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Math Circles: A Tool for Promoting Engagement among Middle School Minority Males

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This article presents results of a case study of a math circle designed for low income, minority students from an inner city middle school. The students were 6th, 7th and 8th grade African American and Hispanic males enrolled in a science, technology, engineering and mathematics focused charter school. The study focused on the impact of participation in the math circle on students and the design features of the experience that were most effective at promoting engagement and positive reactions from students. Participating students reported increases in their interests in mathematics, their confidence in their ability to tackle mathematics problems, and in their enjoyment of mathematics. Competitions and affirmation by a mathematician were key motivating factors for students. Implications for the design of math circles that promote positive mathematical identifies among marginalized populations of students are discussed.

Keywords: math circles, math engagement, math identity, minorities

INTRODUCTION

For several decades policy makers in the United States (US) have been concerned with the rate at which the US education system produces students with the mathematical skills needed to effectively compete in the increasingly technological and global market place (National Academies, 2005). National trends and results from international comparative studies have in many instances presented a mixed picture as US students appear to be making overall progress, but achievement gaps for low income and minority students persist and US students, particularly at some grade levels, lag behind their peers in other industrialized nations (Schmidt, 2012). These results are seen by policy makers as particularly troublesome as projections for 21st century careers show the greatest growth in the science, technology, engineering and mathematics (STEM) disciplines; areas in which mathematical skills are a prerequisite to success (National Science Board, 2014).

Efforts to address the ability of the US education system to produce mathematically competent students have focused on (a) pedagogical and content qualifications of teachers, (b) curriculum and instructional techniques and technologies, (c) course offerings and the structure of educational opportunities, to name a few (Schmidt, 2012; Steen, 2013; Pappan, 2014).A major policy focus of these efforts has been to not only increase the mathematical proficiency of US

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students,
but to increase the access and participation of groups which have been historically underrepresented in the mathematical sciences and STEM disciplines (The White House, 2010). In particular, demographic trends in the US point to the necessity of increasing the number of minorities, women, and low incomestudents who are interested in mathematics and achieve proficiency levels required for STEM professions (President's Council of Advisors on Science and Technology, 2012).

A number of strategies have been pursued to broaden participation in the STEM disciplines. One area that is receiving increasing attention among US educators and policy makers is educational experiences that occur outside of the traditional classroom, often called *informal education*.These include experiences in the home, experiences in the community, and school-based experiences that occur outside of regular class meetings (e.g., academic clubs, field trips, competitions, etc.). There is growing evidence that these experiences can motivate students, promote effort and engagement in STEM courses and yield increases in academic performance (Afterschool Alliance, 2011). Researchers have also noted that these experiences can be critical for under-represented students, many of whom have limited access to enrichment opportunities and role models (Chun & Harris, 2011; Lauer et al., 2003).

In mathematics, out-of-school experiences oftentake the form of math clubs or competitions. In the US, there are no national statistics on the number of participants in after school math clubs or their characteristics. However, research suggest that while minorities and low-income students often participate in these clubs, access and attitudes towards participation are often barriers and the outcomes of club participation are different (Gardner, Roth, Brooks-Gunn, 2009; Gottfried, & Williams, 2013). Other research suggests that teachers may subscribe to stereotypes that limit their willingness to recommend club participationfor certain demographic groups, and that the students themselves may resist participation due to peer dynamics (Larnell, Boston &Bragelman, 2014). In either case, efforts to successfully recruit these students would necessarily be different from thoseused with other groups and, further, it is likely that the dynamicsand activities of the group would change as a result of their participation. Issues of recruitment, group dynamics, and other issues are explored in the case study reported in this article. We successfully recruited a group of 6th, 7th and 8th grade minority boys to participate in a math circle. Below we describe the experiences of these students and the dynamics of the group. The overall questionsthat guided this study were (a) what design features of the experiences were most effective with this population and (b) what were the outcomes?

State of the literature

- Afterschool math clubs and math circles are seen by policy makers and educators as ways of promoting student interest and achievement in mathematics.
- There is evidence that they can be effective, but little empirical guidance on their structure and dynamics, especially as regards minorities and low-income students.
- In the absence of systematic research, developers of clubs and circles are guided by anecdotal evidence and existing practices, but little underlying understanding of processes.

Contribution of this paper to the literature

- This study focused on design features and effects of math circles as regards the process of enculturation of minority middle school students into the community of mathematical learners and professional mathematicians.
- It is one of the first to examine the inner workings of a math circle for this population and to employ a qualitative design to explore the process of enculturation of a marginalized group into an academic community.
- The study will raise questions about the design of math circles, immersion and the processes by which students adopt values and habits of mind of the professional mathematician.

Changing conceptions of mathematics learning

Mathematics, in a recent Gallup Poll, has the somewhat unique status of being one of the least liked and yet most valued school subjects in the US (Jones, 2013). Most adults and many children view mathematics in negative terms. Some indication that the negative view of mathematics may be a function of the educational system is given by the fact that many young children hold positive views of mathematics until around the 4th grade, following which their negative views and avoidance behaviors began to grow. Some common views of mathematics are that there are “math people” and “non math people”, that math is not relevant to the “real world.” There is growing recognition among mathematics educators that these views reflect stale, disconnected classroom experiences, ones founded in conceptualizations of mathematical learning as largely a function of native ability and aptitude. In contrast, for much of the past few decades, there has been a decided push towards a more socio-cultural and constructivist view of mathematical learning. In this conceptualization, mathematical learning is the result of a complex interplay of natural abilities, social context, interests, motivations and attitudes of the individual learner (Boaler, William&Zevenbergen, 2000).

The view that learning mathematics, or any subject, is in important respects a social phenomenon that involves active construction of knowledge by the learner implies not only changes in classroom practices but also points to the important role that out-of-school experiences can play. In the classroom, teachers would promote questioning, exploration, discovery and interactions among students. Connections to the student’s existing knowledge and cultural practices would be important as would a focus on the students’ attitudes and dispositions relative to the subject. In many US classrooms, however, pressures to prepare students for standardized tests as well as teacher knowledge of mathematics prohibit the type of openness and flexibility implied by this perspective (Brooks & Brooks, 1999).

Out-of-school activities are a prime format for providing students with the types of experiences that are consistent with the socio-cultural, constructivist perspective of mathematics learning. Out of school experiences, such as math clubs, rarely have the constraints of the traditional classroom. They may not be led by teachers, occur off the school grounds, and be flexible with respect to the types of activities students engage in. They tend to be voluntary so the types of students that participate usually have some degree of interest and confidence in the subject prior to involvement. Afterschool math clubs can have a number of positive benefits for students (Briggs-Hale, Judd, Martindill& Parsley, 2006): (a) increased student learning in regular classrooms; (b) non-threatening learning environments that can benefit at-risk students; (c) and increases in engagement, inquiry, cooperative learning and peer mentoring.

Design issues

Evidence of the potential for positive outcomes of participation in afterschool clubs is considerable (Afterschool Alliance, 2011). However, these outcomes are not achieved for all students. The structure of these clubs vary considerably and there is evidence of only limited impact of design features of clubs such as whether or not they occur at the school, on weekends, etc. However, there are several design features which have been consistently identified as components of effective clubs (Briggs-Hale et al.,2006): (a) active participation by students; (b) non-threatening environment that encourages risk taking; (c) peer-to-peer interactions, including cooperative problem solving; and (d) games and enjoyment.

In contrast to the notion of a math club, which is often vaguely defined, the concept of a math circle is more specifically consistently with the socio-cultural, constructivist view of learning.

> A math circle is a social structure where participants engage in the depths and intricacies of mathematical thinking, propagate the culture of doing mathematics, and create knowledge. To reach these goals, participants partake in problem-solving, mathematical modeling, the practice of art, and philosophical discourse. Some circles involve competition, others do not; all promote camaraderie. (Math Circle, n.d.)

Math circles have their origins in Eastern Europe and entail having professional mathematicians spend time with youth engaged in a variety of activities designed to promote interests and engagement in mathematics. Although there are many variations of this basic idea, the primary goal is for the leader of the club to induct or initiate students into the culture of mathematics. Participants engage in the games, talk and reasoningof mathematics and are exposed to the world of the professional mathematician. They learn of their "heroes;" myths and valuesare shared as the expert attempts to enlist the youth into the group. In some circles the inductees leave their schools and meet with the expert in "their" place of business, typically a mathematics department. The concept is different from a group of students coming together to enjoy an afterschool club activity, and entails a process of enculturation in which the individual undergoes a process of appropriating the language, values, and habits of mind of a discipline and developsa personal identity relative to the discipline (Scott &Palincsar, 2006; Cuoco, Goldenberg& Mark, 1996; Honing & McDonald,2005) .

Math circles have the potential to impact both cognitive as well as non-cognitive mathematics outcomes for participants. However, there is only limited research on their dynamics, especially as involving minorities or other under-represented groups. There is considerable evidence that these groups may find mathematics settings particularly challenging due to negative stereotypes, lack of prior experience, etc. (Larnell, Boston &Bragelman, 2014; Walker, 2007). In this study we explore the dynamics of a circle designed to serve these students. The questions that guided this study are two: what aspects of the circle were most effective, and what was the impact of the circle on participating students?

METHODS

Research Design

We employed an intrinsic case study design. The case is a math circle designed for low-income, minority youth. The leaders of the circle functioned as participant observers. The circlewas studied during meetings occurring in the department of mathematics at a research extensive university. The circle met once weekly for a period of 90 minutes. These meetings occurred over a period of 9 months, with meetings canceled on holidays, during statewide testing and other school events. A total of 24 meetings were scheduled for the period examined for this study.

Sample

The students involved in this study were twenty-four6th, 7th, and 8th grade middle school students. Of these students, 3 were Hispanic males, 2 were females and 19 were African American males- - the two female students eventually withdrew from the club. All students were from one Title I school. The school is a STEM focused charter school, one that promotes participation in a variety of STEM clubs and activities. The participants in the math club were recruited from the STEM club at the school and therefore had known one another at school and interacted with each other outside of the circle on a regular basis. The participants attended circle meetings on a voluntary basis.

In addition to the students, at least one teacher accompanied the group to each meeting. Additionally, a graduate research assistant was present during meetings for purposes of making observations. Also, an adult was provided by a partnering unit at the university. This person was tasked with assisting the circle leaders as needed. Finally, all but one circle meeting occurred in the department of mathematics. Students and faculty in the department on several occasions interacted with the circle. These interactions were also a focus of this study.

Measures

Several methods were used to collect data for this study:

Participant observations

The club leaders, the mathematician and a board member of the school, functioned as participant researchers- - the board member is also an educational research faculty member at the university where the club met and is referred to below as the *educational researcher*. The club leaders conducted informal interviews with participants, unstructured observations of club meetings, and engaged in reflection and journaling of their experiences. These observations focused on (a) interactions among students, (b) interactions between club leaders and students, and (c) interactions involving the "other" adults present.

Structured observations

Structured observations occurred during 4 club meetings. These focused on the percent of students engaged in club activity. Engagement was defined as on-task behavior. During each of the 4 sessions observed, environmental scans occurred at 20 minute intervals. Majority engaged was defined as greater than 75%. The focus of the observations is described in the tables below.

Surveys

A survey was administered to participating students during the spring semester, towards the end of the club meetings. The survey consisted of 20 items which addressed various factors related to engagement in mathematics.

Analysis

Several different types of data were obtained for this study. Quantitative data were summarized in the form of counts and percentages. These data are used to describe the events and responses of participants. Qualitative data in the form of unstructured interviews and observations were recorded and categorized for purposes of identifying themes. The constant comparative method was used to identify themes. Triangulation of the different sources occurred and additional data were collected until a point of saturation was achieved.

FINDINGS

The findings of this case study are presented in three categories: *Development of the Circle*, *Design Features of the Circle*, and *Impact of the Circle*. The latter two reflect the two major research questions of the study. The first presents the perspectives, views and context of the project. These are important as every aspect of the data collection, processing and interpretation are impacted by the perspectives, assumptions and beliefs we brought to the project.

Development of the circle

The original plan for the circle was to focus on the school's curriculum and incorporate a highly structured instructional component or tutoring into the group's activities. In discussions between the educational researcher and the mathematician, this was dropped. The goals would be to (a) nurture a love and passion for mathematics and (b) to promote mathematical thinking and reasoning. This was decided upon based on a shared belief in the complex nature of mathematical learning and the value of exposure to the culture of mathematics on this process. Our view of the potential of the circle to impact mathematical learning is reflected in the following propositions, adapted from the San Francisco Math Circle project (Wiegers, 2012):

- A Math Circle can be a Safe Mathematical Community which can
  - promote exploration, creative expression, collaboration
  - foster the development of a positive mathematical identity in which the learner views himself/herself as someone who "does" and "enjoys" mathematics
- A Positive Mathematical Identity
  - is associated with positive valuation (intrinsic, extrinsic) of engagement in mathematics
  - high expectancy for success and enjoyment in mathematical tasks
  - increased engagement (voluntary selection, persistence) in mathematical task

Ultimately, we believe that engagement leads to achievement and competence. This does not negate the role of ability in the learning process, but acknowledges the important role that well designed social environments can play (Grabinger, Aplin&Ponnappa-Brenner, 2007).

Design features of the circle

Recruitment

A central motivation for starting the circle was to explore the potential of math circles to engage students who are not traditionally afforded opportunities for math enrichment out-of-school experiences. There was, therefore, no requirement that participants have a record of success in mathematics or that they had expressed high levels of interests in mathematics. While the target population was defined largely by socioeconomic status, the initial cohort was also largely African American and Hispanic males. The recruitment of these students involved addressing the priorities of the teachers and administrators, the concerns of the parents, and the reservations of the students. The teachers and administrators were mainlyinterested in activities which would have a measurable impact on student performance as reflected in course grades and outcomes on standardized tests. It was important that the educational researcher had a history of involvement with the school and had established relationships with staff, especially as it was clear that the circle was not an expanded opportunity for tutoring. It was possible to convince the administrators that the activity would have a positive impact on students' attitudes and interests in mathematics. Related to this, a teacher from the school would attend each circle meeting.

Parents were concerned with transportation and the relevance of the activities to school work. An orientation session was held and the concept was explained as one that would promote interest in mathematics and foster relationships with faculty in the department of mathematics at the university. Again, the support of the administrators and teachers were in evidence at the orientation meeting and helped solidify participation.

The final group that needed convincing was the students. The students were all members of an afterschool STEM club and the circle was to become their Monday activity. There was enthusiasm and excitement at becoming a "resident" of the math department at the flagship university in the state. There was little evidence of anxiety about the experience.

The importance of location

The club met in four different locations on the university's campus. Two were classrooms in the department of mathematics, the communal space in the department of mathematics, and a large meeting room in the School of Education. The School of Education at the university has a math education program, but not a defined space and not a sufficient number of faculty to create a unique identity as was found in the department of mathematics.

Occupation of the space

In cultural anthropology there are spaces associated with certain functions (Low & Lawrence-Zuniga, 2003). The space is reserved for "members" of the group. Permission for outsiders to access the space can be granted, but sponsorship is needed. Of the four spaces in which the circle met, the most significant was a lounge in the department of mathematics. This space had a blackboard, large table and several couches. It was a shared space used by faculty, graduate students and connected to the community coffee pots. During club meetings visitors (faculty and graduate students) frequently stopped by to visit with the group; students in the circle made frequent trips to the restroom with forays into other areas; and there were several occasions in which graduate students were asked to vacate the space so that the club meeting could commence. These interactions highlighted the critical role of the "sponsor" as they often vacated the space reluctantly.

There were artifacts in the space: Rubik's Cube, a chess set, books, and a blackboard on which the graduate students often left complex equations. The circle's students frequently mused at these and traded "knowing" glances with each other. These events, as has often been observed when outsiders are brought into the space of a group, mirrorinitiation processes found when prospective new members interact with established groups.

The space was a defining event for the circle. The lounge gave the circle a type of legitimacy and defined the participants as ***selected*** in a way that would not have been possible otherwise. This was made even moreclear to the students by the fact that the leader of the club was a professor in the department.

Mathcircle activities

As noted above, it was decided that the selection of the activities would be done by the mathematician. This individual would be better informed about the habits of mind, games and other aspects of the culture of mathematics. The activities and topics varied in their complexity. They were chosen to spark interest, be enjoyable, and promote logical thinking. Some topics were chosen to deepen participant's insights into the middle school curriculum.

The topics addressed in the circle are categorized below based on responses of the students. "Math is Magical" are moments that would amaze the students with a sudden surprise at a result or a revelation of understanding. "Math is Logical" refers to the arguments, proofs, and formulation of definitions. "Math is Fun" refers to games, activities, or whimsical topics. In designing the plan of the circle sessions, we would try to incorporate all three.

Math is magical

Two sessions were placed in this category and occurred during the first few meetings of the circle. Mobius bands was introduced by a video demonstration involving a donut and followed with a hands-on activity. The students were arranged in tables and after much clamor and chaos with scissors, they began cutting paper strips along lines as instructed. The overlapping bands that resulted produced audible gasps; the room erupted into chaos as they moved from table to table in *awe* of what they were seeing. Attempts were made by some to explain the perplexing phenomenon to their peers, only to be met with disbelief and amazement. One of the adjectives used to describe this experience by the students was "scary." The multiples of 9 demonstration (A number is a multiple of 9 if and only if the sum of its digits is a multiple of 9) and proof met with a similar "wow" response.

Math is beautiful and essential

A talk and presentation was made by a mathematics educator during one of the sessions. This individual introduced the concept that mathematics is beautiful and essential. The students engaged in solving a puzzle and the presenter told a story of a mathematician, an engineer and a physicist being presented a logic problem. The engineer and physicist were limited in their thinking by their disciplinary constraints while the mathematician applied "pure" logic and showed himself superior to the others. The students, as they listened to the story, smiled and indicated in their gestures their agreement with the primary theme. In the study of groups, it has often been observed that neophytes are brought into groupmembership by learning and embracing the group's myths, learning its stories and embracing its world view. The observer concluded that these students had, the first time for most, been introduced to the value system of the community of professional mathematicians.

Math is logic

Several examples (e.g., Infinity of Sets, Convergent and Divergent Series, Proofs that the Product of Two Negative Numbers is a Positive Number, etc.) exercises and demonstrations were selected to help students view familiar concepts in new and novel ways, with an emphasis on logic. The infinity example was introduced by a discussion of the concept and a demonstration that started with cutting a piece of paper into two pieces. Each piece was then divided again. The students were asked to imagine continuing this process to the atomic level and beyond. Thisexercise, as well as proofs of familiar concepts, was met with amazement and enjoyment by participants. The logical foundations of mathematics emerged as a theme the group reflected in their interactions with the circle leaders.

Math is fun

We wanted the students to play a game that would allow for strategy and fits into the culture of mathematics. We chose Go, the oldest board game in the world. While it is well-known in mathematics departments, its popularity is limited elsewhere in the Western world. We selected an introductory version called Atari Go or First-capture Go. Some of the circle sessions focused on Go strategies (e.g., ladder, net, etc.) while most included Go games for the second half of the session, following a snack. Groups of 3 would often form and have a mini-tournament. The winner would win a bottle of juice. Students of similar ability would usually gravitate to each other. Atari Go was a popular activity. A substantial portion of the students were always anxious to proceed to Atari Go, above all other activities. When we worked on Atari Go puzzles, it would be done as a group with the display of stones shown using a document camera. Some of the studentsimproved their skills as the year progressed and some did not. Surprisingly, students who did not seem to improve maintained their enthusiasm for playing. A couple ofstudents moved away from Atari Go to play chess (a set was located in the math lounge). Other *math is fun* activities included group and individual competitions.

Interactions of leaders with students

One of the recognized characteristics of an effective afterschool program is that it presents an environment in which students feel free to explore, take chances and engage difficult challenges. To accomplish this, the leaders of the club must create and maintain a nonthreatening environment, one that encourages and rewards participation as well as "right" answers. The leaders of the circle had requested that a teacher accompany the students to address any issues with discipline and the like. This removed the circle leaders from the role of disciplinarian. Additionally, the leaders responded to all students with encouragement, made explicit efforts to engage and provide positive feedback. The students gave no indication of reluctance to engage the process and both leaders characterized the interactions as positive.

Interactions of students with each other

The students had prior knowledge of one another and interactions were characterized by the circle leaders as positive. Groups often formed with considerable play, laughter and other indicators of positive interactions. Collective participation and group work were clearly part of the group dynamic, with few individuals classified by the leaders as "loners" or "isolates. " There was general encouragement and support for active involvement and engagement with the tasks of the circle. As noted above, while it appeared that the mini-group formations were in-part based on pre-existing relationships, it was also clear that the circle helped with creation of new groups, notably defined by academic strength or interests. An important question raised from this observation was how participation in the circle impacted dynamics at the school. Interviews with teachers indicated that students in the circle were helped, but the leaders could not define this. In contrast, as membership in the circle changed over the course of the year, it was obvious that the teachers had actively recruited some of their stronger students to join.

Interactions of students with "other" adults

There were three groups of "other" adults in attendance at circle meetings.The first group was teachers from the school. At least one teacher from the school attended each meeting. This individual served mainly as an instrument of order. Students considered off tasks (typically some type of play) were quickly corrected with a glance or movement in the direction of the offending group or individual. There was little indication of resistance and few instances in which specific correction were deemed necessary. The second group was the helpers assigned by the funding project. This would typically be one person, a teacher from a different school, who would also address issues like noise levels as the students moved through the hallways of the mathematics department. The final groupof adults in attendance were studentsand faculty in the department of mathematics. These individual stopped by sporadically, but their presence was typically met with great curiosity by the students as to "who" they were. Graduate students who occupied the meeting space typically had brief interactions with the group, but those were also deemed by both circle leaders as significant as the students appeared to take great notice and expressed considerable curiosity about them. It is worth noting that they were usually closer in age to the students than was true of faculty or circle leaders.

Outcomes

In addition to the reflections, informal observations and interviews, two other types of data were collected for this case study. The first was a series of structured observations using an adaptation of an existing observation tool. The second was a survey administered to the students during the last month of circle meetings.

End of semester survey: mathematics attitudes items

Table 1 presents results from items on the survey related to attitudes towards mathematics. Most respondents (9 of 10) indicated that they thought mathematics was important [Item 1], were interested in mathematics [Item 8; 5 of 8], liked mathematics [Item 2; 9 of 10] and had confidence in their ability to solve mathematics problems [Item 3; 6 of 9]. In contrast, 6 of 9 indicated that they had not enjoyed mathematics classes in the past [Item 4]. There was little anxiety [Item 6] about tackling mathematics problems (2 of 9) but more hesitance than expected when asked about reservations about participating in mathematics discussions [Item 7; 5 of 9]. These responses were largely consistent with the feedback from students regarding mathematics and what they had gained from participating in the circle. They were also consistent with the conclusions reached by the circle leaders based on their observations. However, it should be noted that only 10 of the 24 participants completed the survey.

Structured observations: engagement indicators

Table 2 presents results from structured observations that focused on indicators of student engagement. For most indicators the majority of observations were positive, indicating that they were observed frequently. These included evidence of listening to presentations, responding to prompts, etc.

Structured observations: instructional indicators

Table 3 presents results from observations focused on instructional techniques. These included efforts by the presenters to involve all students, creation of a safe environment conducive to risk taking, etc. The sessions were not necessarily tied to the middle school curriculum, but were often relevant. These indicators were again consistent with the observations made by the circle leaders and supportive of the conclusion that the circle was conducive to active involvement by students.

Structured observations: implementation

Table 4 presents the final set of observations made during selected sessions. These also focused on the instructional environment of the circle and included such items as informing students about learning objectives, age- and grade-level

Table 1. Survey items related to mathematics attitudes

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Item 1	I think mathematics is important.	0	0	1	3	5
Item 2	I like math.	0	0	1	3	5
Item 3	I feel confident in my ability to solve mathematics problems.	0	0	3	4	2
Item 4	In the past I have not enjoyed math class.	1	2	0	5	1
Item 5	I receive good grades on math tests and quizzes.	0	0	3	4	2
Item 6	When I see a math problem, I am nervous.	1	4	2	2	0
Item 7	I am not eager to participate in discussions that involve mathematics.	0	1	3	4	1
Item 8	Mathematics interests me.	0	1	3	3	2

Table 2. Structured observations: engagement

Engagement Indicators	Proportion of Times Observed
Majority of students listening to or interacting with mathematician	11/16
Majority of students involved in on-task behaviors with each other.	12/16

Table 3. Structured observations: instructional indicators

Instructional Indicators	Proportion of Times Observed
Involved all by requesting and inviting equal participation.	14/16
Used active, experiential instructional approaches.	14/16
Created emotionally safe environment.	14/16
Provided collaboration opportunities for students/teachers.	14/16
Encouraged self expression, responsibility & decision-making.	10/16
Used multiple ways to convey the lesson.	6/16
Opportunities for one-on-one & group instruction.	13/16

Table 4. Structured observations: lesson implementation

Implementation of Lesson Plan	Points assigned out of maximum of 16.
Students were informed of the learning objectives of the lesson.	14/16
Meaningful connections were made between/among disciplines.	16/16
Activities were age- and grade-level appropriate.	16/16
In-depth "Big Ideas" were addressed.	15/16
Examples from different disciplines were used.	13/16
Terminology was appropriate.	14/16
Processes of creating, performing were incorporated.	14/16
Assessment and feedback was ongoing.	14/16
There was a final evaluation of student learning.	13/16
Students had the opportunity for reflection.	16/16

appropriate activities. All indicators of instructional activity were observed during the majority of scans made during the observations sessions. These observations match the intentions of the circle leaders to employ *best practices* with regard to presentations and the overall organization and functioning of the circle.

DISCUSSION

Two research questions guided this case study: what aspects of a math circle were most effective for low-income, minority middle school students, and what impact did participation in the circle have on the youth? We elected to approach this experientially and in an interpretive fashion. We did not operate within any specific research paradigm, but instead more generally attempted to relay the experience as leaders of the circle. We also decided to add a survey and a set of structured observations by a third party. We used the latter two sources to verify or call into question the conclusions we reached.

Our study started with a reflection on the nature of mathematical learning. There was general agreement that learning mathematics is the result of a complex interplay between natural ability, personality factors, and environmental influences. We agreed that relevant environmental influences could be meaningfully divided into formal school activities and out-of-school activities, with math circles falling in the latter category. We launched this effort with a guiding belief that math circles could function as an intervention that would directly impact the mathematics learning process of students. More specifically, borrowing from the San Francisco Model, we postulated the following:

- A Math Circle can be a Safe Mathematical Community which can
    - promote exploration, creative expression, collaboration
    - foster the development of a positive mathematical identity in which the learner views himself/herself as someone who "does" and "enjoys" mathematics
- A Math Circle can Promote

- positive valuation (intrinsic, extrinsic) of engagement in mathematics
- high expectancy for success and enjoyment in mathematical tasks
- increased engagement (voluntary selection, persistence) in mathematical tasks

There is growing evidence to support these propositions. What was less clear was how to translate math circles in particular, and afterschool math clubs more generally, into an experience that would have a positive impact on the mathematical learning of students whose previous experiences in mathematics classes may have been largely negative. Further, we were not clear on how best to design the circle experience for students for whom low expectations and negative stereotypes may have been an accepted part of their identity as mathematics learners. We therefore engaged the experience with the idea that it would be a fluid experience and evolve throughout the academic year. It was our intent to learn from the participating students what an effective circle would be.

What impact did the circle have on participating youth?

In response to this question our conclusions were consistent with those reported for math afterschool enrichment activities. Based on our observations and results of surveys we concluded that the circle impacted the student's (a) attitudes towards mathematics, (b) views of themselves as mathematics learners, (c) engagement and expectancy of success for mathematical tasks, and (d) willingness to engage in collaborative mathematical tasks. In addition, there was some suggestion that participation in the circle impacted the dynamics at the school and those of the student's home environments. Based on interviews with teachers and participants, the selection of students to participate in the circle initiated a labeling process by which the students were designated as "good at math."

The design of inclusive math circles

What did we learn about the design of clubs for this population that could inform future practice? While there are general guidelines for afterschool clubs, our approach was to be flexible and allow the structure to evolve. We framed the club as "not tutoring," which is a common format for the target population of students. We concluded that there were 6 major components of the design that were most effective.

Control of the physical environment

The environment is a well know factor in educational settings. Simply repainting a building and cleaning its grounds can significantly impact the behavior of students and staff. Similarly, elementary classrooms are organized purposefully with bright colors, particular seating arrangements and blankets for mid-day naps, all in response to perceived needs and intended outcomes for students. Cultural anthropologists and sociologists have for decades recognized the important role that structures can play in human behavior. Of particular relevance to our study was whether or not the physical location of the math circle would help with the enculturation process. We thus transported the students to the *space* of the mathematicians and placed them in the common area, where collective activities are most likely to occur. Several outcomes were noted: (a) they responded with great enthusiasm and excitement at being in the space; (b) they expressed interests and curiosity about the artifacts (books, games, etc.) in the space; and (c) they were able to interact with graduate students and faculty.

The circle leader

Many math clubs are led by classroom teachers, often the same teachers who teach the regular courses. These can be effective but are often limited to those students the teacher actively recruits for participation. Similarly, the scope of the mathematics and the other aspects of the mathematics culture are less likely to be found with an individual teacher in contrast to that found in a mathematics department.

Labels and normative expectations

As the year progressed, we came to recognize that the act of selecting the students impacted their standing among their peers and with their teachers at the school. We also had occasion later in the year to interact with parents and observed that participation in the circle was accompanied by expectations for positive outcomes for students and a belief that their selection represented affirmation of their intellectual potential.

Creation of a safe mathematical community

The inner workings of the circle were guided by several goals, one being to create a positive environment for the students. We found the following to be useful: (a) consideration of the types of concerns, experiences the students may have had in the past- - stereotype threat, teacher negative feedback, poor prior achievement, disengagement in math classes; (b) open, receptive and engaging posture from the leaders; (c) absence of negative feedback; (d) expressions of love and enjoyment of the subject by the leaders; and (e) creation of an environment of fun, with the absence negative competition.

Natural grouping: peer collaborations

An important goal of the circle was to facilitate and promote collaborative explorations among the participants. We allowed the structures to be fluid, without any expectations of seating assignments, and the like. In this format, natural groups of students formed, ones that were defined by willingness to engage and compete in particular.

Games and competition

Competition was a constant source of enjoyment for the participants. This was true during lectures, collective challenges, or while playing the game Atari GOES. The students appeared to enjoy gauging their progress relative to that of their peers and sharing the results with the circle leaders. It is worth noting that evaluative assessments were focused on the task, not the individual, the goal being to maintain a task oriented environment.

Value of mathematics

Efforts to impact the participants' views of mathematics took several forms: (a) convey a love of the subject; (b) specifically discuss the value of mathematics in careers; (c) specifically discuss the value of mathematics relative to other sciences; (d) make explicit comparisons of the value of mathematicians to other practitioners in other disciplines; (e) discuss the "lore," "myths" of mathematicians; (f) discuss the *heroes* of mathematics; and (g) have the recruits judged by members in good standing.

These design elements were conceptualized as part of an enculturation process in which the students were introduced to the culture of mathematics.

CONCLUSIONS

In a recent report the US Department of Education (National Academies, 2005) noted that access to qualified mathematics teachers, opportunities to enroll in advanced mathematics courses, and participation in enrichment opportunities were often limited for minority and low-income youth. These discrepancies have been noted as part of a complex set of circumstances that tend to lower performance in mathematics for these groups (Walker, 2007). This is problematic, in that there is general consensus that the US must increase the number of minorities, women and other under-represented groups who have the mathematical skills and coursework necessary to successfully matriculate through baccalaureate (BS) degree programs in the STEM disciplines (National Science Board, 2014). Participation in informal mathematical experiences such as math clubs has been shown to directly impact enrollment in advanced math courses and overall performance in math courses (Gottfried & Williams, 2013). In this study we explored the development of a math circle designed specifically for low income minority youth. There is ample evidence to suggest that the experiences of some minorities and women in mathematics may present unique challenges. This study was designed to determine the impact of participation in a math circle for youth in this population and to identify those aspects of a math circle design that appeared to be most effective.

The results indicated that what made the circle effective is similar to what makes classrooms effective. As noted by Berry (2008) the experiences of African American boys who were successful in mathematics reflect several key factors: recognition of abilities, support systems and a positive mathematicaland academic identity. This is consistent with much current research which emphasizes that mathematics is a social activity and consistent with our findings in this case study. We further found that circle leadership and the location of the circle are potentially important factors in its effectiveness, perhaps moreso for this population which may often lack positive role models with regard to mathematics and affirmation of ability.

The study is limited in that only one circle was examined and none of the factors considered to be impactful were systematically manipulated. The students were all members of a STEM club and attend a single middle school, one that was STEM focused. In this respect, they are only a subset of the general population of low-income students. Nevertheless, this exploratory, intrinsic case study design raises several questions and suggests directions for future research. In particular, effective design of math circles for this population would benefit from insights into the type of obstacles students experience prior to and during participation in the circle. Systematic manipulation of design features of the circle may provide additional insights and studies with populations that are more typical of schools attended by low-income students could be insightful.

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