Engagement in Practice: Community Outreach Through Student-Led Math Circles

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Program Description

Since 2017, the Department of Mathematical Sciences at Stevens Institute of Technology has been running an outreach program by organizing math circles for elementary and middle school students at local community centers such as public schools, public library, and Boys & Girls Club. A math circle is an enrichment program that engages participants, typically K–12 students, in interesting, challenging, and fun mathematics in an informal, collegial setting. There is no universally accepted definition of what constitutes a math circle; indeed, as Saul [1] puts it, "Any situation in which people are exploring mathematics for its own sake, —for the sake of their own enjoyment of the subject, —may be termed a math circle." Math circles aim to expose participants to authentic mathematical problem-solving and discovery, and to foster conceptual understanding and an enjoyment of mathematics. They have a long history going back to Eastern Europe, where they were a means for professional mathematicians to share their knowledge and love of mathematics with young students [2]. They gained some popularity in the United States beginning in the 1990s [2], and although the literature on math circles is limited, research suggests that they successfully engage youth underrepresented in STEM, including Navajo youth [3] and middle school minority males [4], as well as positively impact participants' mathematical task value, i.e., their desire to engage in mathematical activities [5].

Under our initiative, each math circle is organized by the efforts of three parties: university faculty, university students, and community partners. The core idea is that each of these parties may like to organize a mathematics enrichment program but is unlikely to do so alone. Indeed, it has been our experience that

- there are professional mathematicians (such as university faculty) who would be interested in organizing a math circle for their community but lack the time or energy to conduct math circle meetings and manage the logistics;
- there are university students who love mathematics and would enjoy teaching it to youth in an informal setting, but who are not prepared to manage logistical issues, develop lesson plans, and acquire supplies;
- organizations that serve youth may wish to offer them math enrichment but lack domain-specific expertise.

The effort of running a math circle program is therefore divided between these three parties.

- Math faculty members (whom we call math circle organizers) secure funding, hire and train undergraduate students, compose and prepare ready-to-use materials, communicate with the community partner, acquire supplies as necessary, and gather feedback.
- Undergraduate STEM students (whom we call math circle leaders) participate in the training provided by the faculty, prepare for the math circle meetings using the materials provided by the faculty, lead the math circle meetings, and give feedback to the organizers.
- Community partners advertise the program to parents, manage enrollment, and host the math circles, including providing meeting space and necessary staff.

Although the participating youth are the primary beneficiaries, all three of the above parties stand to gain. Indeed, math circle organizers foster stronger relationships with their local community, improve the visibility of their department, provide richer educational experiences to their students, and may pursue new funding opportunities; math circle leaders benefit from a unique educational experience and can effect positive change in society; and community partners leverage the expertise of mathematicians and talented STEM students to provide valuable math enrichment to the youth whom they serve. In recent iterations of the program, math circle leaders enroll in a special credit-bearing course through which they receive more substantial training. We elaborate on this course in the next section.

There is a further benefit, namely that this model allows math circle organizers to run a larger number of math circles than they would if they were to lead them themselves. We have organized as many as seven in-person math circles simultaneously. Since 2023, we regularly run three to five in-person math circles in a semester.

It is worth emphasizing that enrollment in the math circles that we organize is handled by our community partners. Thus, our math circles are generally not selective, and they draw from relatively small populations. Sometimes, they include youth with poor math backgrounds or negative perceptions of mathematics. We therefore do not set ourselves the goals of preparing participants for mathematical competitions or tackling advanced topics. Our primary aim is to increase participants' interest in—and appreciation of—mathematics.

Since 2017, through the efforts of 2 faculty members, we have organized over 60 math circle programs, averaging 3 to 4 per semester. Participants are usually students in grades 3–6 (which corresponds to an age range of 8–12 years old), although we have worked with middle and high school students (that is, up to age 18) as well. A typical meeting pattern is 2 contact hours per week, e.g., an hour on Monday and an hour on Wednesday, for a stretch of approximately 10 weeks, but we have organized math circles that ran for as little as 6 weeks and as many as 17.

The mathematical content selected for meetings depends on the particular circle (the age and mathematical background of participating youth, the program duration, and the specific needs of the community partner) but involves some combination of problem sets centered on a certain mathematical theme (such as parity, symmetry, a combinatorial principle, cryptography, and so on) and mathematical games, puzzles, or hands-on activities. Typically, the meetings alternate between problem sets and other activities.

The program requires a relatively low level of funding. The expenses are compensation for math circle leaders, typically at the usual on-campus undergraduate hourly rate based on one hour of preparation time for each contact hour; and purchasing supplies not already available at the university or at the community partner site, such as commercial games, puzzles, or specific materials, e.g., dice or origami paper. Our program has been supported by internal and external funds, including grants from Mathematical Association of America, Alfred P. Sloan Foundation, PNC Foundation, and, most recently, National Science Foundation. It is theoretically possible to run the program with little to no funding, by foregoing the purchase of commercial products and

offering an alternative way to compensate undergraduate students for their time. The next section explains how else undergraduates can be compensated for their effort.

The specifics of the week-to-week operation of the program have varied over the years. In the next paragraph, we give a brief overview of those things that have remained constant, and we refer the reader to [6] for an extended account of the program in general. We describe the current version of the program in more detail in the next section.

Given the relative inexperience of our math circle leaders, and for redundancy in general, we aim to staff each math circle with two math circle leaders. Further, we prefer to maintain a ratio of at most six participants per math circle leader. Therefore, we usually ask the community partners to restrict enrollment to 10 (at most 12) participants. Once a math circle is set up and running, every week proceeds the same way: math circle organizers prepare math circle materials (typically, handouts for math circle participants and instructions for math circle leaders) and communicate these materials to math circle leaders. The latter are responsible for conducting the meetings of the math circle. The community partner is responsible for on-site logistics such as providing a meeting space, a staff member, or supplies. At the end of the week, math circle leaders share feedback with math circle organizers.

Current State of the Program and Community Engagement Course

One of the key points of feedback the program received from the math circle leaders, from our community partners, and from our colleagues at large, is that the training we had been offering to math circle leaders could be more substantial and systematic. To act on this feedback, we converged on the idea to offer a credit-bearing course, wherein the enrolled students learn about math circles, extracurricular mathematics, and teaching strategies; and then, for the majority of the course, lead math circles at a community partner site, all the while engaging in reflections on their experiences and providing feedback to the instructor via course assignments and discussions at weekly meetings. An added benefit of this course is a reduction in the required funds, since the enrolled students receive course credit rather than monetary compensation.

A qualitative analysis of the effect of the program on the participating undergraduates can be found in [7]. Here we focus on a practical account of the program.

Before the course begins—ideally several months in advance—math circle organizers communicate with community partners to establish math circle program dates, tentative meeting patterns, enrollment targets, and other expectations. At the same time, the course is advertised to students majoring in STEM fields, and interested students are interviewed and enrolled based on the projected number of math circles. The students are selected based on their availability given the math circle meeting patterns as well as their academic performance, primarily in mathematics courses.

The course itself is split into a preparatory part, when the course meets for 3 hours per week (for 2–3 weeks), and an in-service part, when every week the course meets for 1 hour and the enrolled students teach 2 hours of math circles. The course addresses the following topics:

1. Overview of math circles: definitions, history, types, notable figures and their work.

2. Participation in a mock math circle.
3. Relation between math circle content and the underlying mathematics. “Deep dive” into an example problem set.
4. Classroom management strategies (in collaboration with Teaching and Learning Center at Stevens Institute of Technology).
5. Overview of math circle content: topics in geometry, combinatorics, logic, discrete math.
6. Overview of math circle content: mathematical games, puzzles, hands-on activities.
7. Leading inclusive math circles (in collaboration with the Office of Student Culture and Belonging at Stevens Institute of Technology).
8. Principles of composition of math circle content.
9. Overview of sources of math circle content.

As a final project to be delivered at the end of the course, students compose their own content that could be used for a meeting of a math circle.

Ideally, the preparatory part includes at least topics 1–4 from the above list. In practice, the length of this part has varied, since the start of the in-service part depends on the needs and restrictions of the community partners. Furthermore, during the preparatory part the enrolled students are assigned to specific community partners, based on students’ schedules and community partners’ meeting patterns and enrollment numbers. At each math circle, we aim for approximately 10 youth participants and 2 math circle leaders. To date, the course has been offered 3 times, with enrollments of 6, 8, and 10 undergraduate students.

During the in-service part of the course, the organization of the course is a refinement of the general weekly cycle described at the end of the preceding section:

- Two to three days before the first math circle meeting of the week, math circle organizers prepare the week’s materials and communicate them to the respective students. The latter can be done via the university’s learning management system, or through third-party project management software. At the same time, a preparation assignment is posted for the enrolled students. It asks students to study the materials and to answer questions about them. The questions serve to structure students’ preparation. The assignment includes prompts such as:
    1. “What math ideas or notions is this problem set/activity actually about?”
    2. “Which problems (or parts of the activity) do you expect will stump participants?”
    3. “For each of the problems you identified above, suggest a hint or an easier problem that may help participants make progress.”
- During the week, on the scheduled days, the enrolled students pick up physical supplies (prepared by the math circle organizers) and conduct math circle meetings at their community partner site.
- After the last math circle meeting of the week, a reflection assignment is posted for the enrolled students, where they are asked to recount and reflect on how their meetings went. The assignment includes prompts such as:
    1. “How many children were in attendance?”
    2. “What did children work on?”
    3. “In what ways did your experiences differ from what you expected?”
    4. “When I think about this math circle meeting, I would say…”
    5. “What did you learn from your interactions with the children?”

- At the end of the week, a one-hour meeting of the course is held, where students share and discuss their experiences from that week and receive additional guidance. As time allows, the remaining course topics are covered.

Ideally, the math circles conclude with some time left in the semester, which affords the students time to work on final projects. As a final project, the students prepare and present a set of materials for one meeting of a math circle, similar in organization to the materials they have been receiving weekly throughout their math circle's run. At the same time, math circle organizers gather feedback from the community partners (and through them, if available, the feedback of parents of the youth participants). Our approach has been to offer the course every other semester. Students who have completed the course are offered an opportunity to lead a math circle in the following semester for a stipend, subject to budget constraints and partners' needs.

Challenges and lessons learned

Here we give a brief account of a selection of challenges we faced and the resulting lessons we learned.

Time and effort commitment. Although our approach allows us to run more math circles than we would be able to by ourselves, it still requires a significant commitment of time and effort. We would like to highlight that it was crucial that the program is organized by two faculty members rather than one, both to create a division of labor and to bounce ideas off of each other. We therefore recommend partnering up with at least one colleague for a similar endeavor.

Enrollment issues at community partners. Recall that we delegate math circle enrollment to our community partners. It may happen that a math circle is substantially under-enrolled or over-enrolled, which requires fewer or more math circle leaders than planned to work at that site. This would not be a critical issue if not for the fact that the course has a set roster of students who count on receiving credit for the course. In the case of an under-enrolled math circle, we found it important to have at least one community partner open to last-minute expansion of enrollment or increasing the number of math circles offered. It is also crucial to finalize all plans and placements for the semester before the university add/drop period ends. In the case of an over-enrolled math circle, we found that the easiest solution is usually to bring on university students who have participated in the program previously, offering them monetary compensation for their effort.

Attendance. Another issue that may arise is lack of stable attendance. At some community partner sites, the same youth participants may not show up at every meeting. This restricts our choice of mathematical content, since we cannot offer a curriculum where new material relies on the participants' familiarity with previous material. Given that our general goal is to spark interest in mathematics, this does not pose a significant problem. However, if we were to pursue another goal such as training participants for mathematical contests or studying a particular topic in depth, we would need to manage attendance much more carefully.

Retention and mathematical content. Program-to-program retention poses another challenge. It is common for youth participants who attend one math circle program to sign up for another one in

the next semester. It is also common that they don't. This makes selecting content for meetings challenging, since the content needs to be engaging for both returning and new participants. This is addressed by developing a large library of possible topics and planning each particular math circle's curriculum with both the preceding and the following iteration at that site in mind.

Scheduling issues. Finding both a suitable date range and meeting times for math circles can be a challenge, since they need to work both for the community partners and for the university students. In our experience, planning ahead and clear communication with community partners are important. In some cases, community partners can adjust their operations to accommodate the schedules of university students; in other cases, they cannot, but if this is known well in advance, there is time to make more complicated arrangements with students, such as covering different dates with different students.

Content issues. For each math circle, certain types of mathematical content work better than others. Which content will work well in which circle is not always easy to predict. It has been our experience that it is crucial to offer a variety of mathematical content, and to pay close attention to the feedback provided by math circle leaders, adjusting materials accordingly.

Conclusion

We hope that this model for organizing math enrichment in our local community can be adopted at other universities. As a final remark, we note that our model need not be restricted to mathematics enrichment. Indeed, we believe that it can be adapted to every STEM field to inspire and engage young learners.

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