Women's Experiences Within the Communities of Practice of a Doctoral Mathematics Program: Insights Into Persistence

Brandi Whiteman
Oregon State University

For decades, women have consistently earned fewer than 30% of PhDs in mathematics in the United States each year. Advancement through a doctoral mathematics program can be viewed as a process of integration into the communities of practice within the department, and a student's persistence (or attrition) is influenced by experiences that enhance or inhibit their participation in the activities of each community. In this preliminary report, I discuss the experiences of six women in a doctoral program and their participation in the coursework, research, and graduate teaching communities of practice in their departments. In contrast to past studies that propose that these communities of practice are mutually exclusive, my participants' accounts illustrate some overlap between them.

Keywords: women, communities of practice, doctoral mathematics

Women have been underrepresented in the discipline of mathematics for decades, particularly in higher education settings. Data from the Survey of Earned Doctorates, conducted by the National Center for Science and Engineering Statistics (NCSES), shows that women consistently earned between 27%-29% of doctorates in mathematics and statistics each year between 2010 and 2020 (NCSES, 2024). Further, in the year 2020, non-white women accounted for only 8% of doctorate recipients in mathematics and statistics (NCSES, 2024). Since at least the 1970s, research dedicated to understanding the underrepresentation of women in mathematics and other STEM fields has revealed several cultural, institutional, and structural barriers to obtaining a graduate degree (Ceci et al., 2011; Roby, 1973). Research that focused specifically on the experiences of non-white women has highlighted additional layers of inequity that further pushes them to the margins (Malcom et al., 1976).

Background

Though much of the conversation has been focused on identifying barriers and highlighting inequities in higher education, some studies have also investigated factors that contribute to the persistence and success of women and women of color in graduate mathematics programs. For example, Borum and Walker (2012) found that among Black women who held PhDs in mathematics, early exposure to mathematics and participation in REUs prior to graduate school contributed to their interest and confidence, which helped them succeed. Among women who earned their PhDs in mathematics and secured positions at research institutions as tenure or tenure-track faculty, Miller (2015) found that two of the most important factors related to their success were strong undergraduate preparation in mathematics, and positive relationships with their graduate advisors.

Research addressing the persistence of women, and particularly women of color, in doctoral mathematics has several limitations. One is that many of these studies focus on women who have already completed their doctorates (e.g., Borum & Walker, 2012; Miller, 2015) which provides only retroactive accounts of their experiences. These women also attended different graduate institutions at different times, which makes it difficult to identify any political, structural, or institutional factors influencing their persistence. Additionally, differences in identity have

generally not been incorporated into the analysis of findings, which may unintentionally produce results that center the majority experience (in this case, that of cisgender white women) and erase or invalidate the experiences of minorities. In fact, the incorporation of multiple intersecting identities has often been limited to just race and gender. My study aims to fill this gap by focusing on womxn[1] currently enrolled in a doctoral program in the United States which graduates women at a rate higher than the national average, and by investigating their experiences through an intersectional lens (Crenshaw, 1989).

Theoretical Framework

Herzig's (2002, 2004) persistence framework for students in doctoral mathematics combines Lave and Wenger's (1991) theory of learning through participation in a community of practice with Tinto's (1993) model for doctoral persistence to describe the process through which mathematics doctoral students become academically and socially integrated into their departments and ultimately persist through completion of their graduate program (and thus become full participants in the community of practice of mathematicians). Herzig (2002, 2004) proposed that mathematics doctoral students encounter two sequential but disjoint communities of practice within their departments which they must participate in and become integrated into. These are the *course-taking community of practice* and the *research community of practice*, respectively. As these students become full participants in each, their likelihood of persisting through their doctoral program should increase. However, Herzig (2004) argued that this may not be as simple as moving through one community of practice and into the next.

> If students are to become full participants in the community of practice of mathematicians, they need access to all of the means of membership. … Instead, they are participating in a distinct course-taking community of practice, and their persistence at this stage depends on the degree to which they become integrated into this community. It is not clear to what extent this participation prepares them to participate in the community of practice of mathematics research they will encounter later (Herzig, 2004, p. 181).

In developing this framework, Herzig (2004) was particularly concerned with identifying factors that enhance or inhibit diverse students' access to the community of practice of mathematicians in order to understand how they become integrated into that community. She found that "while there are obstacles to participation and integration that all graduate students face, women and students of color face additional obstacles that limit their opportunities to participate fully and effectively in mathematics practice" (Herzig, 2004, p. 182).

At this juncture, it is worth noting that Herzig (2004) briefly acknowledged the existence of a third community of practice, that of graduate teaching assistants, though discussion of its relationship within the persistence model is absent. Perhaps this is because teaching assistantships aren't a requirement for obtaining a doctorate. However, many mathematics doctoral students, including all of the participants in my study, hold teaching assistantships for at least some portion of their program. Further, mathematics faculty are a large part of the community of mathematicians that doctoral students interact with during graduate school, so teaching is integral to the graduate students' overall practice as mathematicians. Therefore, I will incorporate the *graduate teaching community of practice* into my analysis.

[1] For the purposes of my study, I am choosing to adopt the definition of womxn from the Empowering Womxn of Color Conference, which "uses womxn to describe all who experience life through the lens of womxn in body, spirit, identity past, present, future and fluid." For more information, visit https://ewocc-berkeley.com/history/

While my study design and analysis incorporate intersectionality theory (Crenshaw, 1989), I want to note that this preliminary report focuses the discussion on communities of practice in doctoral mathematics. Intersectional analysis of the findings is in progress but lies outside the scope of the current paper.

Methods

I am conducting a thematic narrative inquiry (Riessman, 2008) to investigate the experiences of womxn currently enrolled in the same doctoral program in mathematics in the United States. The program was chosen because it shows a relatively high rate of women persisting through the doctorate, with over 30% of PhDs in mathematics awarded to women each year for several years (NCSES, 2024). Six womxn initially joined my study, but one discontinued her participation after completing the first set of tasks. Data collected from each individual includes three separate one-on-one interviews (conducted via Zoom), two personal artifacts, five reflective journal entries, and one focus group interview (to be conducted in person). Preliminary findings and discussion will draw from the first interview, the first artifact, and the first two journal entries.

The purpose of the first interview was to understand the participants' mathematical histories up to their decision to pursue a doctorate, and to get a glimpse into what their world as a doctoral student currently looks like. To accomplish the latter, each participant created a map of their doctoral world (their first artifact) that could include anything in their environment that has been meaningful to them during their time in the graduate program. The map was shared prior to the first interview so that questions about the map could be addressed. The interview protocol was largely open ended, beginning with the prompt, "Tell me the story of how you decided to pursue a doctorate in mathematics." Follow up questions inquired about influential people and inspiration, and their engagement with mathematics through time (coursework, research, conference participation, etc.). After obtaining the participant's mathematical history, we reviewed their map artifact together guided by the prompt, "Tell me about the places you included in your map." Follow up questions inquired more specifically about where their mathematical activity happens and where they choose to spend time. Each of the six interviews lasted between 60 and 90 minutes.

The five remaining participants completed their first journal entries within two weeks of their first interviews, and their second journal entries within two to four weeks of the first. Journal entries were structured, guided by prompts which asked about how they engaged in mathematics over the last couple of weeks, including questions such as "How did you share your own mathematical ideas? How did you feel they were received by others? Did your contributions become part of the mathematical conversation?" These journals are intended to capture the continuity of participants' experiences (Clandinin & Connelley, 2000; Riessman, 2008) with respect to their engagement with mathematics in the program over the course of a few months.

To analyze the data, I used a deductive coding scheme using the three communities of practice as broad category codes. Subcodes for each community of practice included "activities" which identified instances of activity or participation in the community, "factors enhance" which identified instances where a participant's experience facilitated integration into the community, and "factors inhibit" which identified instances where a participant's experience disrupted integration into the community.

Preliminary Findings

I found evidence of each of the communities of practice, described by Herzig (2002, 2004), that mathematics doctoral students are expected to encounter during their graduate program.

Each participant provided accounts in varying degrees of detail of their engagement with graduate coursework at their institution, research-related activities, and teaching activities.

Within the *course-taking community of practice*, important activities discussed by all participants, regardless of their current stage in the program, included taking a variety of courses, doing homework, and solving problems. One major factor that enhanced their participation in these activities was collaborating with their peers. Professors encouraged students to work together on their assignments, and the mathematics building provided ample space for doing so. Many participants spoke about their use of shared graduate student offices and openly accessible spaces in the hallways which had seating and whiteboards. During our discussion of her map, Sofya described one such space.

> *Sofya:* Our cohort stays very close to each other, so that – we do this on purpose – so we can like, work a lot together, and mine was the leftmost [office] in some sense. That's [the common table outside of the offices] where we sometimes just go out to all sit there and work, or they like to come to my office a lot. I realized that, like, we usually just end up with sharing one office. Because that's how - we were encouraged to have that. … Every professor will put like, 'You're encouraged to work together.' … I honestly think maybe we spend time together more in 1st year cause we were all in intro classes, and you know how frequent those homework came out. You need to work with each other in order to actually like, survive, sort of.

Having space to collaborate on homework, being encouraged to do so by her professors, and having easy access to others in her cohort all enhanced Sofya's experience and facilitated her integration into the course-taking community of practice in the department.

Though Herzig (2002, 2004) described the *course-taking* and *research communities of practice* as sequential and disjoint, I found that participants in their second and third years have all been able to access the research community of practice despite not having been fully integrated into the course-taking community of practice. For example, Anne was given her first research opportunity the summer before the start of her second year. In her first journal entry, she described working with a group of collaborators on specific tasks with the goal of writing a paper. In her second journal entry, she followed up by saying that she authored one paper and co-authored another by the end of the summer. This indicates that she was able to begin developing several skills needed to become integrated into the research community of practice of mathematicians.

Other forms of participation and activity in the *research community of practice* within the department are through seminars, colloquiums, and reading courses. Many of my participants mentioned attending seminars early on in their program, and the positive impacts this had on their trajectory.

> *Moose:* So I actually joined the seminar for my research group in my 1st year. It's the groups and topology seminar, and I found that to be a really helpful group. The professor, well, the professors behind that, two of which are my co-advisors, really wonderful at accepting people.

Moose was able to gain access to the research community in the area that she was interested in pursuing despite having just entered the program. Feeling accepted in that group further enhanced her experience and facilitated her integration into the research community of practice.

Interestingly, I also found some interaction between the *graduate teaching community of practice* and the *course-taking community of practice*. For example, when Maxine struggled in her first year with coursework despite having a collaborative relationship with peers.

Maxine: I started grad school during the pandemic, so I had, I think, like 2 or 3 friends that we had a little bubble with, and one of them was super high achieving – like, super duper fast, high achieving - and then the other one was also high achieving but did things a different way. And so, I was often just stuck in the middle, like 'I don't know what to do,' so definitely learning to ask for help. And, you know, you say this to our students so much, being like, 'Go to office hours.' *Going* to office hours [laughs].

Maxine described an isolating experience where she felt "stuck" between her two peers, who she positioned above herself as "high achieving" and who approached things differently, but the negative effects of this experience were mitigated by "learning to ask for help" during professors' office hours. In this case, her experience as a teacher who urges her students to attend office hours was reflected onto her own experience as a student struggling in a course and highlighted a path forward.

Discussion

Herzig (2004) argued that "the persistence of a doctoral student in mathematics, and the quality of her experience in graduate school, is a function of how well integrated she is in the academic communities of her department and discipline" (p. 201). My preliminary analysis investigated the experiences of womxn in different stages of their doctoral program to identify opportunities they had to participate in the mathematics community of the department, and factors that enhanced their engagement and integration into the *course-taking* and *research communities of practice*.

Previous research has found that competitive and individualistic environments isolate women from the communities of their departments (Herzig, 2002; Hollenshead et al., 1994; Stage & Maple, 1996). My analysis showed that peer collaboration was both encouraged and facilitated by aspects of the program environment, which promoted integration into the course-taking community of practice. One potential implication of this is that mathematics graduate programs which make concerted and intentional efforts to promote collaborative relationships among its graduate students will increase the likelihood of graduating their diverse students

During the first few years of graduate study, mathematics doctoral students are sequestered away from authentic practices of mathematicians while they focus on completing coursework and preparing for qualifying exams (Herzig, 2002). Herzig (2004) found that this structure denies students access to the *research community of practice* while also forcing them to spend significant time and energy developing skills which may not necessarily enhance their ability to perform mathematics research. However, my preliminary analysis suggests that the course-taking and research communities of practice overlap in this department. Students are offered summer research opportunities at the early stages of their program (even if they haven't yet passed qualifying exams), and they are also encouraged to attend research seminars and take reading courses in the department. I conjecture that this feature of the program plays a key role in the persistence of womxn pursuing PhDs.

Finally, my preliminary analysis suggests that participation in the *graduate teaching community of practice* may influence a student's ability to become integrated into the coursework community of practice. Attending to their students who are struggling may provide a mirror through which graduate students find ways to alleviate their own challenges and persist through their coursework. Further investigation is needed to determine whether and to what extent this is the case. I have the following questions for the audience: (a) Have you encountered graduate programs that offer students early research opportunities? (b) What other ways can graduate students be invited to the research community in their departments?

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