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'Slaughtering this beautiful math': graduate women choosing and leaving mathematics

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The quality of graduate students' relationships with faculty are crucial for students' success. Unfortunately, negative relationships with faculty are common for women in the sciences and mathematics. Six women doctoral students in one mathematics department in the US were interviewed to better understand the nature of their relationships with faculty members, and the effects of those relationships on their decisions to persist or to leave. These women described the limited or negative relationships they had with faculty. They spoke of ways in which they felt ignored, the lack of mentoring, advising, and other guidance, poor teaching, and a general lack of moral support. Each of them described ways in which they felt they did not 'fit in' in the department. These findings are interpreted through two lenses: the idea of participation in a community of practice and all that that entails, and Noddings' notions of caring. Implications for women in mathematics at all levels are discussed.

Introduction

While girls and boys in the US take similar amounts of mathematics in high school (National Center for Education Statistics, 1997), participation of females in mathematics decreases as they progress to higher educational and professional levels. In 1994, women received 47% of bachelor's degree awarded in mathematics in the US. Following this cohort of women into graduate school and beyond we find that also in 1994, women comprised 35% of the full-time graduate students in mathematics enrolled for the first time. In 1996, women received 40% of masters degrees in mathematics, and in 1999–2000, they received 27% of doctoral degrees (National Science Foundation, 2000). In the fall of 2001, 15% of full-time mathematics faculty and 38% of part-time faculty at US institutions were female (Loftsgaarden *et al.*, 2002). While these numbers represent substantial improvement

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over recent years, they indicate that the participation of women in post-secondary mathematics remains disturbingly low.

The mathematics community has become concerned with small numbers of women pursuing higher education in mathematics (National Research Council, 1992). While little is known about the reasons for women's departure from mathematics in particular, studies about the attrition of women from the sciences have implicated an array of causes, ranging from family responsibilities, which impact women more strongly than men (Sonnert & Holton, 1995; Lovitts, 2001; Grant *et al.*, 2000) to epistemological concerns (Golde, 1996; Stage & Maple, 1996). Several authors have found that students who are more integrated into the academic and social communities of their departments are more likely to persist in graduate school (Girves & Wemmerus, 1988; Tinto, 1993; Lovitts, 2001; Herzig, 2002). Students who are not well integrated into their departmental communities and cultures are more likely to leave graduate school for other reasons; for example, poorly integrated students are less likely to put up with financial hardship (Lovitts, 2001). Thus other reasons implicated in attrition actually mask an underlying issue of integration.

Girves and Wemmerus (1988) found that a faculty member 'serves as a role model and becomes the primary socializing agent in the department … It is the number of faculty members a student comes to know as professional colleagues that is associated with involvement in the doctoral program' which in turn is 'directly related to doctoral degree progress' (p. 185). Thus the quality of relationships with faculty is critical for students to become integrated.

Encouragement and moral support from mentors play important roles in students' decisions to enroll and persist in graduate studies in mathematics (Research Council, 1992; Hollenshead *et al.*, 1994; Manzo, 1994; Stage & Maple, 1996; Carlson, 1999; Cooper, 2000; Herzig, 2002). Faculty members help socialize students to understand the norms and practices of the department and discipline (Gerholm, 1990; Etzkowitz *et al.*, 1992; Cooper, 2000), and help them become integrated within the communities of the department, which is an important predictor of degree progress (Girves & Wemmerus, 1988; Tinto, 1993; Lovitts, 2001; Herzig, 2002).

Students who are treated as 'junior colleagues' are more likely to stay in graduate school and complete degrees (Berg & Ferber, 1983; Girves & Wemmerus, 1988; Nerad & Cerny, 1993). Based on a survey of 459 graduate students who had been enrolled in 32 departments at one university in a seven year period, Berg and Ferber (1983) reported that graduate students who earned a doctorate (compared with those who enrolled in doctoral programs but did not earn a doctorate) were 3.4 times as likely (based on an odds ratio) to have reported being treated as a junior colleague by at least one male faculty member, and 4.8 times as likely to have come to know two or more male faculty members quite well. (Of course, students who left without completing the degree might have left before those relationships with faculty had the chance to develop.) Conversely, students who feel they are treated as 'adolescents' are less likely to complete degrees (Nerad & Cerny, 1993).

Women students in the sciences and mathematics receive less mentoring from male faculty than do men students (Berg & Ferber, 1983; Etzkowitz *et al.*, 1992;

Hollenshead *et al.*, 1994; Sonnert & Holton, 1995). Berg and Ferber (1983) reported that male degree recipients were significantly more likely than female degree recipients to have felt treated as a junior colleague by a male faculty member; relationships with female faculty could not be analyzed because too few students in their sample had sufficient interactions with female faculty. In mathematics departments in the US, the fraction of graduate students who are women is almost three times the fraction of faculty who are women; in the Fall of 2001, 12% of full-time doctoral faculty were women and 31% of full-time graduate students were women (Loftsgaarden *et al.*, 2002). Combined with the tendency for faculty to mentor same-sex students (Berg & Ferber, 1983; Reskin *et al.*, 1996), this statistical imbalance presents a substantial obstacle to graduate women in mathematics.

One common cause of attrition in the sciences is an incompatible relationship with advisors (Girves & Wemmerus, 1988; Golde, 1996; Bair & Haworth, 1999); this also has the effect of eroding students' reports of self-confidence (Berg & Ferber, 1983; Golde, 1996). Disciplines in which graduate education is characterized by a lack of faculty mentoring and departmental advising also have high attrition rates and long average time to degree (Nerad & Cerny, 1993). Students who left graduate school have said that if their advisors or other faculty had been more supportive and sensitive, they might have been more inclined to stay (Lovitts, 1996; Herzig, 2002).

Negative interactions with faculty are pervasive for women in science. Sonnert and Holton (1995) documented forms of discrimination that women faced in finding mentors, ranging from professors who would not take on women students to mentors who did not seem to tap into their professional networks as vigorously for their women students as they did for men. Women's opportunities were also limited by being excluded from the informal social networks of their laboratories or departments, being treated as 'invisible,' or otherwise having their contributions marginalized (Becker, 1990; Etzkowitz *et al.*, 1992; Sonnert & Holton, 1995; Stage & Maple, 1996). The Committee on the Participation of Women of the Mathematical Association of America (2003) also reported on sexist behavior experienced by women in graduate mathematics, including unwanted sexual advances from faculty, tolerance of public sexist comments, and professors who openly state that women are not as smart, dedicated, or talented as men.

Thus relationships with department faculty, particularly advisors, are a critical mechanism by which graduate students become integrated and persist in graduate school. The small numbers of women faculty, the importance of positive mentoring relationships, the pervasiveness of negative relationships, and the tendency for faculty to mentor same-sex students all combine to pose a serious obstacle to integration for women in mathematics.

The rest of this paper uses interviews with six women doctoral students in one Mathematics Department to look at the opportunities these women had to interact with faculty, and to begin to understand the nature of the relationships between women doctoral students and faculty as the students learn to become mathematicians.

Method

This study was conducted between the fall of 1999 and the fall of 2000, in the Mathematics Department at a large, public research university in the US. The focus of the program is on the Ph.D., with a Master's degree awarded along the way to the doctorate. This report is based on interviews that were part of a larger study, in which a total of 23 graduate students and 21 faculty members were interviewed. Of these, only the six female graduate students are included here.[1]

In the fall of 2000, there were 51 tenured faculty members (49 men and 2 women) and 6 tenure track faculty members (5 men and 1 woman) in the Department (Department Secretary, personal communication, September 2001). The Department enrolled 116 graduate students (103 full-time), of whom 26 (22%) were female. In the 1999–2000 academic year, nine male and two female students received the Ph.D., and 22 male and four female students received Master's degrees (University website, 2001). Historically, approximately 50% of the graduate students who enter the program complete the Ph.D.; of the 199 graduate students who entered the graduate program between 1983 and 1987, 98 completed the Ph.D. and three were still enrolled ten years later.

Participants were initially recruited through email messages sent to all the graduate students in the department. In addition, particular individuals were invited to participate based on recommendations from other participants. Because of the small numbers of women in the department, many women graduate students were individually invited. Participants were guaranteed confidentiality and the opportunity to review and comment on reports based on their interviews.

The six women had completed between one and more than six years of study at the time of their interviews. One of these women had left the program without the Ph.D., and another decided to leave sometime after her first interview, but contacted me for a follow-up interview after she decided to leave. Two women were working on their dissertation research, one just beginning and the other close to finishing, and had considered leaving the program at some point in the past; at the time of her interview, one of them still thought that she may not complete the Ph.D. One first-year student and another who was working on her dissertation research had never considered leaving the program. In order to protect participants' identities, more specific demographic information cannot be provided.

Interviews explored their initial experiences, interests, and goals in mathematics, reasons for choosing graduate study, expectations about their schooling, experiences in undergraduate and graduate school, conceptions of mathematics, and decisions about continuing or leaving. The interview outlines served as a starting point for the interviews, but each interview was different, covering those parts of participants' stories that they thought were relevant.

The interviews were open conversations. In addition to asking for specific information and facts, Anderson and Jack (1991) call for the need to invite participants to discuss 'the web of feelings, attitudes, and values that give meaning to activities and events' (p. 12) and to give them 'the space and the permission to explore

some of the deeper, more conflicted parts of their stories' (p. 13). These subjective and personal aspects of participants' stories were valuable sources of insight about their experiences within mathematics. However, encouraging participants to talk about these issues can be painful; some participants were discussing what they perceived to be failure. To allow participants to avoid topics that were painful, while still leaving the interviews open to discussion of personal experiences and the meanings derived from them, each participant was given an outline of discussion topics several days before her scheduled interview, so that she had the opportunity to think about those topics, delete anything that she did not wish to discuss, and add topics that she considered relevant (after Burton, 1999b). Among these six women, none made deletions.

Interviews took place in a private office on campus, and ranged from one to three hours, sometimes in two separate meetings. Interviews were audiotaped and transcribed. Participants were offered the opportunity to listen to the tapes of their interviews before giving me permission to use them.

The transcripts were analyzed inductively. After the interviews were transcribed, the transcripts were read while listening to the tapes, and initial codes were developed. The participants' stories were the real guide to coding the data, and codes were developed as necessary to reflect the themes that arose from the interviews, as they reflected on participants' descriptions of their relationships with faculty in the Department. As each transcript was read and re-read, new codes were developed and applied. Once the coding scheme reached a point where it seemed to capture the relevant parts of the participants' stories, all the interviews were re-coded.

As described above, the things the participants discussed differed according to their stories, and as a result, not all participants talked about the same topics. Also, there are only six participants, from which it is not meaningful to derive statistical information (for example, about how many people voiced a particular idea). Consequently, the text below presents a composite of all the participants' stories. Disagreements are presented if they were voiced.

In the text that follows, quotes are presented because they are particularly articulate or clear in expressing common themes discussed by the participants. Quotes were edited for readability, removing stutters and distracting expressions such as 'uh' and 'you know', and references that might reveal participants' identities were obscured.

Results

Although these interviews covered a broad range of topics concerning these women's experiences in mathematics, their discussions of their interactions with faculty and other graduate students comprised almost 20% of their combined interview transcripts. In contrast, the faculty interviewed in the larger study rarely discussed interactions with graduate students, perhaps because they had so few. All of the women interviewed described the limited or negative relationships they had with faculty. While students described different aspects of these relationships, there were several common themes among their comments. In particular, they spoke about

feeling invisible, needing guidance, wanting better teaching, lacking moral support, and wishing to be mentored.

Feeling invisible

The participants felt that first-year students needed more guidance and interaction with faculty. Many students felt overwhelmed during their first year, from the combination of the demands of coursework and for some, the adjustment to being in such a large department.

> I think a lot of people have a similar experience to my first year where I was just thrown in with not that much guidance, not really understanding my classes, just falling behind and not knowing how to get help. I wasn't real comfortable going to my professors. I think it's better when the professors of the first year classes actually reach out and talk to the students and I don't think that always happens. I think sometimes they just come in, they talk and they leave, and the students are left with not knowing what to do.

One woman, who came from a cultural background in which students were expected to conform to a more formal code of behavior, enjoyed the informality and approachability of the professors in the Department.

> What I liked the most is the sense of freedom that you have … I find it very refreshing that here nobody is watching you all the time to see how you behave and how you dress and how you act with other people.

Some of the women believed that the professors do not pay attention to graduate students until they prove themselves by passing their qualifying exams. One graduate student, who was finishing her dissertation at the time of the interview, described her frustration that she did not get any more attention after passing her exams than she did before.

> I had the impression early on that the faculty weren't paying all that much attention to me and I was assuming that it was well, I haven't proved myself yet. I haven't passed my quals, I don't have an advisor. When I do those things that will change and it didn't, which is still a source of frustration to me.

An advanced student described how accustomed she had become to this lack of attention. Later in her studies, when someone did show an interest in her work, she was surprised.

> I've very, very rarely had faculty members say, 'So what are you working on? Tell me about your work.' … After I gave a talk on Thursday one of the [faculty] who had been at the talk came up to me afterwards and in the context of talking about the talk, said 'I've worked on some somewhat related things and maybe we should talk sometime.' … That is a novel feeling to me and it shouldn't be, especially not when I've been around as long as I have.

Five of the six women felt that the professors were unfriendly, or even hostile. Several described the faculty as not caring.

> If I had to change the profession of mathematics, I would make people nicer. And I think that that would have lots of repercussions … I think we would have more women in mathematics if people were nicer.

Each woman described the ways in which she sometimes felt awkward in a professional world with so few women. The women talked about the variety of ways that they did not feel that they 'fit in.'

> I had one female professor in my time here and it was so much easier to get interested because I could imagine myself being her. It's strange that I would just naturally get more interested in a class with a woman at the front and maybe it was because she was also a good lecturer and a lot of fun. The math department seemed so much like an old white guys' club, and I didn't really see that I had a place in the old white guys' club.

Needing guidance

In this mathematics department, each student was assigned an initial advisor at the beginning of her first year who usually remained in that role until the student passed qualifying exams and found a research advisor. These women found this system ineffective, and rarely spoke with or got useful advice from their advisors.

> He must have had a million of us little advisees and he obviously took little or no interest in the direction of my academic career, and really he had no reason to … It's not that he didn't like me, it's just that he didn't necessarily care … Had I had an advisor who I felt like I could ask, 'Do you think this is the right course?' 'How should I be proceeding about this, that, the other thing?' If I had gotten some advice that I felt like this person was advising me and not just advising a first-year grad student who comes here with a vague interest in [subject], I would have gotten something out of that.

As a result, they did not receive the advising they felt they needed or expected, saying that they suffered from the lack of advising, which might have helped them make better decisions about courses to take and could have given them a more clear idea of what to expect. Three women felt that because of the bad advice, or lack of advice, they received when they started the program, they ended up in courses that were inappropriate choices for them or did not take courses that would have contributed to their mathematical training in important ways.

> He would give us these hard homework problems and I would go in to ask him about it … Eventually I'd go and ask him stuff and then he'd say something like, 'You really need to work on your algebra more. You should really take algebra next year.' … I went in to ask him a question about this homework. Instead of explaining something to me, he would correct what I had done wrong with my education which is really what *he* had done wrong, because I had wanted to take that course and he told me not to. That was infuriating … It made me feel badly that I didn't have the algebra background. And Professor Y did the same thing. He said that [course] was an unwritten prerequisite for [course] but no one told us that. I wanted to take that course but I was discouraged from it, and then they tell you this all later and it made me feel ashamed, like I didn't have the background, therefore I was bad. Like I was an insufficient student.

Wanting better teaching

Although the graduate students complimented some lecturers for their clarity or organization, or for making the material interesting, their complaints about the teaching of the courses included the lack of interaction between the instructor and the students, difficulty discerning the important information, incomprehensible lectures, non-English textbooks, and the lack of motivation or connections among mathematical ideas and the mathematical 'big picture'.

> He'd come in and he would race through the stuff on the board and we would furiously copy down what he was doing and it seemed like just streams and streams of words, signifying nothing. Then we'd have a month of this with no homework … really no indication of what on earth was going on, not much in terms of why we were doing what we were doing or where this was going. Just, 'Ok, here's a lemma,' 'Here's the proof,' 'Here's another lemma,' 'Here's the proof,' 'Here's a theorem.' Very little motivation, and I think I didn't see the whole big picture.

Most of the women graduate students complained about the lack of feedback mechanisms in their courses. In many of the first-year courses in this doctoral program, professors do not give students feedback on their work; in some classes, work was not even assigned or collected.

> The algebra course we had I think two assignments over the whole semester, unless I'm mis-remembering and there was only one, and that's not enough feedback. Even in the topology course where we probably had four or five homework assignments over the course of the semester, there was still not a whole lot of feedback from those particular assignments … After assignments were due, there would be a point where we'd say, 'Alright we're going to take today and just talk about these problems that were in the homework assignment.' That was a useful form of feedback. Although a more individual, 'this is where there's a flaw in your argument' or 'this is where you've overlooked something' would have been useful too.

They complained that they either could not ask questions, or felt that they were rebuffed or chastised when they did.

> I go and ask a question like 'I don't understand this part of the notes. When you go from here to here and there's really no explanation,' and I'd be told, 'there's a very good book on this in the library.' It got to the point where it's becoming offensive … There was one time I went to go see Professor X in office hours and he was on the phone. He said, 'Can you come back in ten minutes?' I said, 'Sure.' I came back in ten minutes and he was gone. Sometimes I've sent an email saying, 'You only have office hours once a week and I didn't understand something and I can't come to office hours today. Can I set up a time to meet you?' and he wouldn't respond for five days and then he'd say, 'Why don't you come to my office hours?' It got to the point that it was so evident that this guy didn't want office hours or to teach his class that it was just offensive.

In contrast, another student described being able to get helpful answers to her questions.

> In one of my courses in my second semester we had homework and we were encouraged to go and discuss with the professor the problems and the homework, so I used to go and discuss with him quite a lot.

Some of these women described boring classes in which the excitement for mathematics was missing, with little explanation.

> [Course] wasn't a terribly pleasant experience during the course because I had learned a bit of [subject area] before but this person's approach was a little different. That's alright but he didn't really explain very much to us, so during most of the time during this course I was sort of a little lost … He would go over and he would do theorems and things like that but I think it might have been my fault too because he had the sort of voice that tended to make me not pay attention to it. So after a while I would be mechanically writing down things that he wrote on the board without really registering what they meant.

These women had all come into the program with a passion for some aspect of mathematics, which helped motivate them to work very hard to understand mathematical concepts and ideas.

> I find it intriguing. It's very beautiful. I love working on it, I really do … It's just fascinating to me. It's the only subject that ever really made me want to go out and read more … Being able to understand it and being able to do it, for me it was a huge motivation, knowing that if I put some more effort into whatever class, I can almost understand it but I'm missing this part. All I have to do is figure out this one thing and then I'll understand all about this theory, and I knew that I could do that part. I could talk to my professor, I could read the book again, I could go through the notes again. There are a lot of ways to figure that out.

Unfortunately, the education they received in the department left them with a 'bad taste' in their mouths, and some described having lost their love of mathematics.

> I had taken a lot of this material before and I'd sit there in horror. He was slaughtering this stuff. This was stuff I thought I wanted to study [for] the rest of my life and he's sitting there just slaughtering this beautiful math. It was horrible. I just wanted to start screaming in the middle of class, 'No! You're not talking about it right! Make it clear!'

Lacking moral support and encouragement

The moral support and encouragement provided to graduate students by mentors have been found to be particularly valuable (Hollenshead *et al.*, 1994; Cooper, 2000; Herzig, 2002). The women in this study said that when they did receive such support, it made a big difference to them.

> I think the main reason that I'm still here is having gotten support from him and it's really more emotional support and moral support at the one critical time … The time I thought most about leaving, my advisor was there and basically said 'No, you shouldn't do this. You are close to finishing. I know, I do believe you can do this.'

However, these instances were the exception, rather than the rule. Most of the women complained about the lack of moral support and encouragement they received from their instructors and advisors.

> There was virtually no encouragement from the professors to start … One professor I know of said to one person I know … [that] they didn't really care about us until we

> passed the quals because until we passed the quals we hadn't proved ourselves and so they weren't even going to bother thinking about us. That was what it felt like my first year, like we were nothing. They didn't care at all … It would be a lot better if they could reach out more … maybe take an interest in what students are doing … It's hard for me to get used to being just average for the group I'm in. I guess going from a big fish in a little pond to the whole ocean is sort of painful, and I'm not sure there's anything that math grad school here could do about that. Well, they could be more encouraging, right? They could tell you sometimes that you did well, maybe.

Wishing to be mentored

All of these women complained of ways in which they did not received mentoring in mathematical thinking. They described wanting to know more about how their professors think about mathematics, how they approach solving problems, or how their work fits into the broader mathematical landscape.

> I have learned to do mathematics enough to work on my thesis but I often don't feel like I'm doing things as efficiently as I could be … How do you go from seeing 'This looks like a pattern alright' to actually proving it? … I don't feel I've learned enough about how to research productively and how to tell when I'm tackling a problem that's just going to be too complicated or going about it in a way that's going to get too unwieldy. I haven't yet really figured out how to decide when I can trust my intuition to follow something and when that's likely to lead me astray … Researchers could explain or demonstrate how their own thought processes work and how you go from saying, 'One should be able to calculate the [mathematical term]' to saying, 'I'm going to use this technique, and I'm going to look for this kind of evidence.'

Even the women who were close to finishing their dissertations noted that they had not had any mentors in graduate school.

> There were a number of people that were encouraging and said 'You're doing very well' or whatever but no one influence stands out.
>
> So no particular mentor?
>
> No.

One woman said she came to graduate school expecting to be treated like a junior colleague, and was disappointed that that was not what she found.

> Graduate school should really be more of the mathematical apprenticeship than it is now in the sense that as graduate students we should be learning to be mathematicians and we should be learning to interact as mathematicians, and I don't feel like I get much encouragement. That involves a lot of interactions between people, between faculty members and graduate students. My biggest frustration is that there isn't enough of that and I don't feel like the department as a whole in some sense cares.

One benefit of being treated as a junior colleague is that it can help a student develop 'tacit knowledge', the unspoken cultural rules and informal knowledge of the discipline that graduate students need to master, and which they develop through contact with more experienced researchers (Gerholm, 1990). If students have limited interactions with faculty, then they will have limited opportunities to develop tacit

knowledge about the discipline. One advanced graduate student enjoyed support she received from a new faculty member, who helped her develop some tacit knowledge about mathematics.

> What he is doing is he's telling all the graduate students, 'Yes you should go to the colloquium.' And then … a couple days after he runs a session where he goes over some of the concepts that were discussed there … I was also thinking that I wish someone had been doing this five years ago. I would have gotten so much out of this. Another thing he's doing in conjunction with that is what he's referring to as a 'tricks of the trade' workshop, things that you have to know as a working professional mathematician that you never really get taught explicitly but somehow you need to know.

Discussion

The six women participants described relationships with their professors that might be characterized by 'benign neglect', in which there was little interaction either in or out of class. Here I will present two different frameworks for interpreting these results.

Participation in a community of practice

Theories of situated learning posit that learning happens through participation in social practices, and indeed that learning is inseparable from that participation (Boaler, 2000). The learning of doctoral students happens as they participate in the communities of practice that reside in their programs and departments (Lave & Wenger, 1991; Wenger, 1998).

Wenger (1998) describes three dimensions that define a community of practice: a joint enterprise, a shared repertoire, and mutual engagement. A joint enterprise is mutually negotiated and defined by its participants in the course of pursuing it, and includes notions of mutual accountability among participants. A shared repertoire is similar to what Gerholm (1990) calls 'tacit knowledge,' described above, which includes the unspoken norms by which the discipline operates. Both the joint enterprise and shared repertoire are constructed and negotiated by participants as they mutually engage in the activities of their community. These three dimensions of a community of practice parallel three aspects of the learning that students do in graduate school: they learn mathematics (they enter and construct the joint enterprise), they learn how to behave like mathematicians (they enter and construct the shared repertoire), and they develop a sense of belonging within the discipline (they engage mutually with the other community members) (Boaler *et al.*, 2000; Herzig, forthcoming). To become mathematicians, then, students need to learn to *think*, *act*, and *feel* as mathematicians do.

Although students may not be equipped to participate in the community of practice in the same *ways* as the 'old-timers,' they can participate in 'peripheral' ways, and, as their skill and knowledge increase, the nature of their participation will change. 'The important point concerning learning is one of access to practice as resource for

learning, rather than to instruction' (Lave & Wenger, p. 85). The activity of the community provides a 'curriculum' for students, who learn through their participation in that activity. 'Participation in the cultural practice in which any knowledge exists is an epistemological principle of learning. The social structure of this practice, its power relations, and its conditions for legitimacy define possibilities for learning' (p. 98).

The nature and extent of relationships among all members of a community of practice are critical components of participation. In order to increase the numbers of women in mathematics and to enhance the quality of their learning, mathematicians need to provide opportunities for women graduate students to develop meaningful and substantive relationships with faculty, both in and out of class, in ways that enhance these students' participation in mathematical practice—leading them to learn to think, act, and feel like mathematicians.

The women interviewed for this paper had limited opportunities to participate in mathematical practices. They described distant relationships with faculty, in which the faculty provided few glimpses of how they think about mathematics and had little to do with the students outside of class. Without assignments in class and feedback on their work, and without meaningful, mutual interactions with faculty, these women had few opportunities to develop their abilities to think mathematically, to learn to work as mathematicians, or to develop a sense that they belonged there. Their work as doctoral students was structured to sequester them from the community of practice of mathematicians, and for some, it had precisely the effect of making them feel like outsiders to mathematical practice, rather than leading them to participate in it more centrally.

Given that the faculty in this department were mostly male, and the tendency of faculty to mentor same-sex students (Berg & Ferber, 1983; Reskin *et al.*, 1996), it is little surprise that these women felt they had no mentors. Burton (1999a) interviewed 70 practicing mathematicians in the UK, and found that none of them had had a female advisor, yet many of the 35 women she interviewed were advising graduate students; she concluded that there may be reason to expect that women will have increased opportunities to have women as advisors. This hope was not yet borne out by my data.

Caring

Noddings (1984, 1992) proposes a model of education based on the notion of caring: for self, for strangers and distant others, for animals, plants and the earth, for the human-made world, and for ideas; it is the last of these that will be of interest here. Noddings argues that, in order to engage students in school in productive ways, and in order to help them develop into caring, moral adults, educators need to engage those students in caring relations within schools.

Noddings (1984, 1992) identifies four components of education from a perspective of caring: modeling, dialog, practice, and confirmation. In effective mathematics teaching, then, teachers would do four things. They would model their care for

mathematics and for their students. They would engage students in dialog—in meaningful, mutual, open-ended discussion. They would provide students with opportunities to practice caring about mathematics; this is not intended to merely be rote drill in mathematical computation, but engagement with the habits of mind often referred to as 'mathematical thinking.' And they would provide confirmation to their students—positive, affirming feedback that stems from a trusting, established relationship.

The women I interviewed experienced none of these things. Although they initially cared a great deal for the world of ideas represented by mathematics, they described classes devoid of enthusiasm, which failed to communicate the 'big picture' or motivation for mathematical ideas. Likewise, they perceived that the faculty did not care about them as students. The faculty did not model caring, either for mathematics or for these women.

Students had few opportunities to interact with the faculty about mathematical ideas; most of their coursework consisted of listening to professors lecture, and the students reported not even being able to ask questions, in or out of class. They wanted more and better advising, and reported few mentoring relationships. The only opportunities they had to engage in dialog about mathematics were with other graduate students.

These women complained about courses with few assignments that often were not graded, and although they often tried to find their own problems to solve, they wished for meaningful feedback on their work so that they could develop their mathematical thinking. They described not knowing how their professors think about mathematics, and what they thought they might learn from seeing just that. The faculty did not set up situations in which students could practice caring about mathematics.

Given the lack of interaction between faculty and graduate students, there was little mention of positive feedback of any kind. The women described a lack of encouragement, and little meaningful feedback on their work. The faculty did little to confirm these developing mathematicians.

Rather than helping these women develop more care for mathematics, the experiences these women had in graduate school actually diminished their enthusiasm and care for mathematics. The absence of caring relations these graduate students experienced begs another question: What kind of modeling does this experience provide for the students who do survive graduate school, and go on to be teachers themselves?

What does this mean for women in mathematics?

In many mathematics doctoral programs in the US, work is expected to be individualistic and independent (National Research Council, 1992). It may be that female graduate students' interactions are different from those expected by male faculty, and are misinterpreted as inferior, rather than different, as was also reported by Etzkowitz *et al.* (1992):

> In [one] department a female academic model based on inter-personal relationships, affiliation and nurturance had become accepted as legitimate and had even become the departmental norm. This was in strong contrast to another research site where the expression by women of a need for these characteristics in the laboratory environment was derided as a desire for dependence and emotionality by the adherents of the patriarchal system that was in place. (p. 174)

However, this view of a typical woman's 'style' is problematic, in that it overlooks the many individual ways in which women interact. An alternative explanation is that the lens through which faculty view graduate students imposes stereotypic interpretations on women's behaviors. Indeed, other authors have reported that women graduate students in science and mathematics have been stereotyped as less capable and uncompetitive, and as a result they may not be taken seriously by faculty (Becker, 1990; Stage & Maple, 1996; Committee on the Participation of Women of the Mathematical Association of America, 2003).

For at least two women in the study reported here, the lack of care they perceived from faculty had the effect of leading them to leave the program without completing the Ph.D. Two other women described their deliberations about leaving, but it was an overt act of care on the part of a faculty member that led them to stay.

Building caring relations between faculty and graduate students, and between graduate students and mathematics, can offer important avenues to integration in the community of practice of mathematicians, for women and for men. Perhaps not surprisingly, many of the men interviewed as part of the larger study described similar experiences and concerns within the Department. What was unique to the women was their unanimous descriptions of feeling that they do not fit into the male-dominated culture of mathematics, a feeling that presents a substantial obstacle in their path to developing a sense of belonging in mathematics.

The web of factors that cause the disproportionately low participation of women in mathematics is very complex, and the task of identifying those causes is not a simple one. While the experiences reported here may not be entirely unique to women, the additional obstacles that women face in developing a sense that they belong in mathematics presents them with a particular challenge. These results are presented with the hope of adding another dimension to our attempts to understand women's relative lack of participation in mathematics.

The results reported here may represent issues faced by women in other disciplines as well. Mathematics is often included in categories along with the physical, natural, or computer sciences, and the nature of knowledge in mathematics bears many similarities to the knowledge in the sciences (Biglan, 1973; Becher, 1989). However, at least in the US, the nature of *graduate research* in mathematics has strong similarities to research in the humanities. Science students generally begin research early in graduate school and work in organized research teams, which is rarely the case in humanities (Golde, 1996; Lovitts, 2001; Tinto, 1993) or in mathematics, where students often don't begin research until they have completed their graduate coursework (National Research Council, 1992). Graduate research in mathematics and the humanities is more likely to be individual and isolated (National Research

Council, 1992), compared with a high degree of collaboration in the sciences (Becher, 1989; Nerad & Cerny, 1993; Tinto, 1993; Golde, 1996). As in mathematics, graduate studies in humanities emphasize absorbing knowledge through teaching, activities which are downplayed in the sciences in favor of actively conducting research (Golde, 1996). These similarities between the study of mathematics and the study of other bodies of disciplinary knowledge imply that the findings reported here may in fact reflect issues for women more broadly than just in mathematics; further work should explore these issues for women in higher education more broadly.

Etzkowitz *et al.* (1992) describe graduate research as 'hierarchical and patriarchal. This is due, in part, to its origin in apprenticeship practices and a heritage of discipleship in which master scientists create successors in their own image as a form of asexual reproduction' (p. 159). Many of the graduate students educated at this elite institution will work as faculty at colleges and universities throughout the country, where they will be responsible for educating the vast numbers of students who will become teachers at the pre-college level. Since teachers' own classroom experiences shape their beliefs and knowledge about mathematics teaching and learning (Fennema & Franke, 1992; Thompson, 1992), we need to be concerned about the impact of graduate mathematics education on mathematics education at all levels. That is, if the survivors of this grueling educational environment teach the way *they* were taught, and the pre-service teachers they teach later teach the way *they* were taught, then it is alarming to consider the net effect of this model of graduate education on children learning mathematics in schools.

The mathematics community has been concerned with the state of doctoral education, including the small numbers of women and minorities completing the Ph.D., and the decreasing proportion of Ph.D.s awarded in the US to US citizens (National Research Council, 1992). In order to open the discipline of mathematics to a broader range of students, and to engage them in mathematics in meaningful ways, students need the means to participate in the practices of mathematicians in genuine ways, in the context of relations based on care among teachers, students and the discipline of mathematics.

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Note

1. A seventh woman was excluded because the issues she chose to explore in her interview were not relevant to the current study.

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