5-2020

Mathematics Coaching, Professional Development, and Teacher Practice

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Introduction and Problem Statement

Mathematics is a cornerstone subject in the field of education. It can be an exciting, collaborative experience full of wonderment and exploration. When students are engaged in learning math in meaningful ways, they learn to make sense of mathematics. John Hattie (2017) describes mathematics knowledge as "one of the significant gatekeepers in modern society" (p. 1). A good mathematics foundation at the elementary level is essential to students' development of mathematical understanding in middle and high school. Students who perform well in high school mathematics are more likely to attend college. At the college level, students who succeed in math classes are more likely to finish school and earn a degree. Finally, individuals need a strong math background as they enter today's workforce. Strong math skills will open the door to many high paying math related fields such as engineering, economics, computer science, and marketing (Hattie, et al., 2017).

Many factors contribute to student success. One of the most significant is the effectiveness of a teacher. An educator's mathematical knowledge for teaching positively predicts student gains (Hill, Rowan, & Ball, 2005). Instructional decisions that teachers make on a daily basis significantly impact the learning of their students. Although research has identified highly effective practices for teaching mathematics, many teachers continue to employ less effective pedagogy. Teachers often teach mathematics as they learned it, through memorization and practice of procedures (NCTM, 2014).

The National Assessment of Educational Progress (NAEP) was first administered in the early 90's. Until 2009, the percentage of students proficient in math steadily improved. Since that time, this biennial test has shown stagnant scores. In 2015, there was a slight dip in

mathematics for both 4th graders and 8th graders. Results from 2017 showed that the percentages have not bounced back, with 40% of fourth graders and 34% of eighth graders at or above proficiency (The Nation's Report Card; Jacobson, 2019). In Maine in 1998, grade 8 students had an average score of 271, which was 10 points higher than the national average of 261. In 2017, that 10 point difference had shrunk to 4 points. For 4th graders in 2000, the average score for Maine students was 230 as compared to 224 for the Nation. In 2017, that 6 point difference had shrunk to 1 point (240 as compared to 239). Even more alarming is the fact that NAEP shows that achievement gaps are getting wider. There was an increase of 6 points between scores of the students in the top ten percent and students in the bottom ten percent between 2015 and 2017 (Barshay, 2018).

Many districts are turning toward professional development (PD) as a means to improve student learning. However, there is not always a clear vision of what PD looks like, and there are many different types. Sometimes experts are brought into a district to provide training. Other times, teachers are sent off site to receive PD from an outside source. Often, these sessions are one time opportunities with minimal impact (West & Staub, 2003).

Recently, math coaching has begun to be utilized in pockets of communities throughout the country. Coaching is a strategy that can be used to provide on site, continual professional development in a specific area. Although it has been used in literacy for decades, it is new to the area of math. Therefore, research on the effect of math coaching has been limited. There have been a handful of initial studies investigating the relationship between math coaching and teacher knowledge or student achievement, but the results are often conflicting (Althuser, 2015; Killion, 2017; Kutaka et al., 2017; Obara, 2010).

By learning more about how coaching impacts teaching practices and which types of professional development have the most impact, we can better determine for districts how to utilize resources to support teachers as they work to implement best practices that will ultimately lead to improved student achievement.

Review of the Literature

Introduction

The National Council of Teachers of Mathematics published *Principles To Action* in 2014. In *Principles to Action*, they called for a move from "pockets of excellence" in mathematics to "systemic excellence" (NCTM, 2014, p.3). They went on to identify five "troubling and unproductive realities" in the mathematics classrooms of today:

1. Too much focus is on learning procedures without any connection to meaning, understanding, or the applications that require these procedures.
2. Too many students are limited by the lower expectations and narrower curricula of remedial tracks from which few ever emerge.
3. Too many teachers have limited access to the instructional materials, tools, and technology that they need.
4. Too much weight is placed on results from assessments, particularly large-scale, high-stakes assessments that emphasize skills and fact recall and fail to give sufficient attention to problem solving and reasoning.
5. Too many teachers of mathematics remain professionally isolated, without the benefits of collaborative structures and coaching, and with inadequate opportunities for professional development related to mathematics teaching and learning. (p.13)

Knowledge of Teaching

Teaching requires specialized knowledge. In 1986 Lee Shulman, a pioneer in the research of teaching, reframed the study of teacher knowledge. He proposed that there is a knowledge that is unique to teaching. He coined the term pedagogical content knowledge, which provides a bridge between content knowledge and pedagogy, the practice of teaching (Shulman, 1986).

Researchers since that time have sought to define exactly what mathematics knowledge is required to teach math. They have identified three categories of subject matter knowledge: common content knowledge, specialized content knowledge, and knowledge at the mathematical horizon. They have also identified three categories of pedagogical content knowledge: knowledge of content and students, knowledge of content and teaching, and knowledge of curriculum (Ball et al., 2008; Hill et al., 2008; Thames and Ball, 2010).

Teacher Knowledge and Student Achievement

Research has shown that there is a relationship between teachers' mathematical content and pedagogical knowledge and student achievement (Campbell et. al, 2014; Tchoshanov, 2011; Hill et al., 2005). Campbell (2014) found a positive correlation between teachers' math content knowledge and student achievement on standardized state tests for upper elementary and middle school. Although there was no correlation between teachers' pedagogical content knowledge and student achievement at the upper elementary level, there was a strong relationship between the two at the middle school level (Campbell et al., 2014).

According to Tchoshanov (2011), teacher knowledge of concepts may be a predictor of students' mathematics achievement. He found that teachers who possessed a strong knowledge

of concepts and connections had a positive impact on the success of their middle school students in the area of math (Tchoshanov, 2011).

Content and Practice Standards

The Common Core State Standards (CCSS) were created to provide a uniform set of standards for all students by defining what content students need to acquire at each grade level. In addition to content goals, the CCSS identified eight Standards for Mathematical Practice:

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning. (CCSS, 2012)

These practices create an expectation that students will engage with the content standards in meaningful ways that will lead to a deeper understanding of mathematics. Although the CCSS outline the content students are to learn and describe how students will interact with that content, they do not provide a description of how teachers will engage students in the Mathematical Practices.

Teaching Practices

In *Principles to Action*, the National Council of Teachers of Mathematics identified eight Mathematics Teaching Practices that provide a research-informed framework for improving teaching and learning mathematics:

1. Establish mathematics goals to focus learning.
2. Implement tasks that promote reasoning and problem solving.
3. Use and connect mathematical representations.
4. Facilitate meaningful mathematical discourse.
5. Pose purposeful questions.
6. Build procedural fluency from conceptual understanding.
7. Support productive struggle in the learning of mathematics.
8. Elicit and use evidence of student thinking. (p. 10)

These high leverage pedagogical practices are the blueprint that is missing in the CCSS. They are the key to increasing the engagement of students in the Standards for Mathematical Practice. These teaching practices are essential if we want our students to obtain a deep conceptual understanding of mathematics (NCTM, 2014).

Mathematics Teaching Practice #4: Facilitate Meaningful Mathematical Discourse

NCTM describes MTP#4 as the heart of any mathematics lesson (pg 246). Discourse among students is essential to meaningful learning of mathematics. Discourse includes purposeful exchanges of ideas through various forms of discussion including verbal, visual, and written communication. Through these interactions, students learn to share ideas, construct viable mathematical arguments, and develop language. In order to effectively use discourse to deepen learning, a teacher must decide how to extend student thinking while maintaining a focus

on the central mathematical idea. Additionally, he/she must provide opportunities for students to talk together, ask questions, and respond to one another in order to build shared mathematical understanding (NCTM, 2014). Research has shown a connection between opportunities for mathematical discourse and increased learning for students (Michaels et al, 2008). However, orchestrating effective math discourse is complex, requiring various teaching actions (NCTM, 2017).

Professional Development

Although teachers have been provided with content and practice standards through the Common Core State Standards, and a list of high leverage pedagogical practices has been created by NCTM, many teachers still need support in implementing highly effective pedagogy. Veteran teachers and new teachers alike can be lacking in the pedagogical knowledge necessary to implement the Mathematics Teaching Practices. It is the responsibility of principals, coaches, and school leaders to provide professional development (PD) to ensure teachers are engaging in high leverage teaching practices (NCTM, 2014).

Local districts are looking for ways to improve math achievement for students. Professional development can offer an opportunity to increase both content and pedagogical knowledge of a collective unit. Professional development for teachers has been shown to have a positive impact on teacher content knowledge, instructional practices, teacher efficacy, and student achievement (Althauser, 2015; Garet et al., 2016; Kutaka, 2017; Wilkins, 2008).

A study conducted by Kutaka et al. in 2017 explored the effect that Primarily Math (an inservice mathematics specialist program) had on mathematical teaching knowledge of teachers in grades kindergarten through third grade. They found that the professional development

resulted in more growth in knowledge for teaching numbers and operations, less math anxiety, and a tendency to lean more toward student centered beliefs about teaching and learning math (Kutaka, et al., 2017).

A quantitative study by Althauser was designed to determine the impact of a professional development program on teachers' efficacy, both general (beliefs about the factors associated with how students learn) and personal (perception of one's effectiveness to teach) in teaching mathematics and students' achievement. The teachers received two years of professional development focused on curriculum alignment and formative assessment. The study showed that professional development had an impact on professional practice, teacher efficacy for mathematics, and student achievement (Althauser, 2015).

A 2016 report by the Institute of Education Sciences examined the impact of professional development on teachers' math content knowledge, instructional practice, and student achievement. The study showed that the content-intensive PD positively affected teacher knowledge with an increase of 21 percentile points of participants over the control group. It also had an impact on instructional practice, particularly the emphasis on the conceptual aspects of math (Garet, et al., 2016).

However, all professional development is not equal. One and done professional development has been shown to have little effect on changing teacher practice. Effective PD needs to be ongoing, providing job-embedded support and opportunities for reflection, and offering teachers opportunities to collaborate and learn from each other (Campbell et al., 2013; West & Staub, 2003).

Mathematics Coaching

Many localities are employing academic coaches to provide professional development in an effort to build the content and pedagogical knowledge necessary to meet the rigorous demands of the Common Core State Standards. Academic coaches can provide teachers with the support they need to explore content and implement new pedagogy and teaching practices. However, math coaching is a relatively new field with many models continuing to emerge (Morse, 2009; West & Staub, 2003).

Lucy West has coined the term content-focused coaching which is grounded in the belief that coaching should be focused on the specific knowledge that is to be learned. The coach and teacher dive deep into the standards that govern what students are to learn (West & Cameron, 2013).

Diane Sweeney has developed another model for coaching. Student-centered coaching focuses on setting specific goals for students and using student data to assess progress toward those goals. This model has a strong connection to formative assessment since the teacher and coach work together to examine student work for evidence of student understanding and use that evidence to inform instruction (Sweeney, 2011).

McGatha and Williams have developed yet another model of math coaching deeply rooted in a focus of the CCSS Standards for Mathematical Practice (SMP). This framework called “Leading for Mathematical Proficiency” is centered on creating “Shifts in Classroom Practice” that are aligned to the SMP (McGatha et al., 2018).

Regardless of the coaching model, the work of all coaches maintains a focus on student learning. The goal of a coach is to provide continuous support to teachers in order to improve learning for all students through a cycle of co-planning, co-teaching, and debriefing (Campbell,

et al, 2013; Hull et al., 2009; McGatha, et al., 2018; Morse, 2009; Sweeney, 2011; West & Cameron, 2013).

Research on academic coaching and its impact on teacher practice and student math achievement is limited. Studies have revealed conflicting findings. In a study comparing two middle schools in south Texas, a relationship was found between instructional coaching and student math achievement. The sixth and seventh grade students in the school without an instructional coach had a higher mean score on the TAKS (Texas Assessment of Knowledge and Skills) than students from the school with an instructional coach (Garcia et al., 2013).

In contrast, another study was conducted within five urban or urban-edge school districts in Virginia. This experimental quantitative research study investigated the relationship between the implementation of math coaching and student achievement. The study involved 24 coaches, each receiving extensive training. Student data was measured using the Standards of Learning Assessment, the Virginia statewide standardized achievement test. Student achievement data was collected on students in grades 3, 4, and 5 for each of the three years included in the study. Results showed significant improvement in the cohorts utilizing math coaches as compared to the control group (Campbell & Malkus, 2011).

In a 2009 NCTM research brief, Maggie McGatha reviewed some of the research which has been conducted on math coaching. She reported that the use of math coaches resulted in an increase of active engagement of students and an increase of best practices by teachers, including an increase in hands on learning and the use of higher order thinking activities. She also found that teachers were more knowledgeable of learning styles and tended to focus more on big ideas. Finally, she found teachers who worked with math coaches emphasized problem solving over

skills instruction and were more likely to engage in formative assessment practices (McGatha, 2009).

Finally, in a case study conducted by Jim Neuberger, several results of math coaching were revealed. First, there was a change in teacher practices which was observed by both the coach and teacher herself. These included more intentional grouping of students, an increase in student interaction and student discourse, and the emergence of a sense of community within the classroom. Second, the teacher described a shift in her beliefs, specifically, that students should make sense of their mathematical ideas, that math can be fun, and that math should be a priority. There was also a self proclaimed increase in the teachers' math efficacy and self reflection (Neuberger, 2012).

Summary

In summary, although many factors contribute to a student's learning, no one can dispute the importance of an effective teacher. Teaching requires specialized content and pedagogical knowledge. Research shows that teachers need support implementing highly effective strategies such as those outlined by NCTM in *Principles To Action*. Districts have used a variety of types of professional development in an attempt to improve the practice of teaching. Most recently, some systems have begun to utilize math coaches. Schools are hopeful that math coaches can help lift teaching to higher levels of math pedagogy and content knowledge. Coaching may be the link to help schools move from the five "troubling and unproductive realities" in the mathematics classrooms of today. Indeed, coaches can break down the walls that keep "teachers professionally isolated, without the benefits of collaborative structures and coaching, and with

inadequate opportunities for professional development related to mathematics teaching and learning" (NCTM, 2014, p.13). However, research on the topic of math coaching is limited.

There are many models of math coaching. Districts employ math coaches in a variety of settings and situations. Some coaches are responsible for one school, some for many. Some coaches are full time, others serve dual roles of classroom teachers and coach. Even the role of math coach and job description can vary from school to school depending on the implementation model (McGatha, 2009; Obara, 2010; West & Staub, 2003).

Coaches come with various training and experience. Some come right out of the classroom. Others have participated in minimal training. Some have graduated from coaching programs.

Not all studies have controlled for the variables of the coach's preparation, expertise, or role. These factors along with conflicting findings are evidence that additional studies need to be conducted. Does math coaching have an impact on teacher pedagogical practice? What type of mathematics professional development will lead to an increase in highly effective math practices? In order to answer these questions, more research is needed (Garcia, et al., 2013; Killion, 2017).

Research Purpose and Research Questions

The purpose of this study was to measure the impact of various forms of high quality, job-embedded math professional development (including math coaching) on instructional practice of teachers in a rural Maine elementary school to determine which types of professional development have the greatest effect on pedagogy. The main goal was to provide teachers with varying tiers of professional development and determine the impact of each tier by measuring the

frequency of the incorporation of Mathematics Teaching Practice #4: Facilitate Mathematical Discourse into classroom instruction.

This study sought to answer two questions:

1. Does math coaching impact teacher pedagogical practice?
2. What are the effects of various types of professional development?

Methods

Research Design

A quantitative quasi-experimental study research design was used to determine the impact of various tiers of professional development on teacher pedagogical practice within the setting of a rural Maine elementary school. I planned and delivered three different tiers of professional development and measured the impact of each tier on instructional practice using a tool designed to look for strategies and tools that are evidence of Mathematics Teaching Practice (MTP) #4: Facilitate Mathematical Discourse.

Tier One consisted of two one-hour workshop-based trainings that delivered explicit instruction on how to incorporate MTP#4 into classroom instruction. The teachers were introduced to resources and strategies designed to engage students in mathematical discussions. They also read and discussed sections of the book *Principles To Action* (NCTM, 2014) that reference MTP#4.

Tier Two involved two one-hour Instructional Team meetings where teachers worked collaboratively in grade level teams to incorporate strategies and tools introduced in Tier One. During these sessions, participants co-planned lessons and activities designed to offer opportunities for mathematical discourse, reflected on the impact MTP#4 has had on student

understanding of mathematics, and set personal goals for further incorporation of mathematical discourse.

The final layer (Tier Three) of professional development came in the form of math coaching. Four teachers participated in a six week coaching cycle with a focus goal of incorporating MTP#4 strategies into instruction. The coaching followed the model called "Leading for Mathematical Proficiency". This framework is centered on "Shifts in Classroom Practice" that are aligned to the CCSS Standards for Mathematical Practice (McGatha et.al, 2018). Coaching consisted of at least one co-planning session each week, one to three weekly co-taught or observed lessons, and at least one weekly debriefing session for each of the six weeks in the cycle.

Population and Sample

The school being used for this study was a small town, rural school in Central Maine. It is one of several elementary schools in the district, serving approximately 200 fourth and fifth grade students. There are ten regular education classrooms and three resource room classrooms (two pull out and one self contained) for a total of 13 teachers. The district currently uses a model for professional development where two hours a month are devoted to professional development. Tiers One and Two occurred during these designated times. All teachers participated in Tier One of professional development. The ten regular classroom teachers only participated in Tier Two of the professional development since the Special Education teachers were released from the second monthly session because of IEP demands. Four teachers were randomly chosen to participate in Tier Three, the math coaching.

Data Collection Strategy

To measure the effect of each Tier of professional development on the level of discourse occurring in each classroom, I collected data on all participants of the study. To collect the pre-study data, I used an observational tool (Appendix A) that contained a check off for actions, strategies, or tools that are evidence of Mathematics Teaching Practice #4: Facilitate Mathematical Discourse. I developed this tool by combining research from three resources focused on implementing MTP#4 into teacher practice (See Appendix A).

The first resource was *Principles To Action* (NCTM, 2014). In *Principles To Action*, NCTM identifies four teacher actions that are evidence of MTP#4:

1. Engaging students in purposeful sharing of mathematical ideas, reasoning, and approaches, using varied representations.
2. Selecting and sequencing student approaches and solution strategies for whole-class analysis and discussion.
3. Facilitating discourse among students by positioning them as authors of ideas, who explain and defend their approaches.
4. Ensuring progress toward mathematical goals by making explicit connections to student approaches and reasoning. (p.35)

These four actions are represented in the data collection tool I used.

The second resource I used to develop the tool was *Everything You Need for Mathematics Coaching* (McGatha et. al, 2018). This book outlines a framework for coaching based on creating shifts in pedagogy focused on the Mathematics Teaching Practices. The observational tool represents the three strategies for MTP#4 developed in this framework:

1. Helps students share, listen, honor, and critique each other's ideas.

2. Helps students consider and discuss each other's thinking.
3. Strategically sequences and uses student responses to highlight mathematical ideas and language. (McGatha, 2018, Appendix B)

Also in *Everything You Need for Mathematics Coaching*, McGatha et al. discuss Talk Moves. In *Talk Moves: A Teacher's Guide for Using Classroom Discussions in Math* (Chapin et. al, 2013), the authors describe actions that teachers can use with students to increase the level of discourse. Research has shown the use of talk moves such as wait time increases the quality of student talk and leads to an increase of student thinking and reasoning (Chapin and O'Connor, 2007). Therefore, I added some Talk Move strategies to the checklist.

The third resource used to develop the observational tool was *Five Practices for Orchestrating Productive Mathematics Discussions* (Smith & Stein, 2011). In this book, Smith and Stein describe five steps for using student work to guide mathematical discourse which I incorporated into the tool:

1. Anticipating: anticipate likely student responses.
2. Monitoring: monitor students' actual responses to the tasks.
3. Selecting: select particular students to present their mathematical work.
4. Sequencing: sequence the student responses that will be displayed.
5. Connecting: connect different students' responses and connect the responses to key mathematical ideas. (p.8)

In addition to a check off list of actions to look for, the observational tool also included a section for notes. These anecdotal notes specified the action or behavior that provided the evidence of MTP#4.

Data was collected twice. Baseline data was collected before the professional development began. The second round of data was collected at the end of the study. To collect this data, the same list of actions, tools, and strategies from the observational tool were put into a survey for teachers to record the frequency of the use of each in their practice (Appendix B). Response was used to determine the increase of Mathematical Discourse opportunities occuring in each classroom.

Data Analysis

The quantitative pre and post study served as evidence of growth for each individual teacher. I aggregated the growth data according to individuals who received the professional development at each tier (Tier One only, Tier One and Two, and all three tiers). I used this data to determine which level of professional development had the most impact on teacher pedagogical practice.

Hypothesis

I hypothesized that teachers at this rural Maine elementary school who received a six-week coaching cycle (Tier Three) would experience more growth in the frequency of evidence of Mathematics Teaching Practice #4 than teachers who received only direct instruction about the practice (Tier One) and teachers who received training about the practice and designated time to collaborate with peers in Instructional Team sessions (Tier Two).

Results

The first question presented in this research study addressed the impact of math coaching on pedagogical practice. The post study data in Table 1 shows that the teachers in Tier One who only attended the two PD sessions provided an average of 5.3 opportunities per lesson for

students to engage in mathematical discourse. The Tier Two teachers who received the PD and Instructional Team sessions provided an average of 11.7 opportunities. Teachers in Tier Three of the study (those that participated in coaching) provided an average of 15.8 opportunities per lesson for students to engage in mathematical discourse. This was an average of 4.1 more opportunities than teachers at the Tier Two level and 10.5 more opportunities than teachers at the Tier One level.

Table 1

Growth in Opportunities for Mathematical Discourse

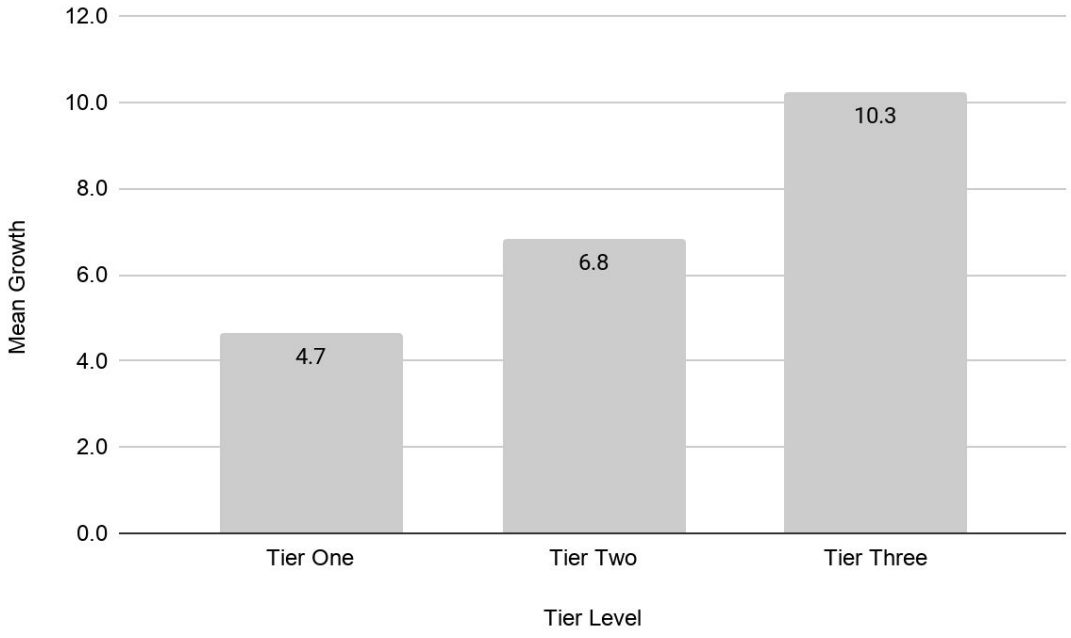
Participant	Tier Level	Pre-study Opportunities	Post-study Opportunities	Increase in Opportunities
A	Tier 1	0	6	6
B	Tier 1	2	7	5
C	Tier 1	0	3	3
D	Tier 2	2	9	7
E	Tier 2	4	10	6
F	Tier 2	5	9	4
G	Tier 2	6	14	8
H	Tier 2	6	14	8
I	Tier 2	6	12	6
J	Tier 3	10	20	10
K	Tier 3	5	13	8
L	Tier 3	1	12	11
M	Tier 3	6	18	12
Aggregated Mean by Tier	Tier 1	.7	5.3	4.7

Tier 2	4.8	11.7	6.8
Tier 3	5.5	15.8	10.3

The second research question asked about the effects of various types of professional development. Figure 1 shows that there was a difference in average growth between the various Tier Levels. Teachers who only attended the PD sessions showed an increase of 4.7 opportunities from the pre-study to post-study data. Teachers who attended both the PD sessions and the Instructional Team sessions showed an increase of 6.8 opportunities. Teachers who received coaching in addition to all PD and Instructional Team sessions showed an increase of 10.3 opportunities.

Figure 1

Mean Growth of Mathematical Discourse Opportunities by Tier



A follow up question on the survey asked teachers to identify what components of the math professional development were most beneficial to them. Three comments described working in grade level teams to analyze data and set learning goals for students. Three described collaborative planning time. Two teachers who had participated in a lesson study with the coach remarked how valuable it was to be able to observe a colleague teach a co-planned lesson and to give to and receive feedback from that fellow teacher. Other teachers valued most the resources provided and routines learned through the PD such as Notice and Wonder and Talk Moves.

Table 2

Responses to Survey Question: What components of the Math PD were most beneficial to you?

Grade Level Teams	● Working in grade level teams to analyze data ● Working with grade level teams to set goals for students ● Working together to dive deeper into data
Time to Plan Together	● Having time to plan with other teachers. ● Having time to plan together for talk moves ● Working in grade level teams to plan for math discourse
Lesson Study	● The observing of a colleague teaching math, and discussing the math discourse. It helped to confirm many things I was already doing in class as well as lead me to teach my problem solving in a more efficient manner. ● I really loved being able to watch a friend teach a lesson. That hasn't happened for me before and I found it very valuable.
Resources	● I loved the "Notice and Wonder/ What Doesn't Belong activities. I use them often ● Talk Moves has been an eye opener… Getting students to respect and appropriately critique each others' responses is something I would like to incorporate more often. ● I love the resources we used around math discourse. Conversation starters were very useful. ● The resources for math discourse ● Conversation sentence starters and discussion on how to use them

Discussion

Results from this study support the hypothesis that teachers who participate in coaching will experience more growth in the frequency of evidence of Mathematics Teaching Practice #4 than teachers who receive only direct instruction about the practice and teachers who receive training about the practice and designated time to collaborate with peers in Instructional Team sessions. Data also shows that there is a difference in the impact of various types of professional development on teacher practice. The teachers who received the most intensive PD (coaching) showed the most growth in their professional practice.

Even within the practice of discourse itself, there are varying levels. Hufferd-Ackles, Fuson, and Sherin (2015) identified five components of a math-talk learning community and created a rubric describing four levels within each component for moving from teacher-centered to student-centered discourse. Results from this study indicate that there was a shift in the types of Mathematical Discourse strategies and tools used. Pre-study anecdotal notes showed that many strategies that teachers used before taking part in this PD were superficial such as Turn and Talks (without expectation or purpose) and eliciting contributions from others (but these were disjointed and not connected to other responses). Post-study data indicates an increased use of student directed actions such as students asking questions of peers to better clarify their own understanding of the thinking of others. Without prompting from the teacher, students were more likely to ask a peer to explain a math strategy, to add onto another student's thinking, or to agree or disagree with their classmates.

Additionally, the perception data used as post-study data in this project provides evidence that teachers who received the most PD were more likely to perceive themselves as incorporating

the tools and strategies into their practice. The less PD a teacher took part in, the less she felt she engaged students in mathematical discourse. The teachers who received the most PD reported that they believed they used those tools and strategies more often. Therefore it appears that coaching may impact a teachers' self efficacy about teaching mathematics.

Limitations

One limitation of this study lies in the collection of evidence. Pre-study data was collected using observational data. This data was hard and concrete utilizing a list of "look fors" of mathematical discourse tools and strategies that were intentionally presented throughout the professional development. The post-study data was collected using a survey due to the sudden closing of schools during the Covid19 pandemic. The data became perceptual, reflecting the frequency the teacher felt she was using the strategies and tools. This allowed for more subjectivity and bias since there were multiple reporters and teachers were reflecting on their own practice.

Another limitation is that it is hard to determine if the increase in application of what was learned in PD was a result of the type of PD that each teacher received or a result of the time designated for PD. Teachers who did not receive coaching participated in a total of 2-4 hours of professional development, depending on the Tier they were assigned to. Teachers who received coaching spent an additional 2 to 3 hours per week with the math coach. This was a total addition of 12 to 18 hours of PD.

The third limitation of this study revolves around the teachers in Tier One. Due to the scheduling of the PD, these were all teachers of special services. By the design nature of their program, many of these classes are conducted in pairs or one on one. Many of the tools and

strategies used for mathematical discourse are not applicable in this setting. Therefore, it is difficult to determine the impact of Instructional Teams. Was the difference in growth between Tier 1 and Tier 2 due to the time spent working in grade level teams or because Tier 1 teachers felt the PD was not applicable to their settings?

Validity

Throughout this study I have ensured validity by planning and conducting all professional development myself; therefore all teachers received the same quality of PD. Despite a change in the method of data collection from the pre to post study data, all methods of data collection were uniform among the participants. Additionally, the four teachers who received coaching cycles were randomly chosen from the population.

Implications

As a follow up question to the survey, teachers were asked what components of the PD were most beneficial to them. Responses to the follow up question indicate that teachers desire time to work collegially. NCTM (2014) described one troubling reality in today's schools as "Too many teachers of mathematics remain professionally isolated, without the benefits of collaborative structures and coaching, and with inadequate opportunities for professional development related to mathematics teaching and learning" (p.13.) Many responses to the survey question describe opportunities that can alleviate feelings of isolation. This will be significant as administrators and other school leaders create professional development opportunities.

As data about the impact of mathematics coaching on teacher practice continues to emerge, this study adds to the body of research. It shows that math coaching may have a positive

impact on the transference of what is learned through professional development to teacher pedagogy. It also indicates that all professional development doesn't have the same impact. The more intensive the PD, the more impact it seems to have on teacher practice. More research is needed to determine if the level of transference of pedagogical knowledge into practice is attributed to the type of professional development offered or the frequency and duration of that professional development. Additional research could also determine if this learning is sustainable over a period of time. Will the use of best practices continue once the coaching and PD sessions have ended?

Conclusion

Coaching has the potential to be a powerful tool in moving teacher pedagogy forward. Coaching is individualized professional development, with the coach typically working one on one with a teacher. It is usually teacher driven, allowing the teacher to choose the focus. Therefore the time spent with the coach is meaningful and relevant to the individual teacher.

In *Principles To Action* (2014), NCTM calls for "moving to action to build a culture of professionalism" (p. 107). They call on principals, coaches, specialists, and other school leaders to:

- Provide appropriate and ongoing opportunities for professional growth and development for teachers, including coaching and collaborative planning opportunities that build capacity to implement the Mathematics Teaching Practices.
- Allocate time for teachers to collaborate in professional learning communities.
- Maintain a culture of continual improvement, learning, and collaboration.
- Support the staffing of mathematics coaches, specialists, and instructional leaders.

- Support sustained professional development that engages teachers in continual growth of their mathematical knowledge for teaching, pedagogical content knowledge, and knowledge of students as learners of mathematics. (pp. 113-114)

As district leaders make decisions about how to utilize professional development to improve instructional practice, research into professional development (and math coaching in particular) will be very important as they decide how to allocate resources such as time and money. In order to make informed decisions, more research is needed to determine the impact that math coaches can have on teacher practice and ultimately student learning. Research regarding the duration and intensity of the PD as well as the impact of working with colleagues and coaches will help guide our administrators as they support teachers in the most effective and efficient manner.

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Appendix

A Observation Tool

B Teacher Survey

C Informed Consent for Teachers

D Letter for Administrators

Appendix A: Observation Tool: Facilitate Mathematical Discourse

Strategy or tool	Evidence
☐ Engages students in turn and talk.	
☐ Provides opportunities to work in collaborative groups.	
☐ Helps students share, listen, honor, and critique each other's ideas.	
☐ Helps students consider and discuss each other's thinking.	
☐ Strategically sequences and uses student responses to highlight mathematical ideas and language.	
☐ Utilizes student sentence starters or discussion prompts.	
☐ Guides student discussion from the periphery of the conversation.	
☐ Waits for students to clarify the thinking of others or to ask questions.	
☐ Explicitly connects students' approaches and reasoning with math goals.	
☐ Solicits contributions from other members of the class.	

Adapted from *Everything You Need for Mathematics Coaching*, McGatha, Bay-Williams, Kobett, Wray, (2018); *Principles To Action: Ensuring Mathematical Success For All*, NCTM, (2014); *Five Practices for Orchestrating Productive Mathematics Discussions*, Smith & Stein (2011); *Talk Moves: A Teacher's Guide for Using Classroom Discussions in Math,* Chapin, O'Connor, & Anderson (2013).

Appendix B: Teacher Survey: Mathematical Discourse Survey

Please indicate how many times you use each of the following Mathematical Discourse tools and strategies during a typical lesson.

Strategy or tool	0	1	2	3 or more
Engage students in turn and talk.				
Provide opportunities to work in collaborative groups.				
Help students share, listen, honor, and critique each other's ideas.				
Help students consider and discuss each other's thinking.				
Strategically sequence and use student responses to highlight mathematical ideas and language.				
Utilize student sentence starters or discussion prompts.				
Guide student discussion from the periphery of the conversation.				
Wait for students to clarify the thinking of others or to ask questions.				
Explicitly connect students' approaches and reasoning with math goals.				
Solicit contributions from other members of the class.				
What components of this year's math professional development were most beneficial to your teaching practice?				

Adapted from *Everything You Need for Mathematics Coaching*, McGatha, Bay-Williams, Kobett, Wray, (2018); *Principles To Action: Ensuring Mathematical Success For All*, NCTM, (2014); *Five Practices for Orchestrating Productive Mathematics Discussions*, Smith & Stein (2011); *Talk Moves: A Teacher's Guide for Using Classroom Discussions in Math,* Chapin, O'Connor, & Anderson (2013).

Appendix C: Informed Consent For Teachers

Math Coaching, Professional Development, and Teacher Practice

You are invited to participate in a research study being conducted by Beth Downing as a graduate student at the University of Maine at Farmington.

Purpose of the study

The purpose of this study is to measure the impact of various forms of professional development and coaching on teacher practice.

Procedures

I will observe all teachers that participate in this study at the beginning of the study to look for evidence of strategies and resources aligned to Mathematics Teaching Practice #4: Facilitate Mathematical Discourse. I will then conduct four professional development sessions designed to introduce the practice and provide tools and resources to implement the practice into math instruction. Some teachers will also attend instructional team meetings where they will plan tasks and lessons that incorporate this practice into instruction, examine student work, and reflect on the impact of the practice on student learning. Finally, up to five teachers will be asked to participate in a coaching cycle focused on the implementation of MTP#4. At the end of all professional development sessions, I will again observe all teachers for evidence of growth.

Potential risks

The risks to subjects may include discomfort having a coach in the classroom. Although all participating teachers will be observed, I will be respectful and non-obtrusive during these observations. The first two forms or tiers of the professional development will be done in our normal professional development sessions and will not require additional time on your part. For teachers who participate in math coaching, the coaching cycle will be six weeks. Co-planning and debriefing sessions will be held at times that you choose.

Potential benefits

The potential benefits of the study include having time to collaborate with peers and the opportunity to work with a math coach. The work of the coaching session will support the work that you are doing in the other professional development sessions. There is the potential that results from this study could improve future professional development.

Confidentiality

No identifying information will be used during data collection. Numbers will be used rather than names to identify participants. Observational data will be kept in a locked cabinet. All data will be destroyed within one year of the completion of the study.

Participation and withdrawal

Participation in the study is voluntary. Observational data will only be used if you agree to participate. You may withdraw from the study at any time.

Audience of the study

Results of the study, without identifying information, will be shared with MSAD#54 administrators to determine the effectiveness of current professional development and to inform decisions about professional development in the future. They will also be shared in May as part of my Capstone Project for the University of Maine at Farmington..

If you have any questions, please feel free to reach out to me at any time at bdowning@msad54.org. You may also contact Brian Cavanaugh at brian.cavanaugh@maine.edu or Karol Maybury at karol.maybury@maine.edu with any questions or concerns about this study.

Thank you for your time and consideration,

Beth Downing

I, _____ agree to participate in Beth Downing's research study. I understand that participation is voluntary and that I can withdraw at any time without consequence.

_____ _____

(signature) (date)

Appendix D: Letter For Administrators

Math Coaching, Professional Development, and Teacher Practice

As a student at the University of Maine at Farmington, I am currently developing a research study on the impact on professional development and coaching on teacher practice. I would like your permission to conduct this study at the Margaret Chase Smith School.

Purpose of the study

The purpose of this study is to measure the impact of various forms of professional development and coaching on teacher practice.

Procedures

I will observe all teachers that participate in this study at the beginning of the study to look for evidence of strategies and resources aligned to Mathematics Teaching Practice #4: Facilitate Mathematical Discourse. I will then conduct four professional development sessions designed to introduce the practice and provide tools and resources to implement the practice into math instruction. Some teachers will also attend instructional team meetings where they will plan tasks and lessons that incorporate this practice into instruction, examine student work, and reflect on the impact of the practice on student learning. Finally, up to five teachers will be asked to participate in a coaching cycle focused on the implementation of MTP#4. At the end of all professional development sessions, I will again observe all teachers for evidence of growth.

Confidentiality

No identifying information will be used during data collection. Pseudonyms will be provided throughout. Data that is collected will be kept in a secure place. All observational data will be destroyed following the study.

Participation and withdrawal

Participation in the study is voluntary. Observational data will only be used if the teacher agrees to participate. As an administrator, you may choose to withdraw from the study at any time.

Audience of the study

Results of the study, without identifying information, will be shared with MSAD#54 administrators to determine the effectiveness of current professional development and to inform decisions about professional development in the future. They will also be shared in May as part of my Capstone Project for the University of Maine at Farmington..

If you have any questions, please feel free to reach out to me at any time at bdowning@msad54.org. You may also contact the course instructor, Brian Cavanaugh at brian.cavanaugh@maine.edu.

Thank you for your time and consideration,

Beth Downing

I, _____ agree to participate in Beth Downing's research study. I understand that participation is voluntary and that I can withdraw my school at any time without consequence.

_____ _____

(signature) (date)