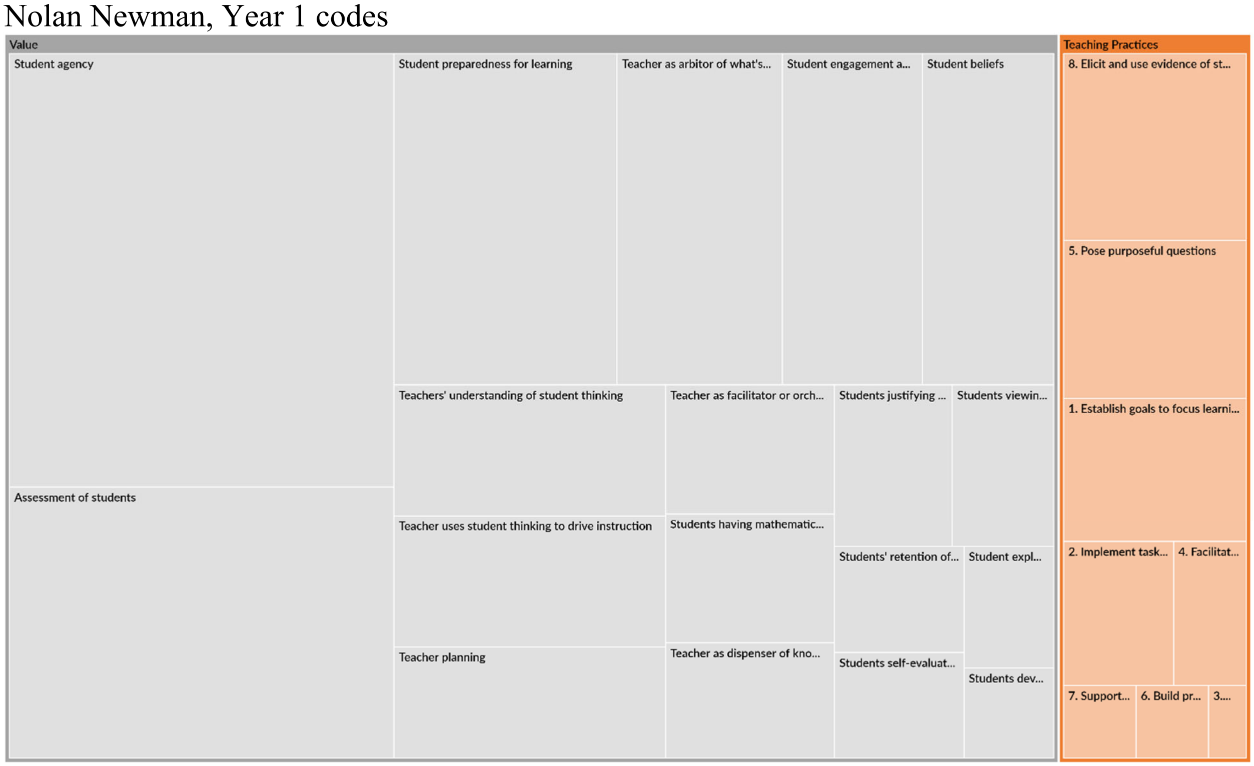
## Appendix P Visualizations of First-Cycle Coding

Visualizations show relative frequencies of codes for each teacher in each year.

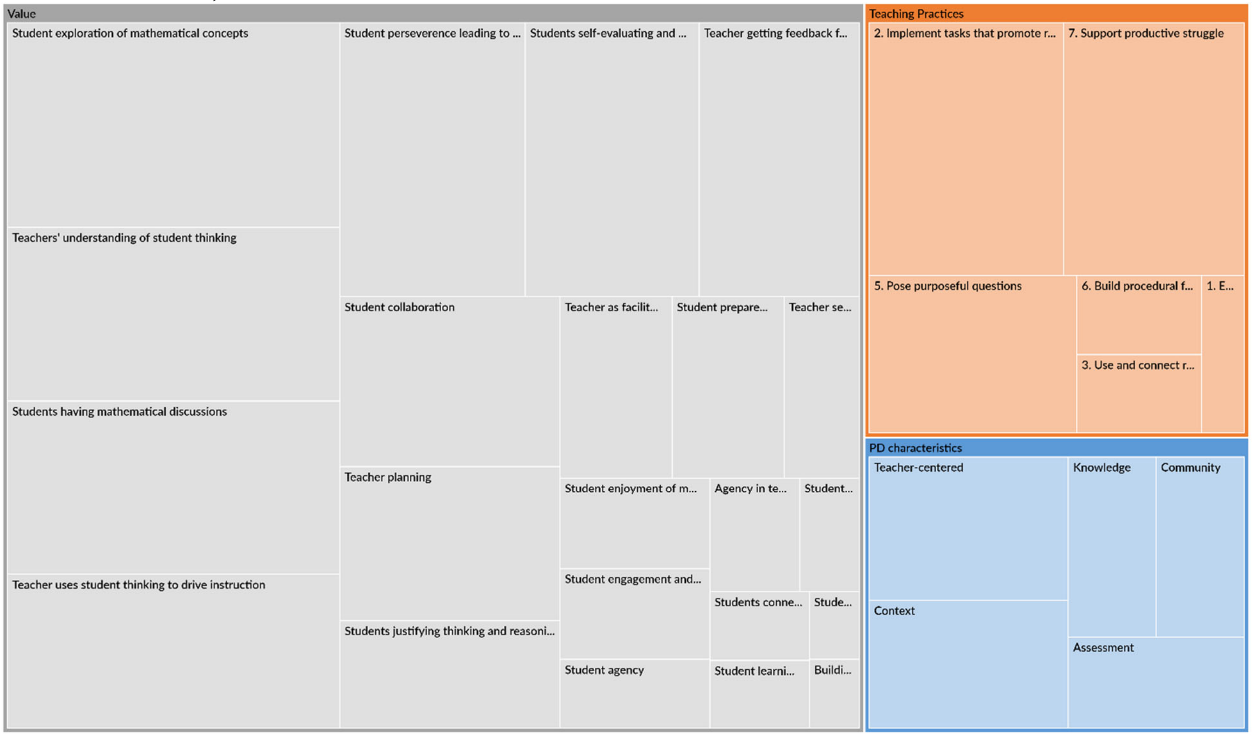
Nolan Newman, pre-Year 1 codes



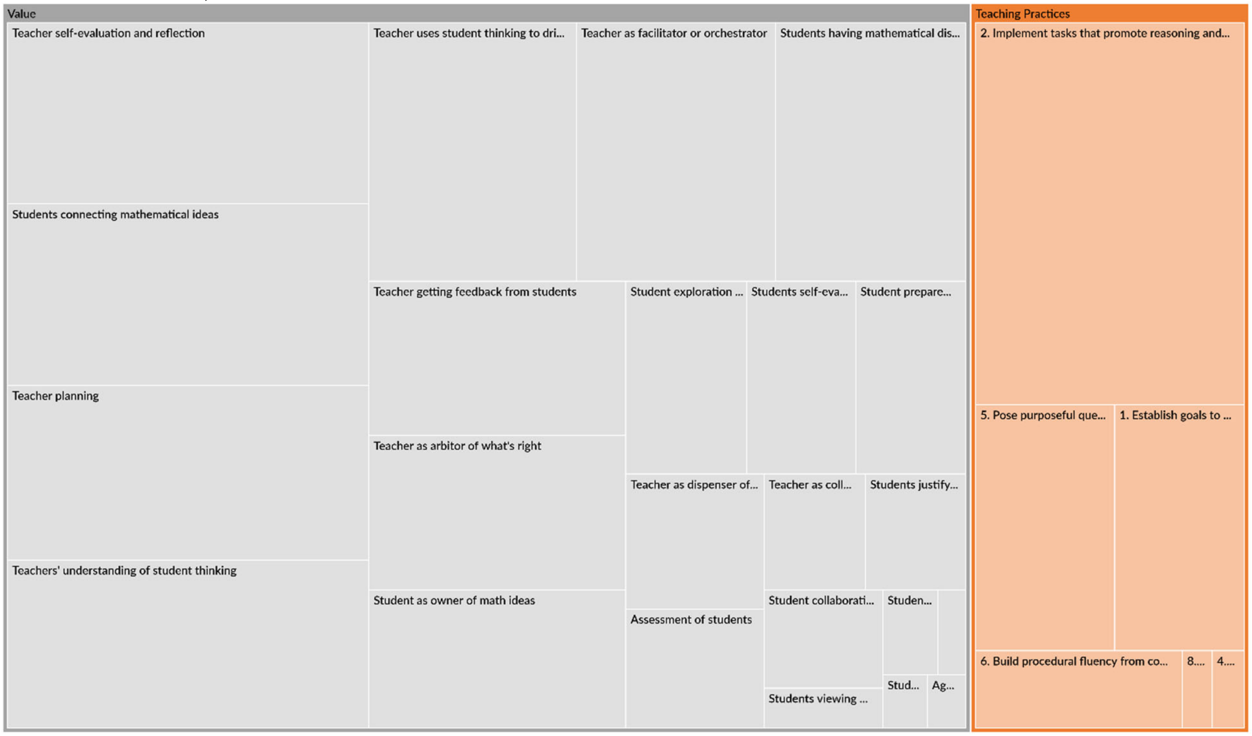

Nolan Newman, Year 1 codes



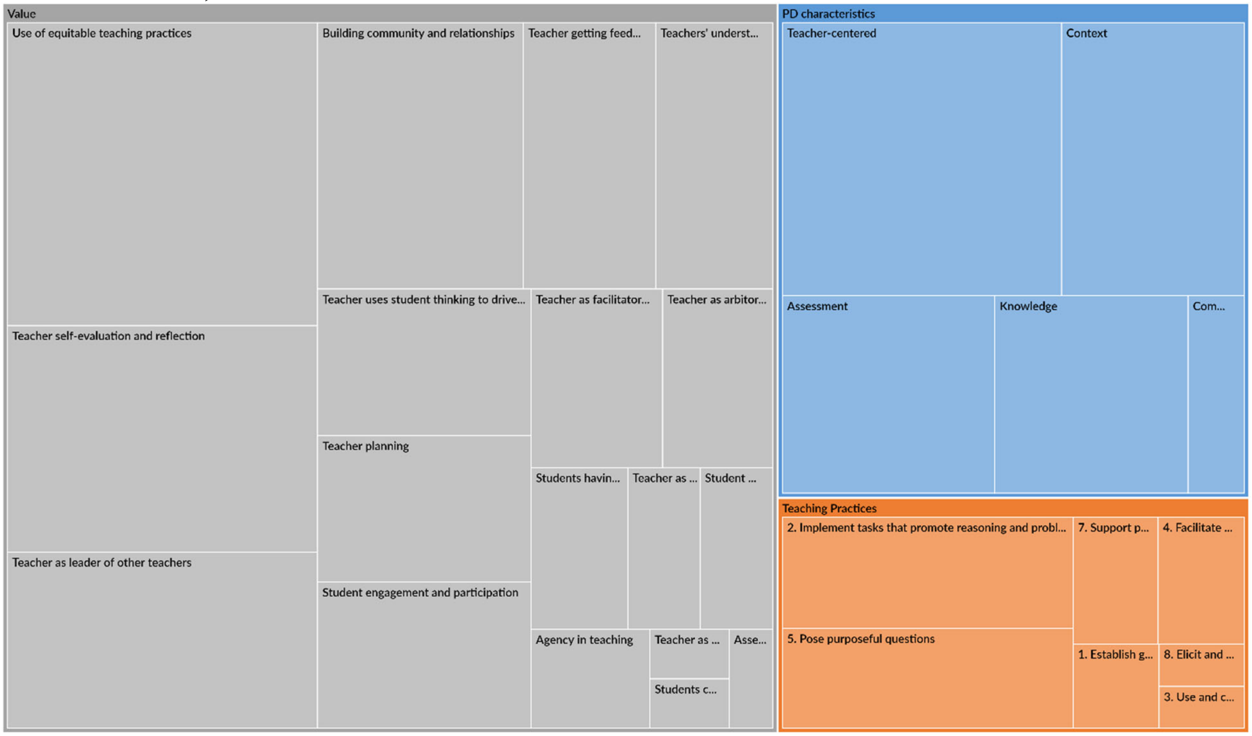
Nolan Newman, Year 2 codes




Nolan Newman, Year 3 codes

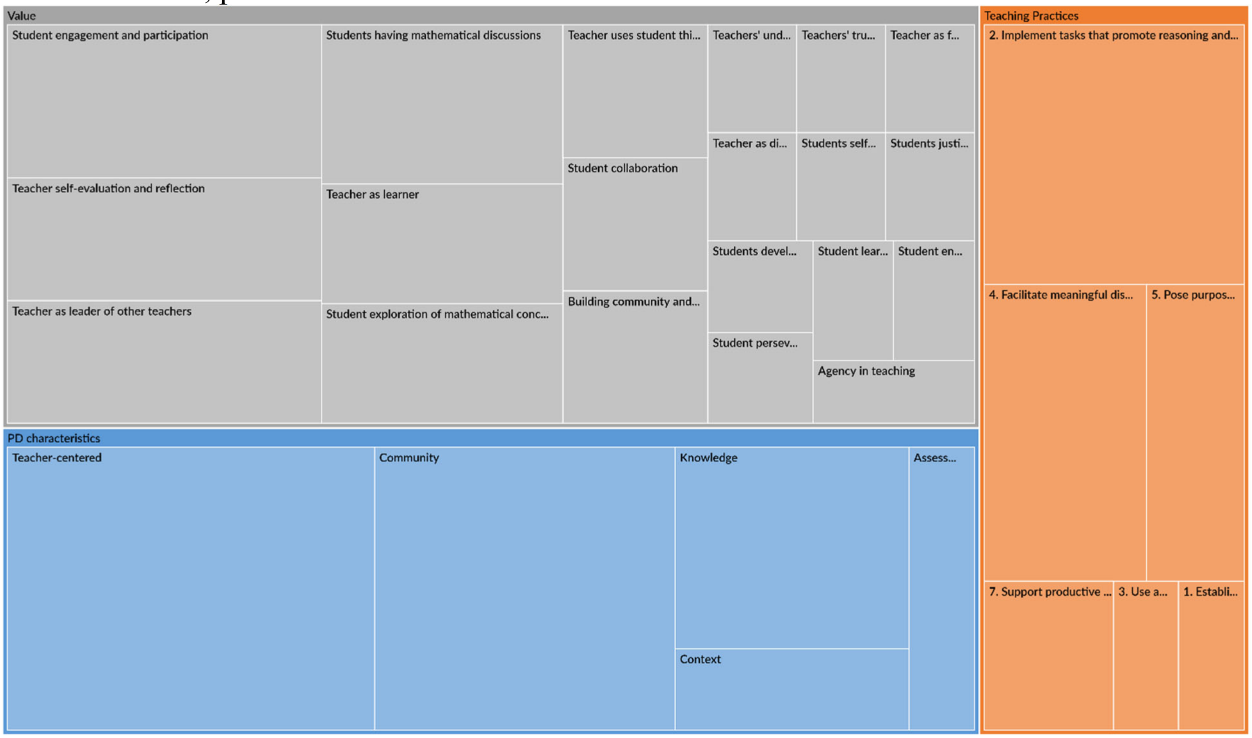


Nolan Newman, Year 4 codes

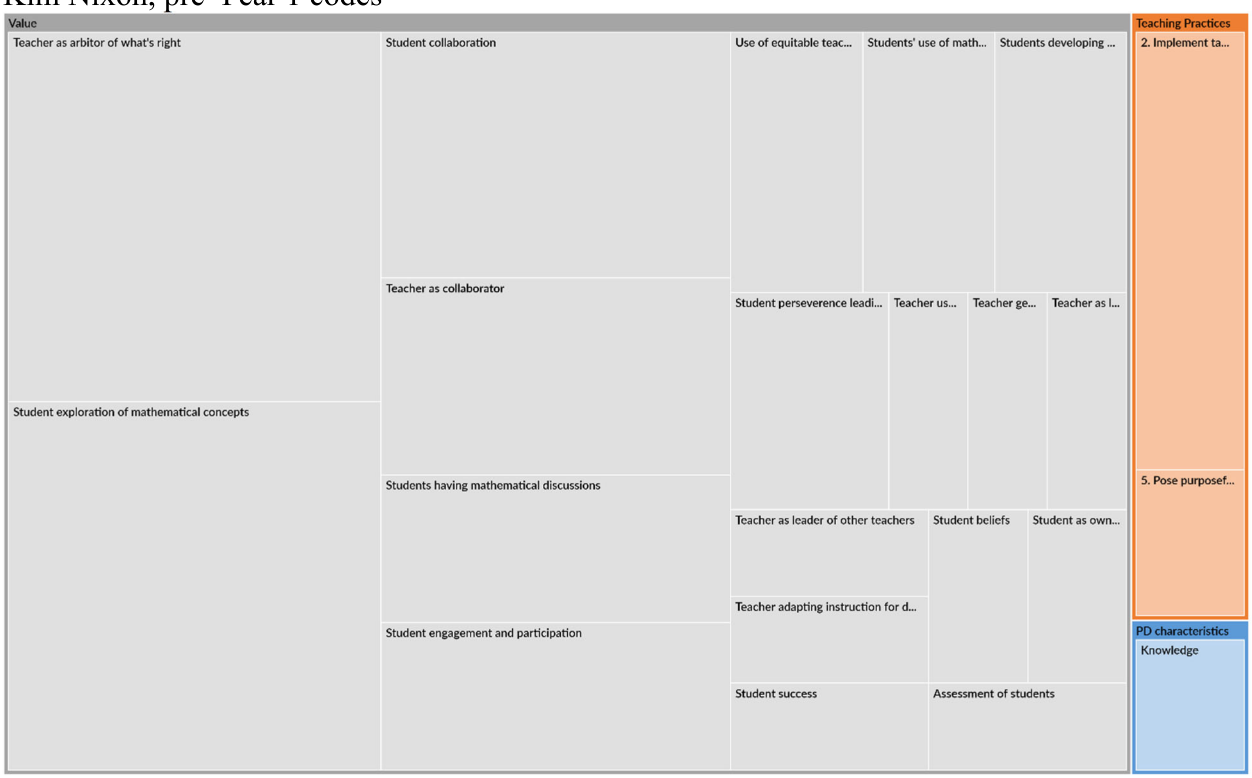



Nolan Newman, Year 5 codes

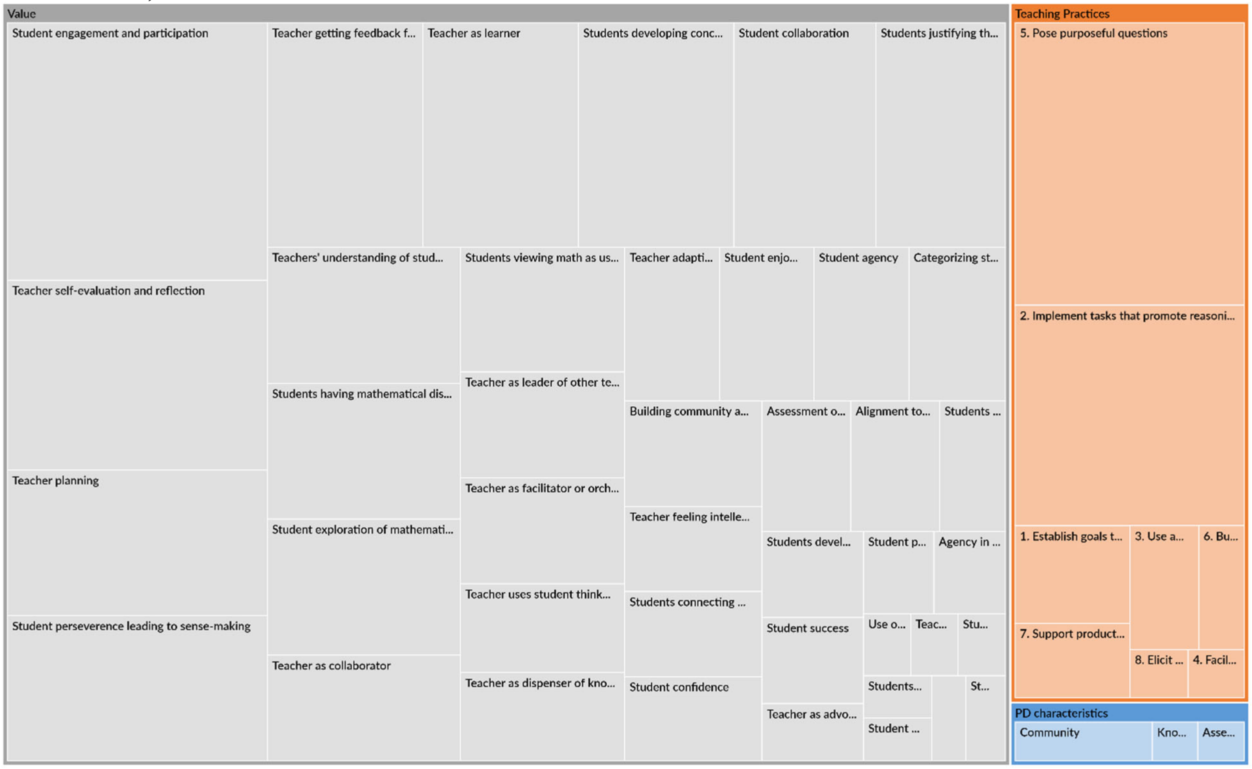
Nolan Newman, post-Year 5 codes



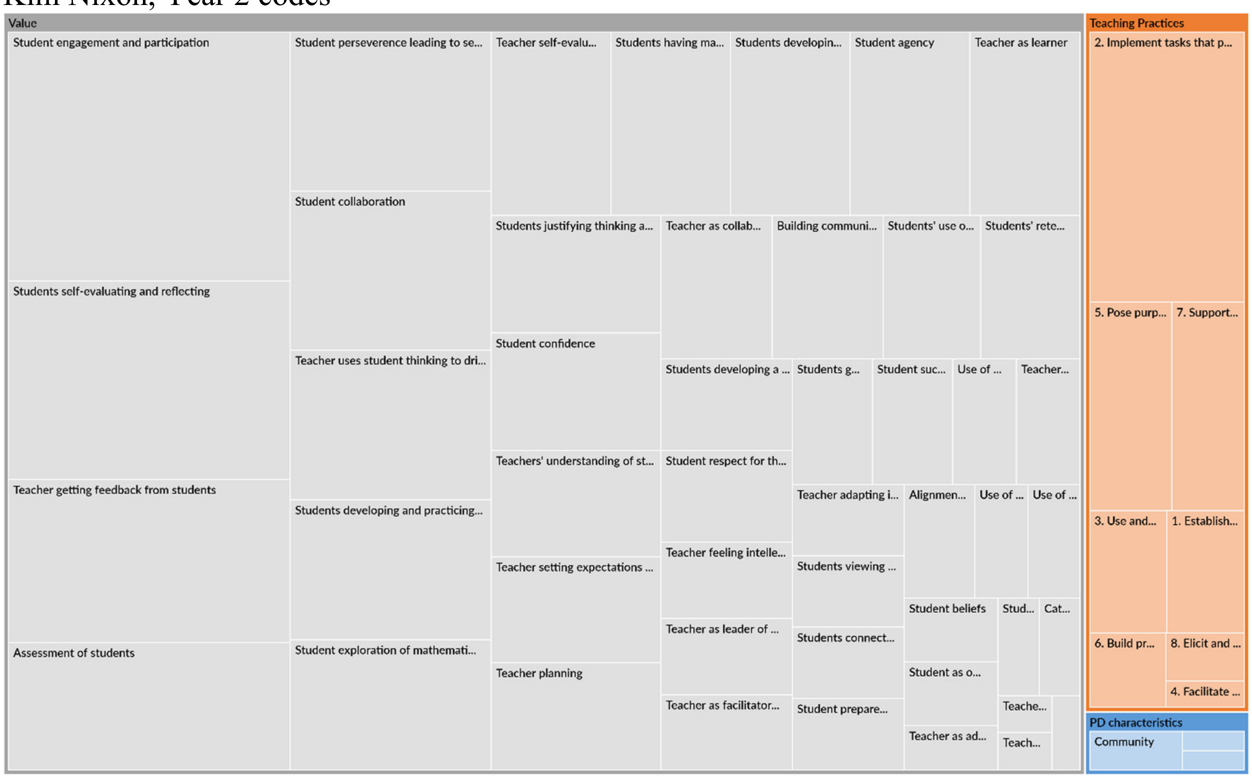

Kim Nixon, pre-Year 1 codes



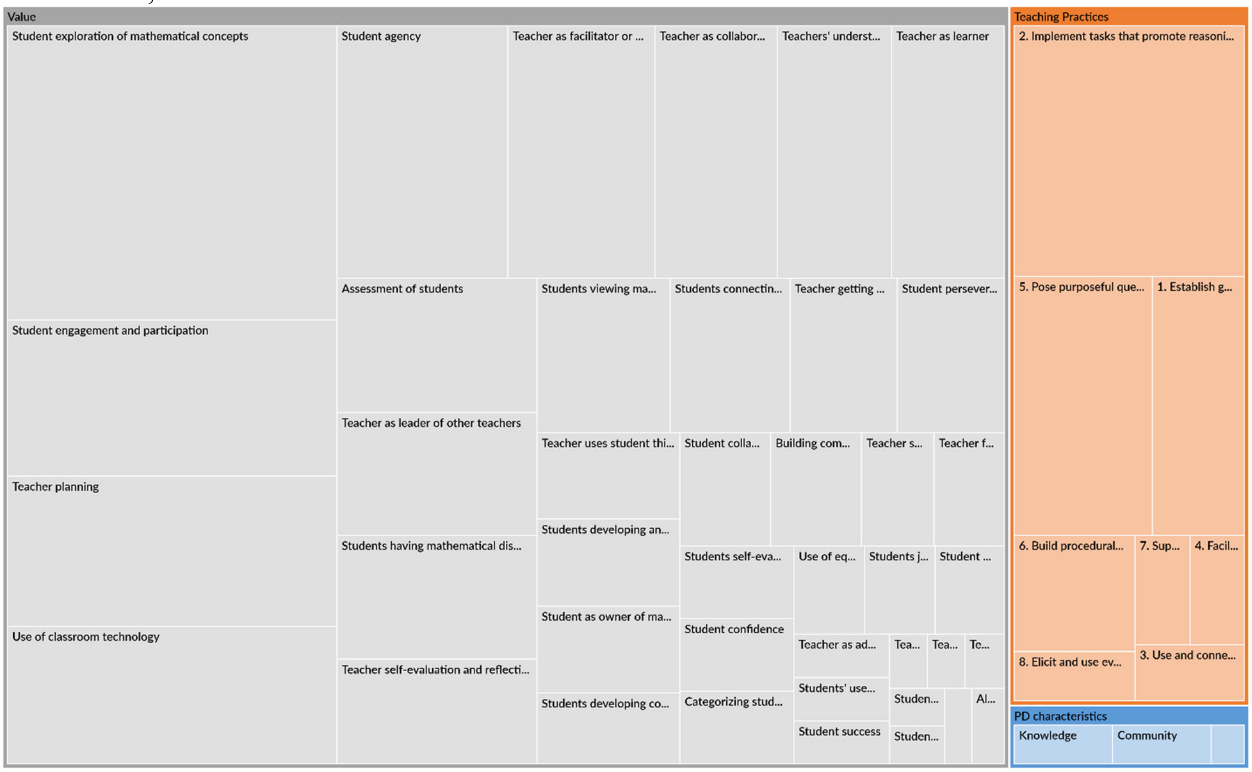
Kim Nixon, Year 1 codes



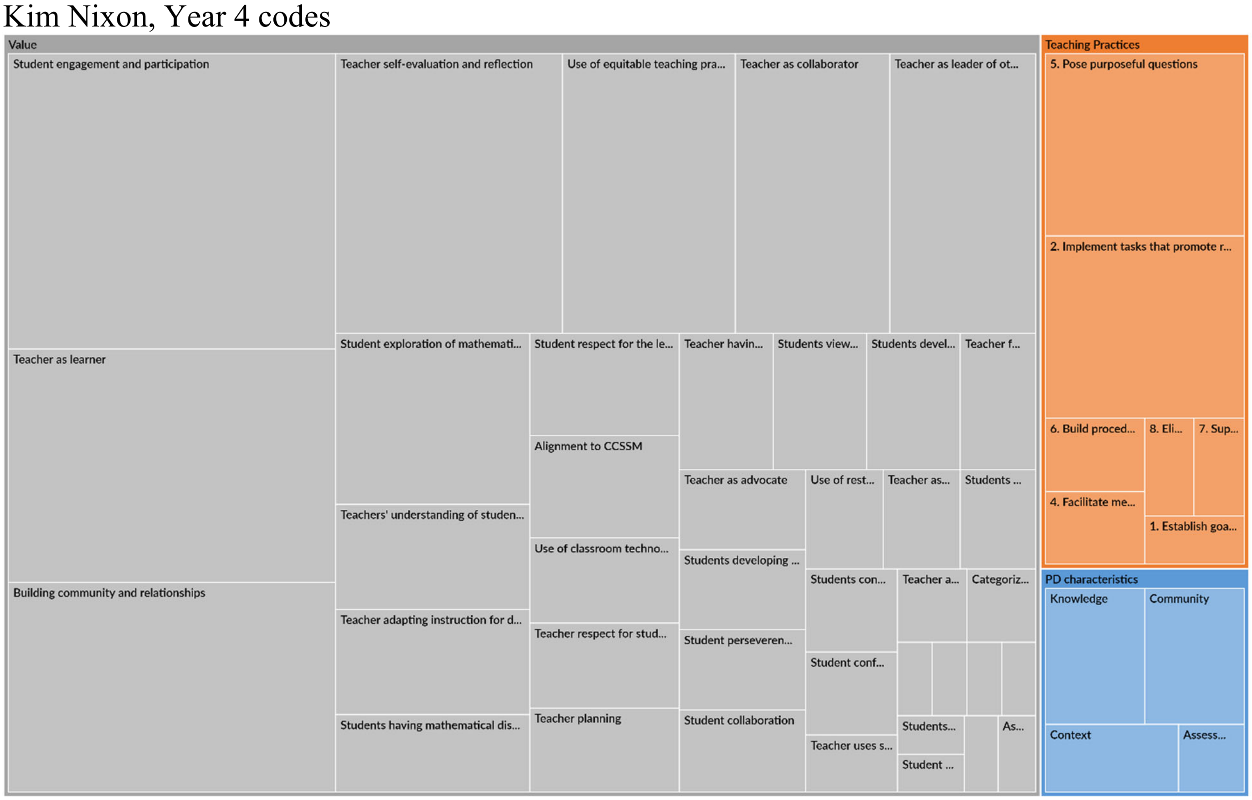

Kim Nixon, Year 2 codes



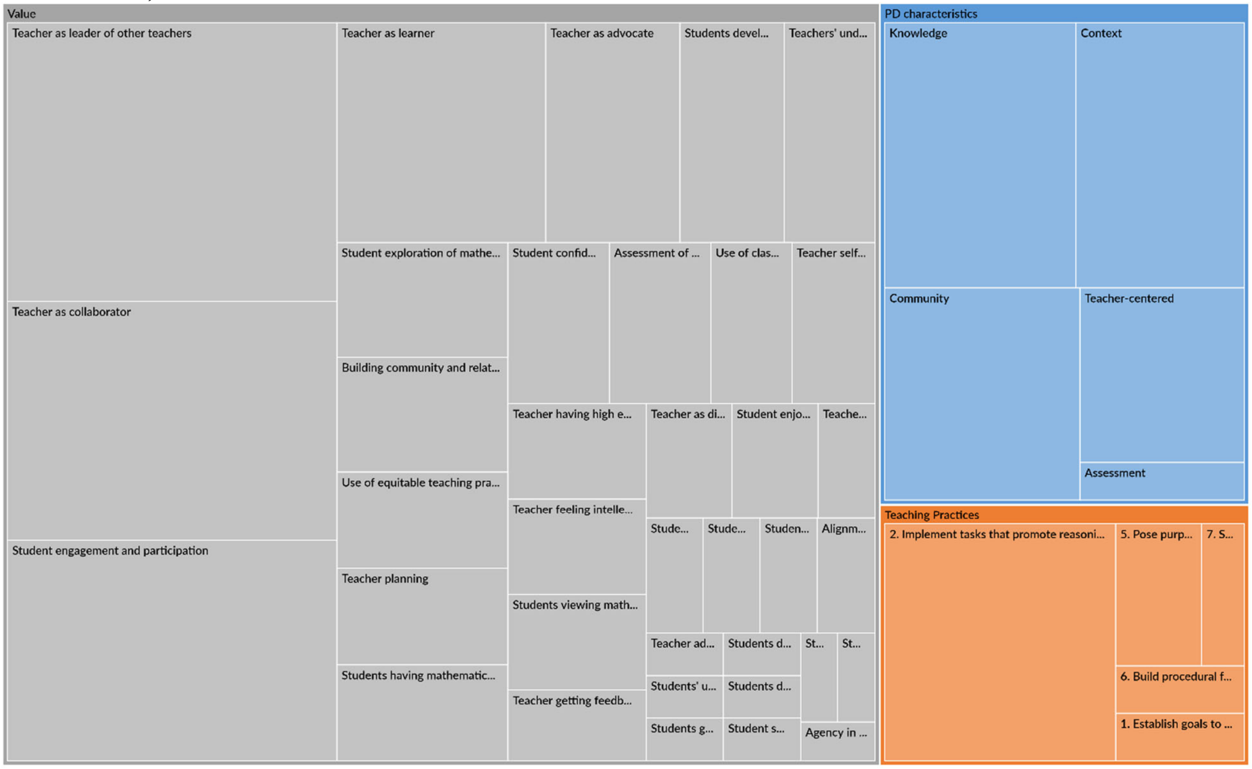
Kim Nixon, Year 3 codes



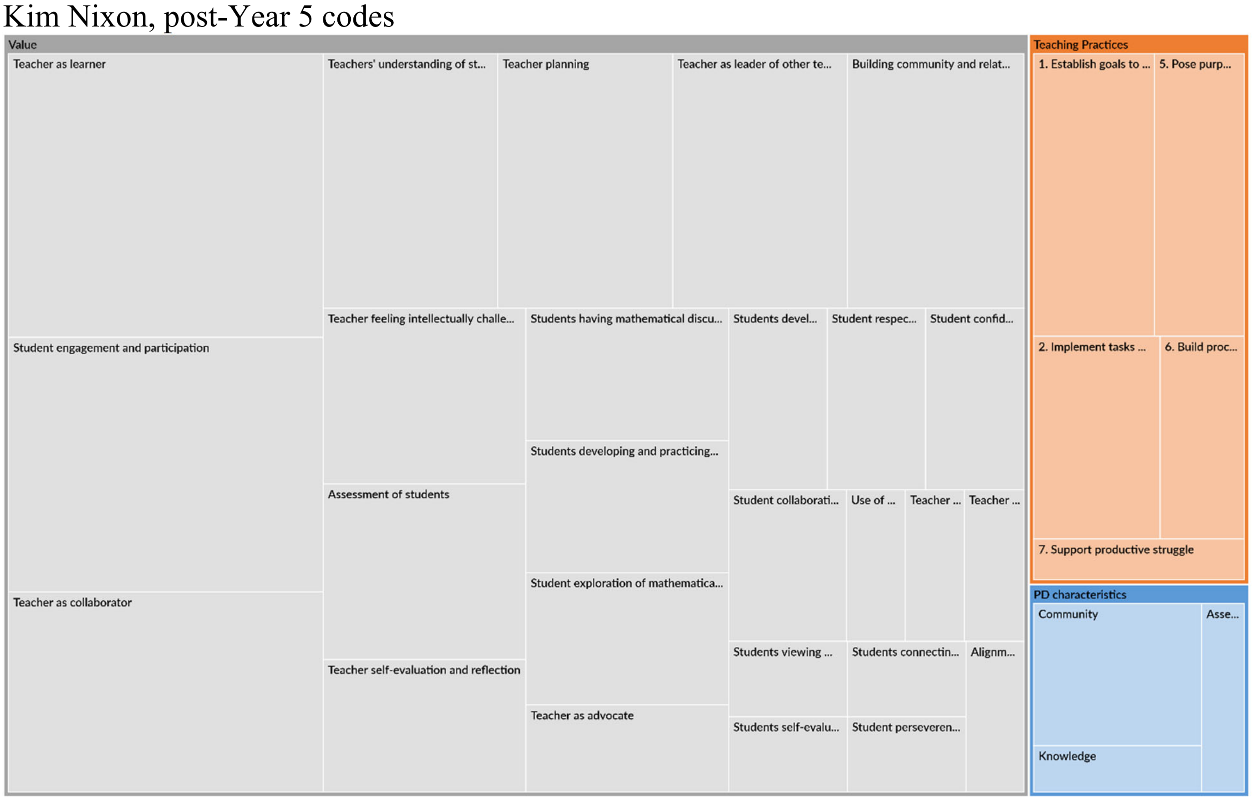

Kim Nixon, Year 4 codes



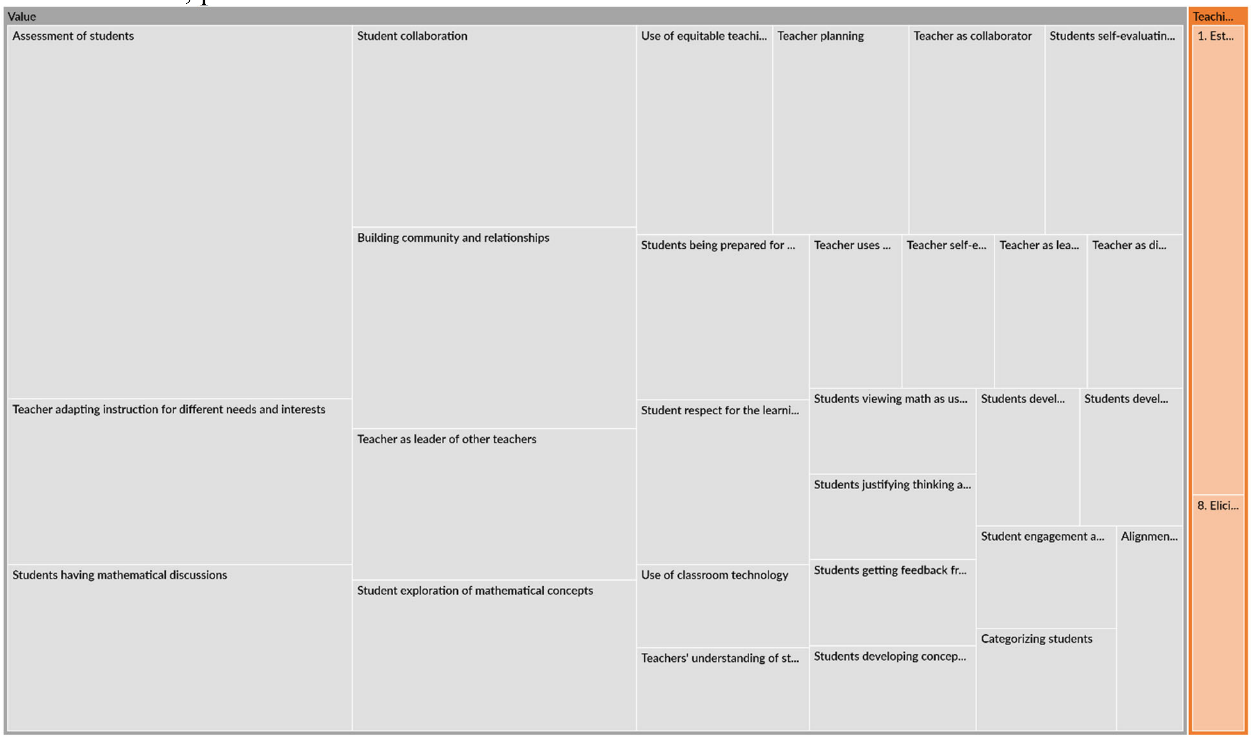
Kim Nixon, Year 5 codes



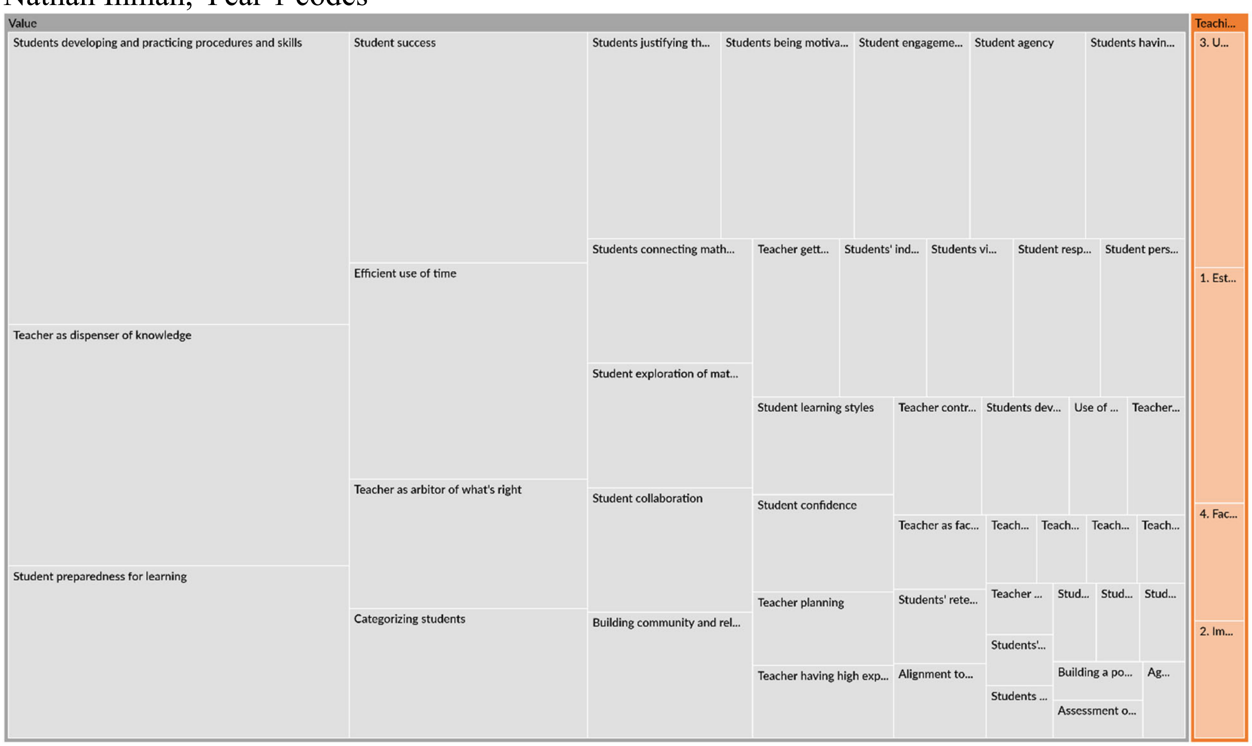

Kim Nixon, post-Year 5 codes



Nathan Inman, pre-Year 1 codes




Nathan Inman, Year 1 codes



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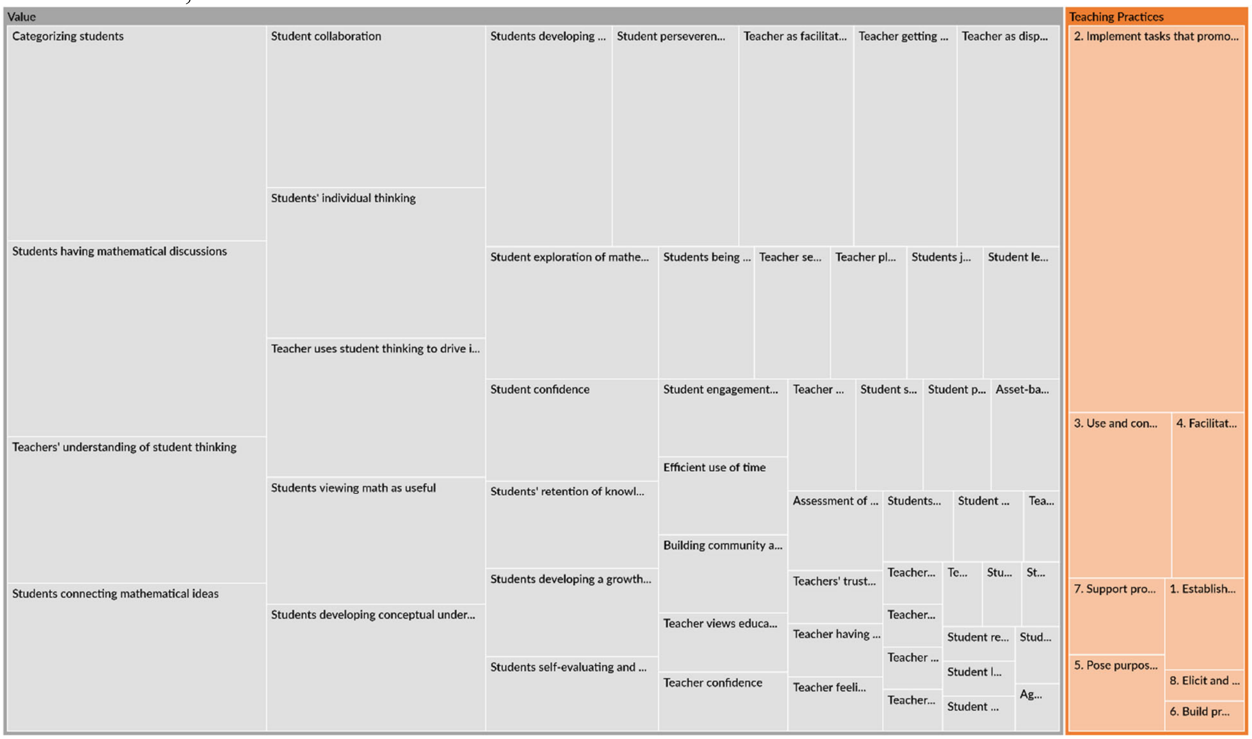
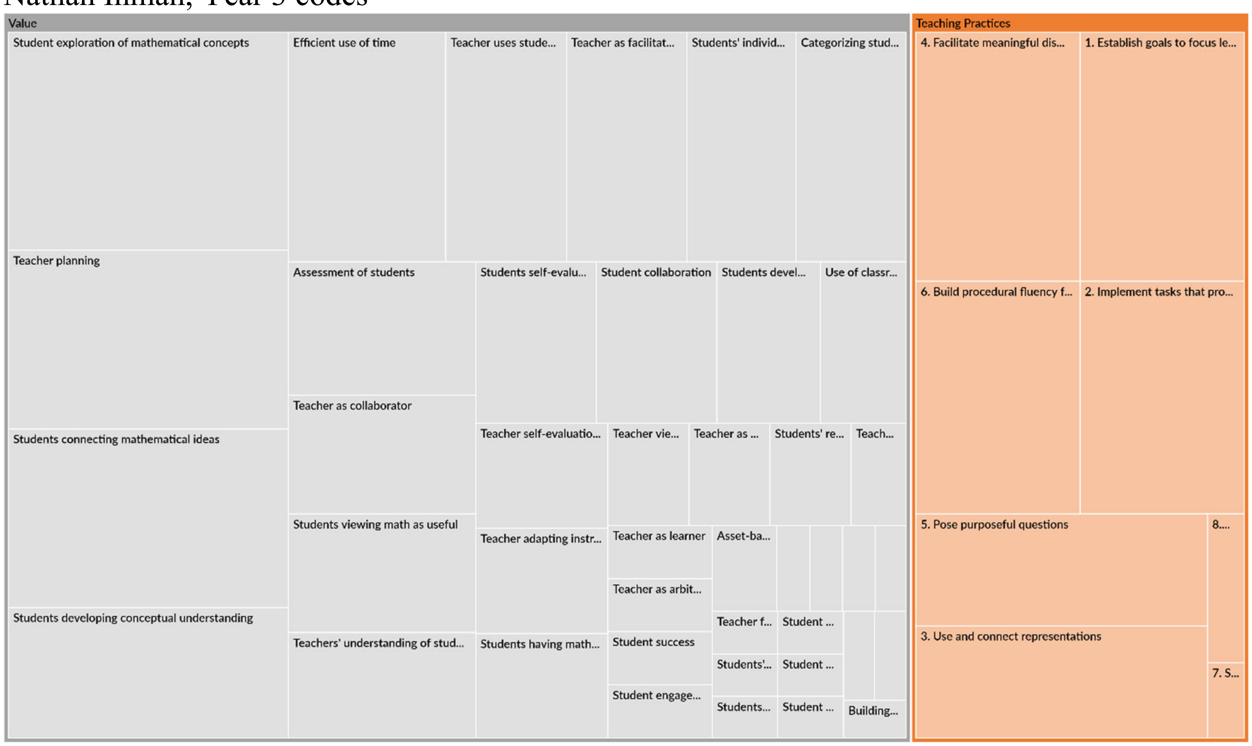
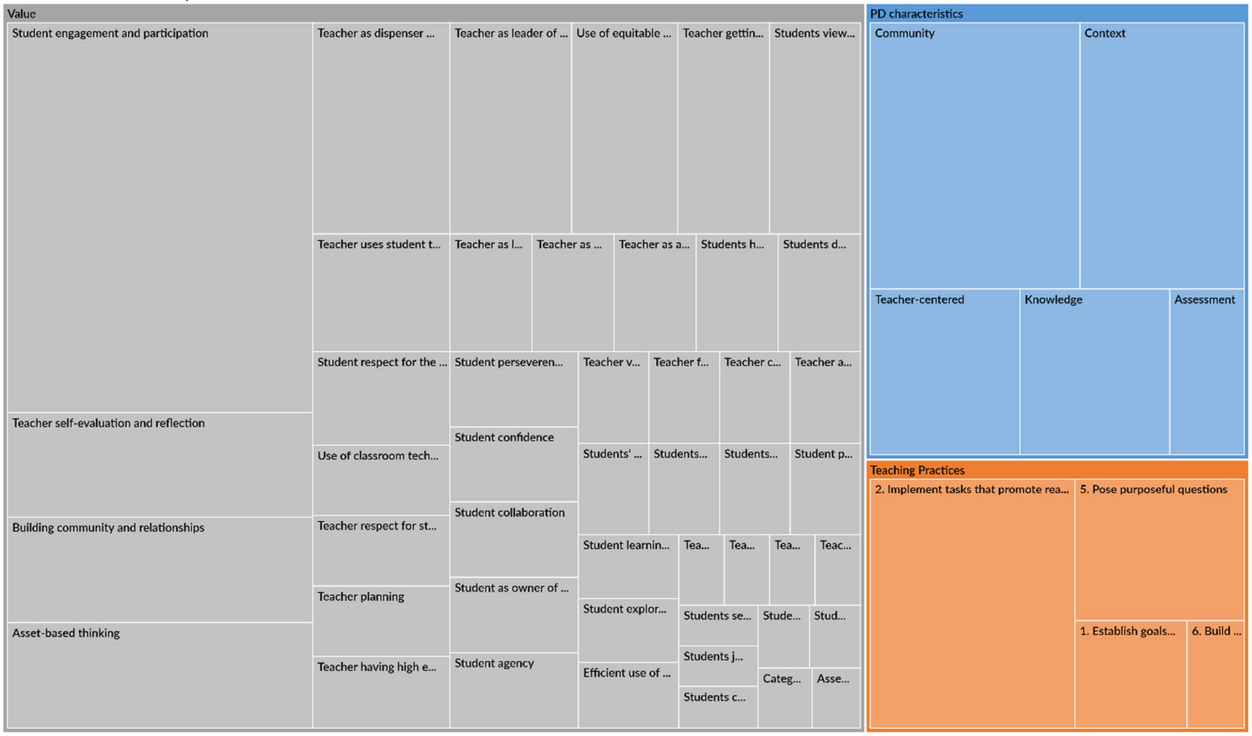



Nathan Inman, Year 3 codes

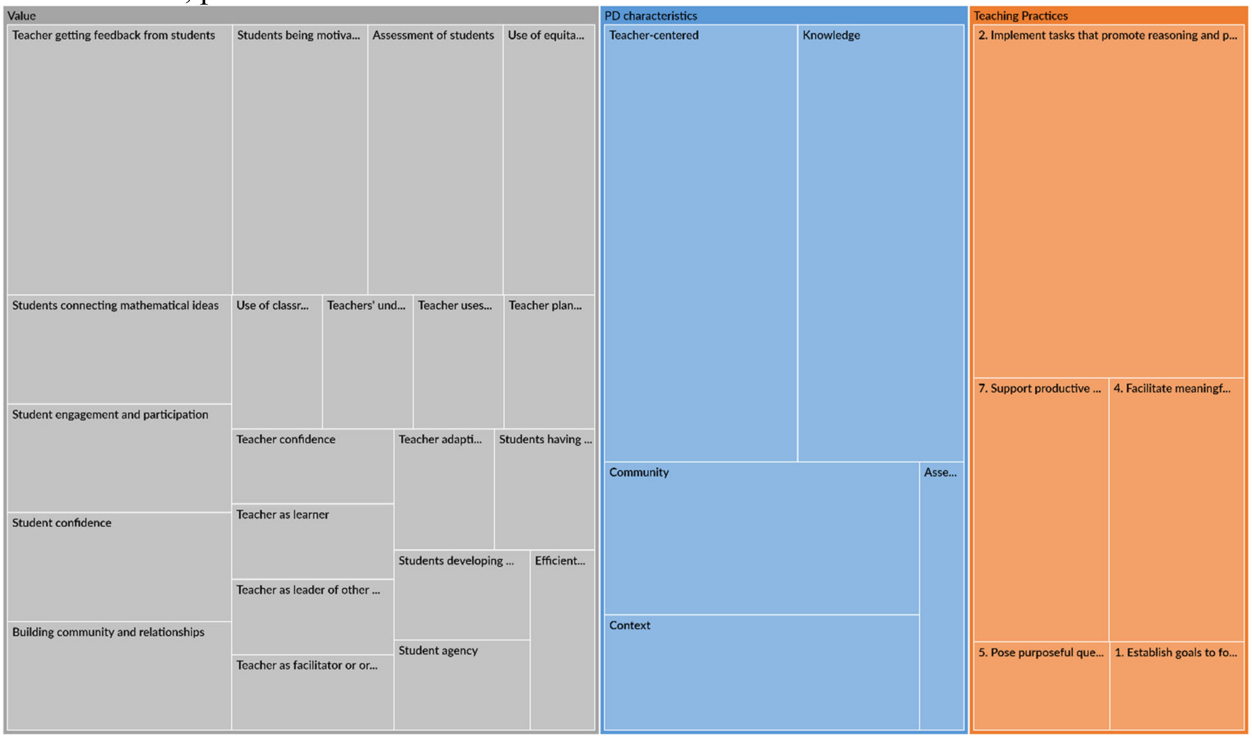


Nathan Inman, Year 4 codes

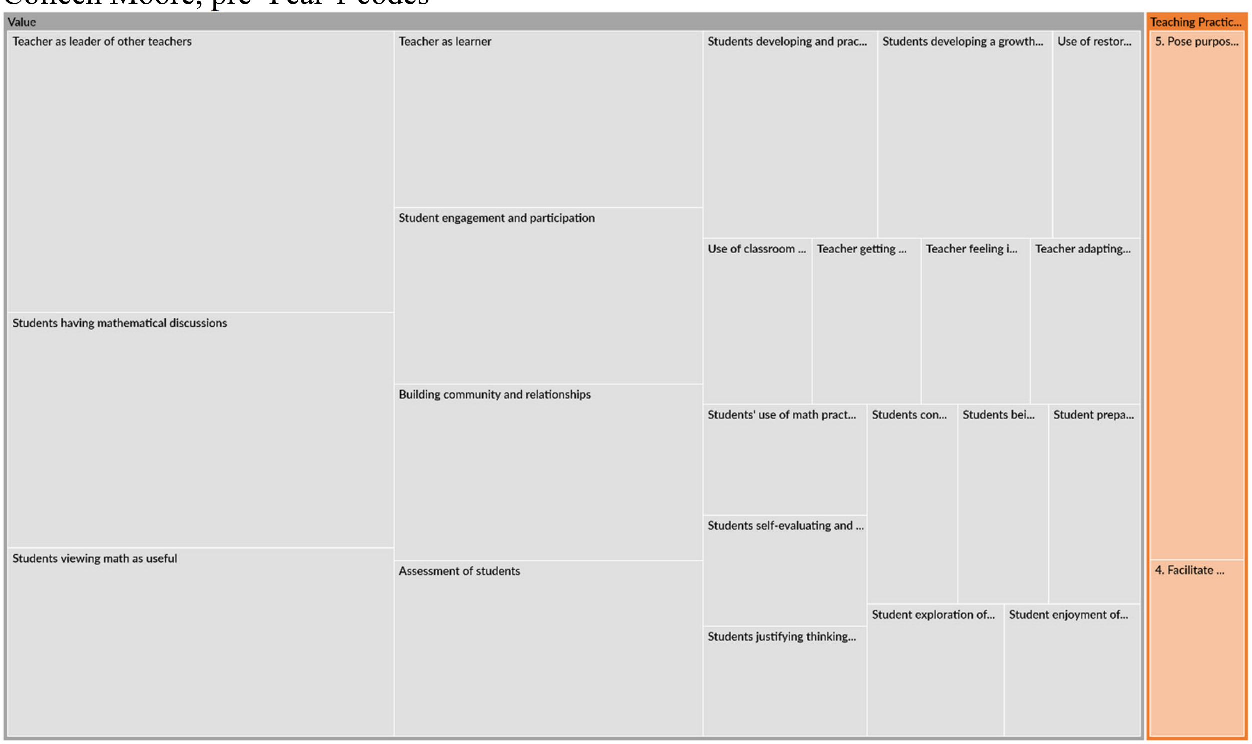



Nathan Inman, Year 5 codes

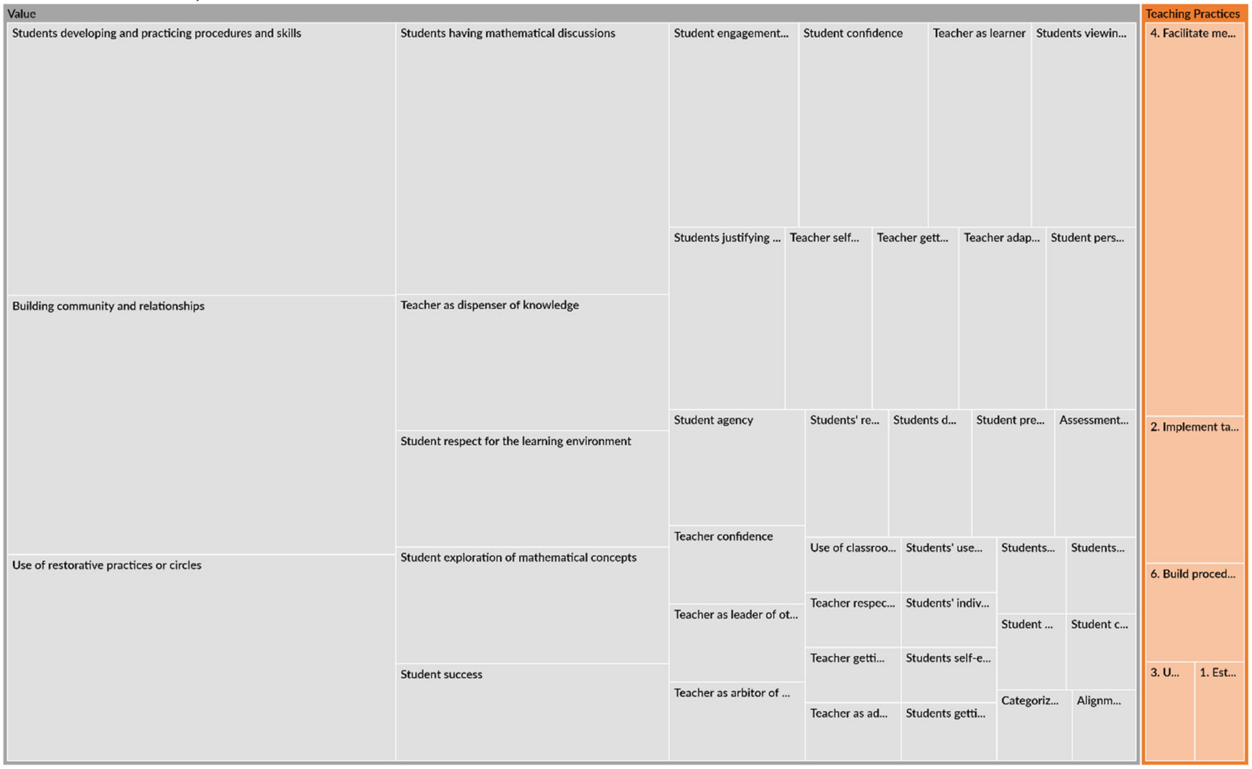
Nathan Inman, post-Year 5 codes



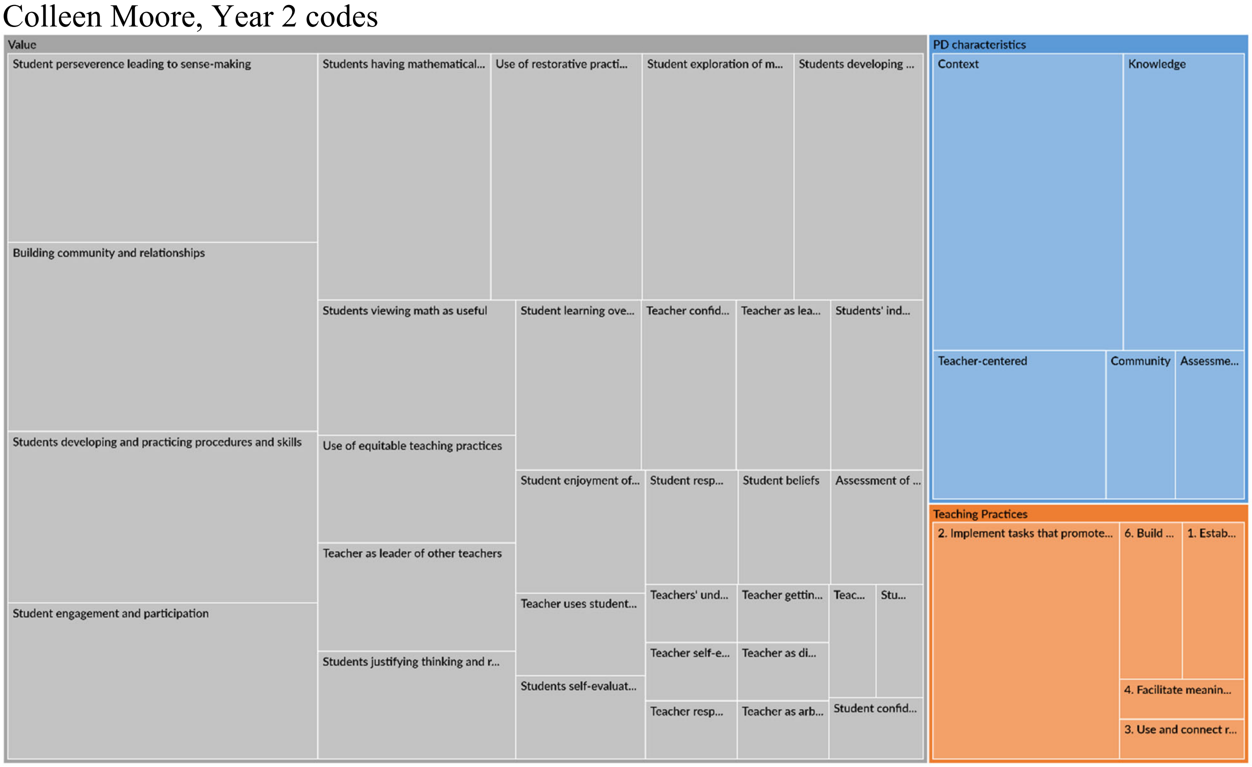

Colleen Moore, pre-Year 1 codes



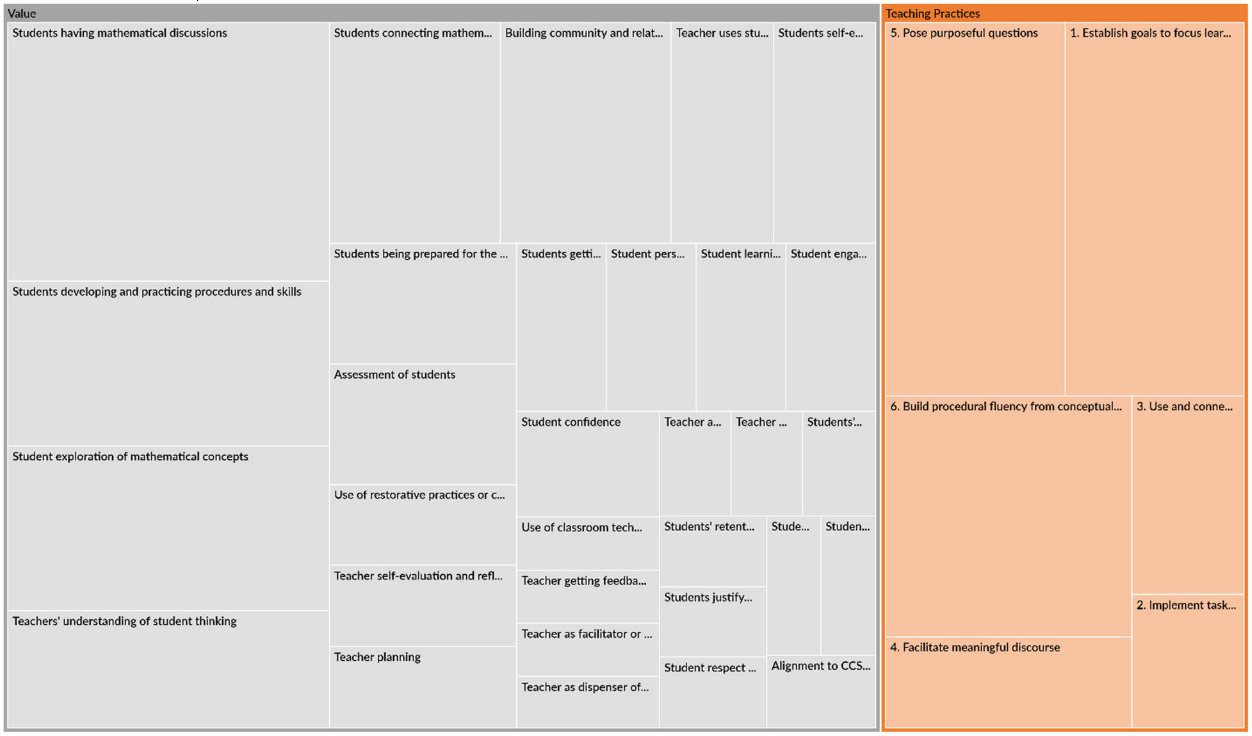
Colleen Moore, Year 1 codes



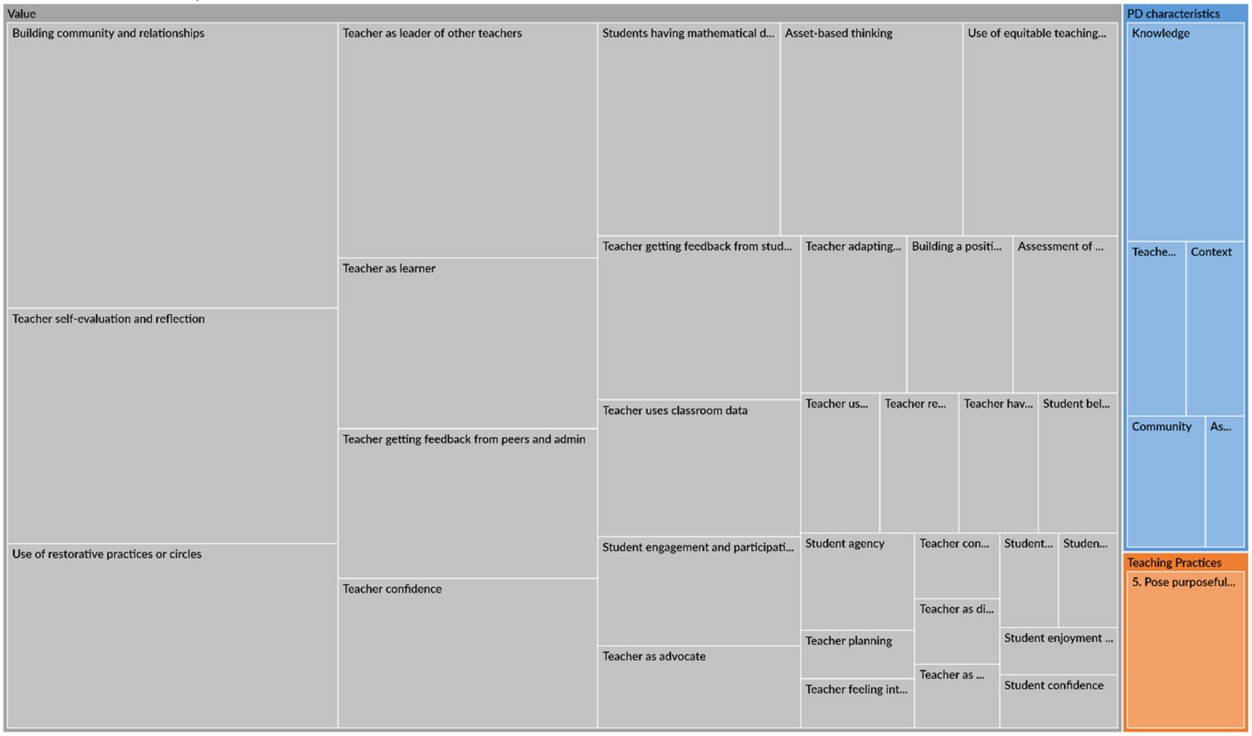

Colleen Moore, Year 2 codes



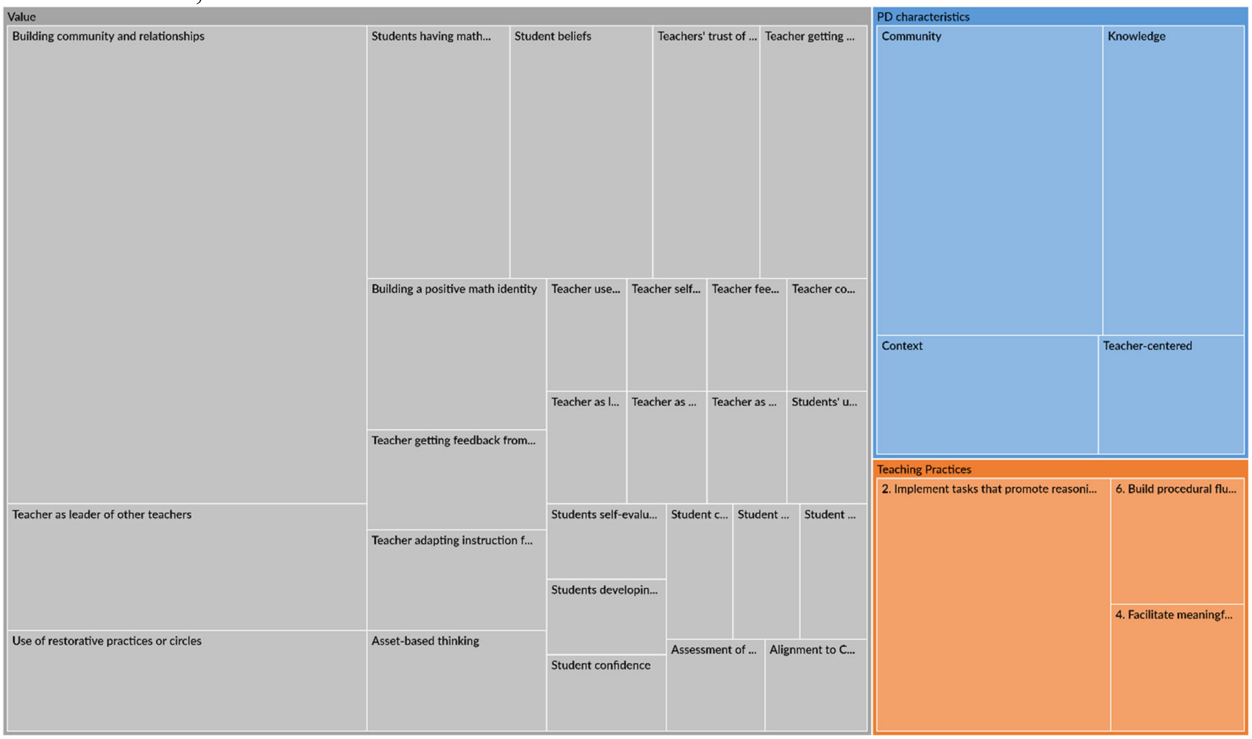
Colleen Moore, Year 3 codes



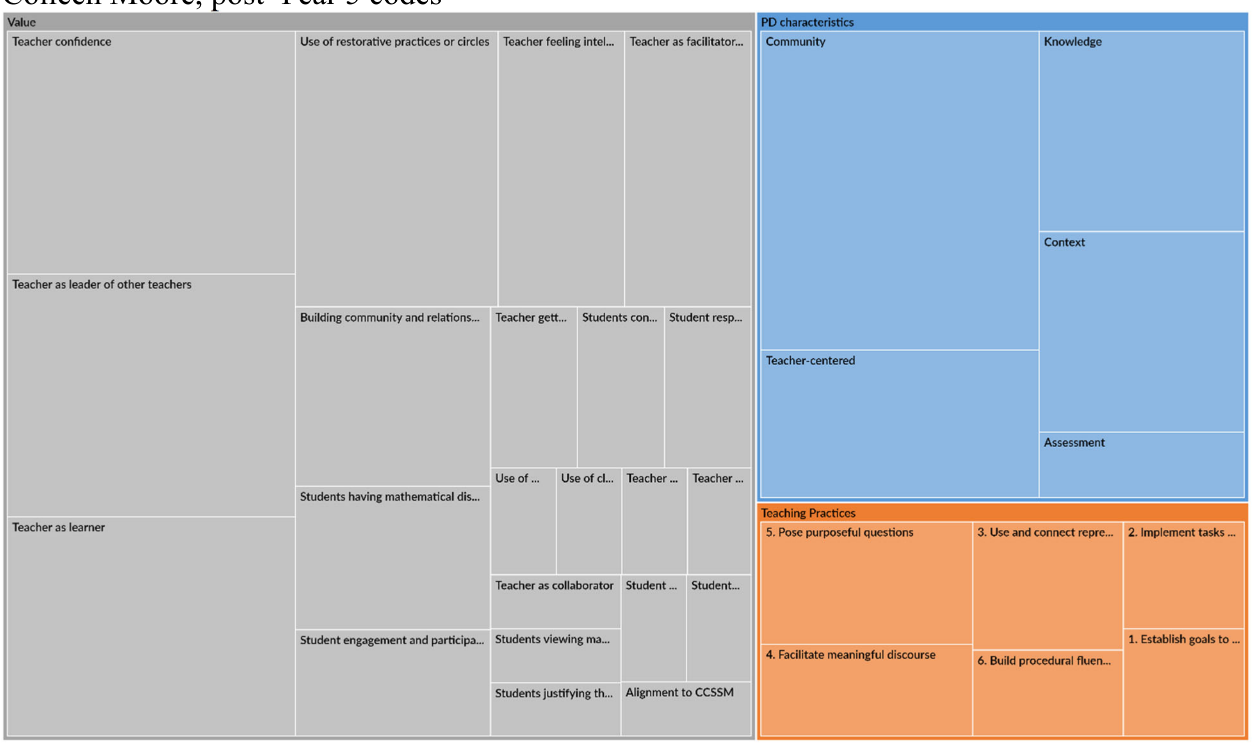

Colleen Moore, Year 4 codes



Colleen Moore, Year 5 codes




Colleen Moore, post-Year 5 codes



**Curriculum Vitae**

# Jenny Sagrillo

## Education

| | |
|---|---|
| Anticipated August 2023 | **Doctor of Philosophy — University of Wisconsin–Milwaukee, Milwaukee, Wisconsin**<br>Urban Education, specialization in mathematics education<br>Advisor: Michael Steele, EdD<br>Committee members: DeAnn Huinker, EdD; Kevin McLeod, PhD; Melissa Boston, EdD |
| 2003 | **Master of Science** — University of Wisconsin–Milwaukee, Milwaukee, Wisconsin<br>Curriculum & Instruction<br>Advisor: Henry Kepner, PhD |
| 1999 | **Post-baccalaureate certification** — University of Wisconsin–Milwaukee, Milwaukee, Wisconsin<br>Computer Science |
| 1994 | **Bachelor of Science** — University of Wisconsin–Madison, Madison, Wisconsin<br>Major: Mathematics Education<br>Advisor: Margaret Meyer, PhD |

## Academic Appointments

| | |
|---|---|
| January 2016 - July 2022 | **Graduate research assistant**<br>University of Wisconsin-Milwaukee, Milwaukee Master Teacher Partnership |
| September 2016 - August 2022 | **Graduate teaching assistant**<br>University of Wisconsin-Milwaukee, Department of Teaching & Learning |
| May 2015 - present | **Lecturer**<br>University of Wisconsin-Milwaukee, Department of Teaching & Learning |
| September 2022 - present | **Lecturer**<br>University of Wisconsin-Milwaukee, Department of Mathematical Sciences |

## Courses Taught

| | |
|---|---|
| Summer Semester 2015-present | **Teaching of Mathematics: Middle School** — Curriculum & Instruction 332 — University of Wisconsin-Milwaukee<br>Methods for the teaching of mathematics in middle school for early adolescent and adolescent (6-12) mathematics education majors. |
| Spring Semester 2018 | **Teaching of Mathematics: Middle School** — Curriculum & Instruction 332 — University of Wisconsin-Milwaukee<br>Methods for the teaching of mathematics in middle school for middle childhood and early adolescent (1-8) education majors. |
| Fall Semester 2017-2021 | **Teaching of Mathematics: Secondary** — Curriculum & Instruction 532/532G — University of Wisconsin-Milwaukee<br>Methods and curriculum for the teaching of mathematics in middle and high schools for early adolescent and adolescent (6-12) mathematics education majors. |
| Spring Semester 2019-present | **Student Teaching Mathematics Seminar** — Curriculum & Instruction 432/432G — University of Wisconsin-Milwaukee<br>Seminar to support secondary (6-12) mathematics student teachers. |
| Fall Semester 2016, 2020-present | **Field Work in Middle School** — Curriculum & Instruction 516/516G — University of Wisconsin-Milwaukee<br>Field supervision for middle-grades student teachers. |

| | |
|---|---|
| Spring Semester 2017, 2021-present | **Student Teaching in Mathematics** — Curriculum & Instruction 431/431G **— University of Wisconsin-Milwaukee**<br>Field supervision for secondary student teachers. |
| 2022-present | **Mathematical Explorations for Elementary Teachers I – MATH 175 — University of Wisconsin-Milwaukee**<br>Theory of arithmetic of whole numbers, fractions, and decimals. Introduction to algebra, estimation, and problem-solving strategies. |
| 2022-present | **Mathematical Explorations for Elementary Teachers II – MATH 176 — University of Wisconsin-Milwaukee**<br>A continuation of MATH 175 in geometry, statistics, and probability. |
| Spring 2017, 2018 | **Current Topics in Curriculum & Instruction** — **Curriculum & Instruction 779** — **University of Wisconsin-Milwaukee**<br>**Topic: Classroom action research** |
| Fall 2018, 2020<br>Spring 2021 | **Research Practicum** — **Curriculum & Instruction 870** — **University of Wisconsin-Milwaukee**<br>**Supervision of practicing secondary math teachers conducting classroom action research** |

## Selected courses as guest lecturer

| | |
|---|---|
| Fall 2018 | **Introduction to Teaching Science in Middle and High School** — Curriculum & Instruction 328 — University of Wisconsin-Milwaukee<br>Presented an interactive mathematics lesson to prospective secondary mathematics education students |

## Professional Affiliations

| | |
|---|---|
| **American Educational Research Association** | 2016-present |
| Division C: Learning and Instruction | |
| Division K: Teaching and Teacher Education | |
| Special Interest Group 087: Research in Mathematics Education | |
| **Association of Mathematics Teacher Educators** | 2016-present |
| **Benjamin Banneker Association** | 2021-present |
| **NCSM Leadership in Mathematics Education** | 2014-present |
| **National Council of Teachers of Mathematics** | 1993-present |
| **Psychology of Mathematics Education, North American Chapter** | 2021-present |
| **TODOS: Mathematics for All** | 2016-present |
| **Wisconsin Association of Mathematics Teacher Educators** | 2016-present |
| **Wisconsin Mathematics Council** | 1994-present |
| **Women and Mathematics Education** | 2021-present |

## Publications and Other Academic Products

**Other**

Desmos Activities collection
teacher.desmos.com/collection/6028559a39a1fb0b79ed529e

Berg, C.A. & Sagrillo, J.L. (n.d.) Using SeeMeTeach® to Generate Responses for Math edTPA Rubrics 6–10. www.seemeteach.com

## Presentations

Lawler, J., Maly, L., & Sagrillo, J.L. (2018, May 2-4). *Designing and Supporting Teacher Learning through Professional Development* [Conference presentation]. Wisconsin Mathematics Council Annual Meeting, Green Lake, WI, United States.

Steele, M.D., Sagrillo, J.L., Kish, J., Knetter, S., Masek, J., & Moran, C.L. (2018, July 11-13). *The Milwaukee Master Teacher Partnership: Enhancing Teacher Practice in Secondary Math & Science* [Conference presentation]. 7th Annual STEM Forum & Expo, hosted by National Science Teachers Association, Philadelphia, PA, United States.

Maly, L., Masek, J., McReynolds, E., Moore, M., Sagrillo, J.L., & Zietlow, M.T. (2019, April 3-6). *One Urban District's Journey to Empower Teachers and their Students* [Conference presentation]. National Council of Teachers of Mathematics Annual Meeting, San Diego, CA, United States.

Sagrillo, J.L. (2019, May 1-3). *There's so much out there! How do I find a good mathematical task?* [Conference presentation]. Wisconsin Mathematics Council Annual Meeting, Green Lake, WI, United States.

Sagrillo, J.L. (2020, April 1-4). *There's so much out there! How do I find a good mathematical task?* [Accepted conference presentation]. National Council of Teachers of Mathematics Annual Meeting, Chicago, IL, United States. (Conference cancelled due to COVID-19.)

Sagrillo, J.L. (2020, May 6-8). *There's so much out there! How do I find a good mathematical task?* [Accepted conference presentation]. Wisconsin Mathematics Council Annual Meeting, Green Lake, WI, United States. (Conference cancelled due to COVID-19.)

Sagrillo, J.L. (2021, September 22-25). *There's so much out there! How do I find a good mathematical task?* [Accepted conference presentation]. National Council of Teachers of Mathematics Annual Meeting, Atlanta, GA, United States. (Conference cancelled due to COVID-19.)

Sagrillo, J.L. & Steele, M.D. (2022, February 3-5). *Developing Justice-Focused Mathematics-Teacher Leaders through a University-District Micro-credentialing Partnership* [Conference presentation]. 2022 Annual AMTE Conference, Henderson, NV, United States.

Sagrillo, J.L. (2022, May 4-6). *There's so much out there! How do I find a good mathematical task?* [Conference presentation]. Wisconsin Mathematics Council Annual Meeting, Green Lake, WI, United States.

## Professional Licensing

T501 - Master Educator Teacher — Lifetime

1400 – Mathematics, grades 9-12

T001 – Teacher — Lifetime

1405 - Computer Science, grades 6-12

## Professional Experience

**Mathematics Department Chair** — 2010-2015

**Mathematics Teacher** — Riverside University High School, Milwaukee, Wisconsin — 1998-2015

Taught classes ranging from Algebra 1 through Precalculus from both traditional and integrated texts, including classes for struggling students. Coordinated lesson planning with other math teachers. Planning included supplementing textbook with additional material to meet the needs of the Common Core State Standards for Mathematics. Facilitated the alignment of department curriculum to the Common Core State Standards for Mathematics.

**Mathematics Teacher — St. Catherine's High School, Racine, Wisconsin** — 1995-1998

Taught General Math, Pre-Algebra, Algebra 1, and Geometry in a traditional schedule. Assisted with the implementation of an online gradebook system.

## Honors/Awards

**National Board for Professional Teaching Standards** — 2008-2018

National Board-Certified Teacher in Adolescent and Young Adult Mathematics

**Chancellor's Graduate Student Award** — University of Wisconsin–Milwaukee — 2016-2017

## Research Experience

**Graduate Research Assistant** — Milwaukee Master Teacher Partnership — January 2016 – July 2022

Research Assistant for a five-year Robert Noyce Master Teacher Fellowship Program. Collaborated with a university-district partnership team to organize program logistics, manage and analyze data, and plan and present teacher professional development for 24 secondary mathematics and science master educators, focusing on pedagogical and content knowledge for teaching.

## Professional/Community Service

Development team consultant for Math for Social Justice secondary mathematics course, Milwaukee Public Schools — Fall 2021 – Spring 2023

## Related Experiences

**Content Reviewer** — EdReports.org — 2015-2016

Evaluated high school textbooks and curricula for alignment to the Common Core State Standards for Mathematics. Collaborated with a team of five to thoroughly evaluate and prepare reports for publication on the EdReports website.

**Professional Development** Facilitator — 2016-2017

School District of Greenfield, Greenfield, WI
School District of Whitefish Bay, Whitefish Bay, WI
Whitnall School District, Greendale, WI
Co-facilitated professional development sessions for local school districts.

**Curriculum Writer** — Mathematics Institute of Wisconsin, Waukesha, WI — 2016

Collaborated with a team to write curriculum for a Geometry professional development module intended for teachers of grades 7-12.