Math Circles: Research Overview

This report provides an overview of the extant research on Math Student Circles (MSCs) and Math Teacher Circles (MTCs), as of February 2023. While MSCs are the requested focus of this report, we would like to note that many more scholarly studies of Math Teacher Circles (MTCs) are available. Because MTCs and MSCs are anticipated to have some outcomes that are similar, a brief overview of MTC results is provided in addition to the requested overview of MSC results.

Math Student Circles

Math Student Circles (MSCs) first came to the U.S. in the mid-1990s. This model of math enrichment, in which students meet regularly with mathematics professionals to engage in problem solving, originated in Eastern Europe more than 100 years ago. The first Math Student Circles in the U.S. originated in Boston in 1994 and in the San Francisco Bay Area (Berkeley and San Jose) in 1998. This presentation by Brandy Wiegers and Diana White provides an overview of the development of Math Circles in the U.S.

Research Findings

Most research on MSCs has been either descriptive or qualitative in nature. Several articles provide relatively detailed descriptions of equity-focused MSCs, including MathAmigos in Santa Fe, the UC Irvine Math CEO program, and the Kittitas Valley Math Circle at Central Washington University (chapter beginning on p. 93). A dissertation by Audrey Winful describes an observational study of the meetings of a single MSC program (the Oakland/East Bay Math Circle). Several articles in the Journal of Math Circles include qualitative survey data from student participants (e.g., this one about the UC Irvine Math Circle). Otherwise, most published articles focusing on MSCs either describe specific mathematics problems, or else describe a specific MSC and its logistical setup.

Demographics
There are a couple of studies reporting on the demographics of MSCs. Specifically, the chapter by Brandy Wiegers (beginning on p. 93) describing the Kittitas Valley Math Circle also contains some data from a national survey of Math Circles for students and teachers conducted in 2016. Based on the results of the survey, Wiegers estimated that Math Circle programs reached approximately 5,000 students and 900 teachers during the 2015-2016 academic year. An average of 20 students participated in each MSC meeting, with approximately half of participants identifying as female.

Elsewhere, Wiegers and her colleagues reported on the results of a national survey from 2017. According to their write-up, “up to 25 percent” of student participants in Math Circles were estimated to be from groups underrepresented in mathematics, and “over half” of active Math Circles had at least one “subgroup” primarily focused on underrepresented students.

Both of these write-ups are presented as high-level overviews of the survey findings, and little detail is available on methodology or how terms were operationalized.

Quantitative Student Outcomes
We have identified only one research study on MSCs that involved the collection of quantitative data on student outcomes (Wiegers, Lai, & White, 2016). This study investigated the effects of MSC participation on students' "mathematical task value and expectancy." Here, "task value" refers to someone's desire to engage in a task (e.g., mathematical problem solving), and "expectancy" refers to their perceived probability of success at that task.

Wiegers et al. conducted beginning- and end-of-year surveys with MSC participants in grades 6 through 12 at six sites of the San Francisco Math Circle over a period of 4 years, and compared them with students in classrooms at their schools who were visited regularly by math graduate students during class time. A total of 2,480 students participated in the study, but no details are provided about the demographics of these students, and the description of how many were in each group (MSC participants vs. non-participants) is difficult to decipher.

The study found that the MSC participants had significantly higher levels of task value and expectancy in mathematics compared with their peers. In addition, MSC students' higher levels of wanting to engage in math and do well at it persisted from year to year, whereas comparison group students experienced a decline in their desire to do math over time.

Although the results of this study are promising, few details are provided about the analyses performed or the demographics of the students.

Areas for Further Research

As noted in our report on Math Student Circles and Diversity, there is a pressing need for improved MSC data collection focused on student and school demographics, longer-term student outcomes, and sustainability. These data will help us identify promising MSC models and practices for future study and potential dissemination and scaling. In addition, we believe it would be worthwhile to study MSC practices related to inclusiveness, which in combination with enhanced program data would contribute substantially to our understanding of what MSC models and practices are most effective for recruiting and retaining diverse student populations.

Math Teacher Circles

MTCs were developed by a group of teachers and mathematicians in the San Francisco Bay Area in the early 2000s. The first Math Teacher Circle was founded in 2006 at the American Institute of Mathematics. This article by Donaldson, Nakamaye, Umland, and White provides a brief overview of the history of MTCs.

Main Research Findings

Many of the studies on MTCs are qualitative and use methodologies such as open-response surveys, interviews, and case studies. Other studies make use of quantitative survey instruments, classroom observation protocols, and tests of mathematical knowledge or problem-solving ability. No MTC studies that we are aware of include a well-designed control group; for the most part, studies use a pre-post model with the MTC participants only. In addition, none of the studies incorporate student data. These limitations are partly due to the design of the MTC model, which typically requires voluntary participation and includes teachers from multiple districts who teach at multiple grade levels.

Primary findings from research on MTCs suggest that they:

Increase teachers' mathematical knowledge for teaching

- White, Donaldson, Hodge, and Ruff (2013) found that teachers' mathematical knowledge for teaching increased significantly over the course of participating in summer MTC institutes. The authors note that "This increase in mathematical knowledge for teaching has potential implications for student learning since previous research by Hill and her colleagues established an association between higher mathematical knowledge for teaching and higher student achievement (Hill, Rowan, & Ball, 2005)."

- In a mixed-methods study, Garner, Watson, Rogers, and Head (2017) reported on the MTC experiences of 25 elementary teachers who all taught at low-income schools. After participating in a three-day intensive workshop and several follow-up meetings, teachers' problem-solving ability (measured through pre- and post-tests) increased significantly, as did their self-reported use of problem-solving activities with their students.

Support productive teacher mindsets

- Using an explanatory multiple case study methodology, Hendrickson (2016) found that teachers' experiences doing mathematics in MTC workshops were influential to their identities both as teachers and as mathematicians. The study also suggests that teachers' experiences engaging with content as learners have implications for their teaching.

- Milless, Good, and Donaldson (2018) conducted a cross-sectional correlational study with 249 MTC participants across the U.S., treating the amount of MTC participation as a "dosage" variable. Increased participation in MTCs was associated with higher reported identification with a "research view" of mathematics. In turn, this view of mathematics predicted higher levels of sense of belonging to math, higher growth mindset orientation, increased grit, endorsement of a mastery approach to instruction, and normalizing mistake-making in math.

Increase inquiry-oriented classroom practices

- Antonou, Patel, and Harsy (2021) reported that teachers participating in intensive MTC workshops showed significant improvements in their dispositions toward inquiry-oriented teaching and increases in their intended implementation of inquiry-oriented methods.

- Marle and his colleagues (2012) reported that after one year of MTC participation, teachers' math teaching self-efficacy increased significantly, and classroom observations using the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002) provided evidence of significant increases in the use of inquiry-oriented teaching practices.

Contribute to greater professional engagement

- Donaldson, Nakamaye, Umland, and White (2018) used themes from national surveys of MTC participants to develop four case studies over two years through repeated classroom observations and interviews. Themes examined were teachers' views of mathematics, their classroom teaching (particularly the use of active or inquiry-oriented teaching methods), and professional engagement and leadership, which all were strongly affected in different individual cases.

- Internal study on teacher retention: A program evaluation conducted by Math Circle Network staff indicated that 80% of the 179 classroom teachers who began participating in the local AIM MTC between 2006 and 2015 remained in the classroom in 2017, consistent with a 4% annual attrition rate, half the national average around that time (Goldring, Taie, & Riddles, 2014) and comparable with rates reported by highly respected teacher leadership programs including Math for America (Mathewson, 2016).

External Reports and Studies

MTCs have also been profiled in several external reports and studies on teacher professional development:

- The Conference Board of the Mathematical Sciences recognized MTCs as a high-quality form of professional learning in the Mathematical Education of Teachers, II report (2012).

- MTCs were highlighted as a "bright spot" in promoting teacher voice by the STEM network 100Kin10 (2017).

- The Future of Math Teaching and Learning report by the MIT Teaching Systems Lab (2021) included MTCs as one of 10 "Innovation Highlights."

In addition, WestEd recently received funding from the Overdeck Family Foundation to conduct a mixed-methods study (surveys, interviews, and observations) on several teacher professional development programs, including MTCs. Preliminary results indicate that MTCs promote teachers' curiosity, confidence, and engagement with mathematics.

Areas for Further Research

There is a great deal of qualitative evidence as well as some quantitative evidence suggesting that MTCs have a positive impact on teachers' mathematical knowledge for teaching, mathematical mindsets and identities, use of inquiry-oriented classroom practices, and professional engagement. However, very little is known about whether and how MTC

participation affects the students of participating teachers. There are many difficulties with designing studies to examine this question, including how to identify control groups and what measures to use to track student experiences and outcomes.

We believe it would be productive to consider designing parallel studies of outcomes for classrooms of MTC teachers as well as for individual students who participate in MSCs. This could provide extremely useful information about the impact of both types of programs and the circumstances under which they are most effective. It could also suggest ways in which MTCs and MSCs could be dovetailed to support better outcomes for students, especially students from groups historically underrepresented in the mathematical sciences.