A MULTI-YEAR STUDY OF THE IMPACT OF A PROBLEM-SOLVING FOCUSED PROFESSIONAL DEVELOPMENT ON TEACHER LEADERSHIP

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This study explored the connections between teacher leadership and a professional development model focused on problem-solving, Math Teachers' Circles (MTC). Surveys were completed by 213 MTC participants resulting in three years of data across multiple sites. A mathematics education leadership framework provided a data analysis tool. Findings suggested MTCs did impact participant teacher leadership, as survey results attended to all three areas of leadership from the analysis framework.

Keywords: Middle School Education; Teacher Beliefs; Teacher Education-Inservice; Teacher Knowledge

Objectives & Purpose of Study

With the implementation of the Common Core for State Standards in Mathematics (CCSSI, 2010), the need for mathematics teachers to be learners and leaders in mathematics education is stronger than in the past. Mathematics teachers are being called upon to not only improve their own mathematical content knowledge and how to teach that content, but also to lead students, parents, colleagues, administrators, and communities in understanding and meeting the new standards presented in the CCSS. Math Teachers' Circles (MTCs) are one form of professional development that may help teachers reach these standards for teaching and leading.

In this study, the researchers highlight the potential of MTCs to develop mathematics teacher leaders. Both are experienced MTC leaders, and they use their knowledge of MTCs, of teacher leadership, and of teacher professional development—augmented with quotes from national surveys of MTC participants—to highlight the potential of MTCs to develop mathematics teacher leaders.

After preliminary background on MTCs, their history, and sample problems, the authors use the PRIME Leadership Framework (NCSM, 2008) as a lens with which to view the work of MTCs. The paper ends with some concluding remarks on growing MTCs as a means for teacher leader development.

Math Teachers' Circles

MTCs are a form of professional development, aimed primarily at middle school math teachers, which tap into the instinct that mathematicians have to share their love of mathematics with others. This makes MTCs an accessible entry point for mathematicians interested in starting to work with teachers and for teachers interested in working with mathematicians to learn more mathematics through problem solving. With the advent of the CCSS, this partnership is particularly timely for both parties.

The canonical model for an MTC involves a leadership team consisting of two mathematicians, two middle school math teachers, and one administrator. After attending a summer training workshop, teams spend a year securing funding and then launch their own MTC the following summer, generally with a 4-5 day residential workshop. Academic year sessions follow, generally about three per semester, with each 2-2.5 hours in duration. Each MTC tailors this basic model to meet the needs of their local setting.

Sessions typically begin with a leader presenting a rich problem that fosters exploration involving multiple levels of deep mathematical content. As the session develops, problems lend themselves, for

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example, to discussions of symmetry, algebraic representations and functions, and arithmetic and algebraic properties like the commutative, associative, and distributive laws. From a problem-solving perspective, problems may lend themselves to the techniques of "ask a simpler question" and "work backwards." Related to the CCSS, it requires teachers to use most, if not all, of the Standards of Mathematical Practice as they explore the various facets of the problem.

A final key feature of some problems is the "low-threshold, high-ceiling" property. That is, an entry-level problem requires minimal mathematics background to understand and begin to explore it, yet it can be connected to research-level mathematics. In addition to in-depth explorations, participants also investigate shorter problems. For example, the following two problems can be discussed in a meaningful way in about 30 minutes: (1) What is the last (units) digit of 7^{503}? (2) What are the last two digits of ^{503}?

Computing either of these by hand would be quite cumbersome, and plugging them into a calculator provides an estimate in scientific notation, but does not help directly with finding the last few digits. Thus, one needs to use mathematical reasoning, in particular concepts of place value and the process of multiplication, to both find and justify a pattern for the last tens and units digits of the powers of 7 that allows one to answer each question. In working through these problems, teachers work directly with content relevant to their students, but at a level that develops their own mathematical reasoning skills. Fernandes, Koehler, and Reiter (2011) and Donaldson, et al. (2014) provide a more in-depth discussion of a problem unfolding in a MTC session, while White (2015) provides a more in-depth description of one MTC.

In addition to working on engaging mathematical problems, many MTCs include sessions or portions of sessions that directly connect to the classroom. These comprise diverse topics such as effective questioning strategies, how to translate lessons learned in MTCs to the classroom, and how to implement the CCSS. Two valuable texts the authors have found to help lead some of these sessions are Boaler and Humprey's (2005) *Connecting Mathematical Ideas: Middle School Video Cases to Support Teaching and Learning* and Burago's (2010) *Mathematical Circle Diaries, Year 1: Complete Curriculum for Grades 5 to 7.*

A somewhat unexpected (at least to the original organizers) consequence of the MTC program has been the development of teacher leadership. This was first discovered on a national survey of MTC participants in 2010, where a surprising number of respondents made comments that indicated that they had emerged as informal or formal leaders in their schools or districts. Moreover, they attributed this to their participation in MTCs. In the remainder of this paper, we discuss how MTCs connect directly with the PRIME Leadership Framework (NCSM, 2008), augmenting our narrative with illustrative quotes from participants.

Literature Review & Theoretical Framework

Need for Teacher Leaders

Reform documents emphasize K-12 students should be learning mathematics through problem solving (National Council of Teachers of Mathematics [NCTM], 2000; CCSSI, 2010).Mathematics Standards call for students to discuss, collaborate and justify their thinking through engaging tasks (NCTM, 2000; CCSSI, 2010) and for teachers to support such work (NCTM, 2014).

Despite this push for reform, middle school mathematics teachers still often teach content in traditional teacher didactic manners emphasizing textbooks and lecture (Grouws & Cebulla, 2000; Kent, Pligge, & Spence, 2003; Weiss, Pasley, Smith, Banilower, & Heck, 2003). With so many barriers to instructional change (Anderson, 1996; Roehrig, Kruse & Kern, 2007), teachers need to feel empowered to make changes to their instruction that benefit student learning (Fullan, 2001).

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Professional Development

Professional development is one avenue for empowering teachers to make changes. Effective professional development should build teachers' content knowledge, immerse them in authentic experiences, address beliefs, involve collaborative communities, and provide long term support (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009;Johnson, 2006; Loucks-Horsley, Hewson, Love, & Stiles, 2003). Flowers and Mertens (2003) described a need for professional development specific to middle school teachers' content and student learning needs. Teachers who attended professional development experiences longer than 8 hours and connected to other school-based initiatives reported the experiences improved their teaching while shorter unconnected experiences did not (Flowers & Merten, 2003). Other studies show long-term professional development of more than 80 hours is needed for teachers to enact inquiry-based practices (Porter, Garet, Desimone, & Birman, 2003). Professional development focused on mathematical problem solving increases teachers' content knowledge and improves pedagogical strategies (Anderson & Hoffmeister, 2007). MTCs are designed using these research-based characteristics: focused on building teacher content knowledge through problem solving strategies, was long-term, and involved building collaborative communities between teachers, mathematics educators, and mathematicians. This study further investigated the connection between high quality professional development and teacher leadership (Yow & Lotter, 2014).

Teacher Leadership

Due to teacher influence on student learning (Darling-Hammond, 1999), developing teacher leadership in mathematics education is one of the most important factors in schools (Pellicer & Anderson, 2001). Dozier (2004) defined teacher leaders as "good teachers who influence others." Before the phrase teacher leadership (Barth, 2001; Lieberman & Miller, 2004), teacher empowerment was the phrase used to describe a similar construct: teachers believing they had the "skills and knowledge to act on a situation and improve it" (Graham & Fennell, 2001; Short, 1994). Subject specific teacher leadership is a recent phenomenon; professional organizations define educational leaders in teaching (NBPTS, 2010; NCTM, 1991). Characteristics specific to mathematics teacher leaders are described in the literature (Langbort, 2001; Miller et al., 2000; Yow, 2007); however, few empirical studies exist (Webb, Heck, & Tate, 1996; Yow, 2010). Therefore, our research question asked *How does teacher involvement in a Math Teachers' Circle impact their enactment of teacher leadership?*

Theoretical Framework

The National Council of Supervisors of Mathematics (2008) developed the *Principles and Indicators for Mathematics Education Leaders* (PRIME) leadership framework responding to a lack of attention to the importance of school leadership in improving teaching and learning (Spillane, Halverson, & Diamond, 2004). The framework "aims to describe actions for mathematics education leaders across all settings, preK-12, in all its complexity" (NCSM, 2008, p. 2). We see teachers as educational leaders closest to student learning and therefore choose to focus on their data.

The framework lists specific actions that fall along a continuum of three stages of leadership growth. The continuum includes knowing and modelling leadership (leadership of self) as stage 1, collaborating and implementing structures for shared leadership on a local level (leadership of others) as stage 2, and advocating and systematizing improvements into the wider educational community (leadership in the extended community) as stage 3 (NCSM, 2008, p. 2). With this focus on leadership in mathematics education, we employed this framework as our data analysis tool.

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Methods

Data was analyzed from a national survey distributed to all MTCs in 2010 and to the authors' local MTCs in 2013 and 2014. Collectively, 213 participants completed the survey measuring MTC teacher impact. The survey contained Likert scale and open-response items asking teachers to rate and address their gains in mathematical content knowledge, attitudes and dispositions toward mathematics, classroom instructional practices, and professional activities. Data was analyzed through the three areas of leadership put forth in the PRIME Leadership Framework (NCSM, 2008). As shared earlier, the framework consists of: Stage 1 Leaders, considered ***Leadership of Self*****,** "know and model" good teaching practices in their own classrooms; Stage 2 Leaders, considered ***Leadership of Others***, "collaborate and implement" these good teaching practices with all students and other teachers and administrators; and Stage 3 Leaders, considered ***Leadership in the Extended Community***, "advocate and systematize" these good teaching practices on a larger scale helping to create instructional change at the district, state, national, or international level. At each stage, leaders are respected for the self-knowledge, influence of others, and advocacy on a larger scale, respectively.

Data was coded using the above three foci. For example, when teachers mentioned impact of MTCs on their own practice, those comments were coded as *Leadership of Self.* Comments that reflected MTC impact on collaborative work, such as "we all worked as a team to try and learn together," or encouraged teachers to invite others to learn with them (e.g., "I've started bringing my colleagues from the department to the Circles as well") were coded as *Leadership of Others*. Lastly, comments were coded as *Leadership in the Extended Community* when they spoke to the impact of MTCs on teachers expanding their sphere of influence to a larger community: "I have started giving presentations at meetings and conferences, have become the mentor for new math teachers, and am peer reviewer of math activities for the classroom at my level for the region."

Results, Discussion, and Conclusions

Findings showed MTC participant responses attended to each of the three stages of leadership put forward in the PRIME Leadership Framework.

Stage 1: Leadership of Self

MTCs allow teachers to develop their content and pedagogical expertise, change practice, and take risks (Yow, 2007), all part of leadership of self. A prerequisite to knowing and modeling good teaching practices is knowing and understanding the content and the disciplinary practices of mathematics. With the advent of the CCSS, many teachers are being asked to teach in ways that are often quite different from how they were taught. MTCs provide an opportunity for teachers to take on the role of learners of mathematics, and to revisit what that role looks and feels like. In fact, in initial end-of-workshop surveys of the MTC program, comments about being back in the role of a learner of mathematics were so prevalently cited as a benefit of MTCs that it was incorporated as a question on the most commonly used end-of-workshop survey form, and has been widely reported at conferences as one of the key outcomes of MTCs.

Math Teachers' Circles focus on building teacher content knowledge through problem-solving while also strengthening teachers' problem-solving skills and fluency with implementing the CCSS Standards of Mathematical Practice. They also learn the habits of mind and the disciplinary practice of mathematics, whereby the "answer" in not always known and uncertainty followed by exploration is the norm. As noted by one participant, "I have not participated in a workshop where I as a person have to struggle through, and the presenter did not share the correct answer." Often times, "answers" to the problems are not immediately given to participants at the end of problem-solving sessions so

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they can continue to grapple and discuss the problem. This directly addresses the first mathematical practice of perseverance in the CCSS (2010).

Teachers see what is modeled in the MTC and develop their pedagogical expertise in their own classrooms:

> In the meetings, they deliberately have us talk about our techniques and approach to the problem. When we think out loud as a group, we start to see patterns, and together we think about tools we can use. When possible, I like to integrate this approach in my classroom, giving my students the tools they need to figure out an overarching problem and then letting them chip away at it collectively until they figure it out.

MTCs provide an opportunity for teachers to be Stage 1 Leaders by allowing them to improve their own content knowledge as well as problem-solving skills. MTCs allow teachers to work in community to learn mathematics and solve problems that they can then implement in their own classrooms. "My classroom teaching has become more student-centered and engaging. Students are working together and discussing problems in groups, or exploring individually before sharing with a larger group."

Stage 2: Leadership of Others

MTCs focus on building community and learning how to solve problems alongside colleagues which lends itself to Stage 2 Leadership of Others by "collaborating and implementing." One teacher noted

> We all worked as a team to try and learn together…As different participants have different backgrounds and learning styles, the group work revealed to be very effective because we used our previous knowledge and our personal ways of seeing, interpreting and solving each problem. The support and the conversation with other members of the circle were always positive and enriching.

Teachers become a part of a community of learners within the MTC and then use this structure to begin similar communities at their schools. Seeing the model of mathematical discussion among the mathematicians, mathematics teacher educators, and teachers helps teachers learn how to facilitate mathematical discussions with their own colleagues. They gain a broader sense of what it means to be a part of a mathematics education community: "I feel that working on mathematics with my colleagues gives me a wider perspective on how to view mathematics and what it means to teach mathematics."

MTCs provide the opportunity for teachers to be Stage 2 Leaders by their returning to their schools and sharing what they learned with their fellow teachers and administrators. For example, following the intensive summer workshop, teachers invited colleagues from their schools to join us at our monthly Saturday meetings so they could see for themselves the types of mathematics and problem-solving in which we engaged. Some of these guests came to more than one Saturday meeting to extend their own learning and take what they were learning back to their schools and classrooms. In addition, one of the mathematics teacher educators invited her preservice teachers to come to the Saturday sessions. Their visit introduced them to current practicing teachers and offered them an opportunity to see what types of professional development are available to teachers and how they may incorporate such problem-solving approaches into their own future classrooms. One teacher wrote, "I've started bringing my colleagues from the department to the Circles as well, and that helped them realize that there really is something to this approach. It's also helped us cohere as a group back at school, and our students benefit immensely."

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Stage 3: Leadership in the Extended Community

MTCs provide an opportunity for teachers to be Stage 3 Leaders by their sharing what they have learned on a larger scale. For example, teachers from MTCs have presented at state mathematics conferences. During these presentations, teachers advocate for strong instructional practices by explaining what happens during MTC meetings and then present rich problems that they themselves have spent time solving with their students. They discuss the rich mathematical content of the problem and the mathematical directions they or their students may take to solve the problem. One teacher shared, "I have started giving presentations at meetings and conferences, have become the mentor for new math teachers, and am peer reviewer of math activities for the classroom at my level for the region."

Because MTCs often span several schools and school districts, teachers are able to interact with an extended community of math teachers within a region and increase their ability to systematize the practices used in MTCs. This leads to teachers building a wider network of colleagues with whom to learn and collaborate: "Participating in the MTC meetings has encouraged me to network with others and attend conferences with them." This newfound agency of being a member of a professional community also builds confidence in MTC participants, which results in taking on more of a leadership role in areas outside of their classrooms as well: "[Being a part of an MTC] has given me the confidence to step into more of a leadership role and a role in developing curriculum and lesson plans." Another participant who has become an instructional coach credited MTCs with helping in her job transition. "My leadership role in our math circle has correlated directly with my role change in my district from classroom teacher to teacher leader (instructional coach)." Strengthened by belonging to a professional mathematics education community empowers teachers to be mathematics teacher ambassadors (Yow, 2007) charged with telling others about the work they are doing in the MTCs and in their classrooms with students.

Concluding Remarks

MTCs provide a valuable professional development experience for mathematicians, mathematics teacher educators, and mathematics teachers. A powerful outcome of MTCs is the sense of community and broader understanding teachers gain of mathematics and the mathematics education community as a result of their participation. Even more, they provide an opportunity to develop mathematics teacher leaders by offering teachers the opportunity to develop in the areas of leadership of self (e.g. developing their content and pedagogical expertise, changing practice, and taking risks), leadership of others (e.g. becoming a part of a learning community), and leadership of the extended community (e.g. teaching their colleagues).

MTCs have the potential to impact mathematics teacher leadership on a national level given there already exists a national community and network of MTCs. Preliminary research has already been published on MTCs (White et al., 2013) and their relationship to mathematical knowledge for teaching. Also, Marle, Decker, and Khaliqi (2012) report that at one MTC, after a year of participation, classroom observations showed increases in the use of inquiry-based learning and in pedagogical content knowledge. More research is needed among long-standing MTCs to measure how extended participation in an MTC aides the continued evolution of a mathematics teacher leader from Stage 1 leadership to Stage 3 leadership (NCSM, 2008).

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