Supporting Women Mathematics Doctorates: Investigating the Community Elements of Successful Programs

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Abstract: This study is designed to help identify practices and strategies that encourage women to attend and graduate from university mathematics departments. It consists of three phases, the first two look at 15 different mathematics departments, providing a brief look at their recruitment policies and practices. The third phase examines three mathematics departments in depth. The researcher will spend two to three weeks at these schools. Wenger's (1998) communities of practice is the overarching framework of the study with pieces of the Carnegie Initiative of the Doctorate (Golde & Walker, 2006) adding a finer lens to the data analysis. The results of this collective case study will be reported both as the aggregate of the original 15 mathematics departments, and as a description of the three departments examined in depth.

Introduction

Research centered on women in Science, Technology Engineering and Mathematics (STEM) has largely focused on the reasons why women choose to leave STEM careers and fields of study (see Herzig, 2002; 2004a). But there are women who do not choose to leave, and are successful in their academic pursuits and careers. Also, there are mathematics departments that foster environments through recruiting policies and department dynamics in which women want to participate. Often, these programs are actively trying to increase gender diversity in their departments. As a result of increasing diversity within a specific program, these departments are influencing the diversity within the mathematics community itself, which is traditionally male, by recruiting and retaining women faculty and graduate students.

This study focuses on graduate mathematics programs with high percentages of women. This means that the 30% or more of the students graduating from these programs are women (Jackson, 2004a). By examining the practices of such mathematics departments, the researcher hopes to discover those practices which encourage women to attend and graduate from these

graduate programs with doctorates. Along with practices and strategies for recruiting and retaining women, the study will also investigate how women within those mathematics departments experience and perceive the departments' efforts and the relevance to their academic careers.

This paper addresses the issues surrounding women's under representation in graduate mathematics programs and as a result looks for solutions to increasing the number of women who participate. "Under representation" is a broad term and needs to be more clearly defined, because one can argue that women are not under represented and that their numbers have increased in graduate mathematics programs throughout the country over the last few decades (Jackson, 1991, 2004a). However, for the sake of this research, "under representation" of women means that the percentage of women studying graduate mathematics is less than the percentage women comprised in the US population (Leggon, 2006). This research centers on the graduate mathematics departments in doctoral granting institutions, because these universities carry out major gate keeping tasks by training the next generation of mathematicians as well as encouraging or discouraging students to pursue careers in mathematics (Leggon, 2006).

The main research question is: *what is a successful mathematics program in terms of recruiting and producing women with mathematics doctorates?* The study will attempt to answer this question by looking at the following sub-questions:

(1) What are the practices and strategies mathematics departments employ for recruiting women?

(2) What strategies do they use for retaining a high percentage of their female graduate students?

(3) How do the women within those programs perceive the recruitment and retentions practices and strategies?

(4) What are some of the socio-cultural aspects of the mathematics department women find supportive in their pursuit of the doctorate?

Framework

There is no single solution to increasing the number of women participating in STEM. Therefore, the research will take a holistic point approach to studying women in graduate mathematics. On such view is the theory of communities of practice and the role those communities play in recruiting and retaining women (Lave & Wenger; 1991; Wenger, 1998). The researcher chose the community of practice framework because humans are social beings and learning can be thought of as a social activity. The learner is expected to acquire their needs and interests from society. The understanding gained by the learner includes both formal and informal knowledge constructed through the social interaction and participation within different communities. A community of practice is a collective learning environment, which, over time, results in practices that reflect the pursuit of enterprises, such as becoming a mathematician, and the accompanying social connections within that particular group (Lave & Wenger, 1991; Wenger, 1998).

Another definition for a community of practice is "a group of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wenger, McDermott, & Snyder, 2002). Through examination of this definition, there are three key parts that leads the researcher to believe that mathematics departments in universities can be communities of practice. First, these departments have a large member base that is *passionate about the mathematics*. Graduate students and faculty members do not pursue fields in which they have little interest or motivation to study. Second, the graduate students and faculty *deepen their knowledge* about mathematics,

either through course work or research. Finally, students and faculty hopefully *interact* on a continuous basis, through collaboration or informal meetings. Membership within a community is essential to a social participation learning perspective.

Communities of Practice vary widely in both name and style within different departments. However, there are three basic tenets of a community of practice: domain, community, and practice (Wenger et al., 2002). Figure 1 shows the three elements in a Venn diagram. In the very center where the three elements all overlap is the community of practice. The Domain is the common ground and a sense of common identity that a group shares. Community is the social structure of learning. Finally, practice is the shared set of frameworks, knowledge, resources and tools (Wenger, et al., 2002). All three of these tenets need to be developed in parallel and are dynamic, such that new practices arise and old ones are thrown out (Wenger, et al., 2002).

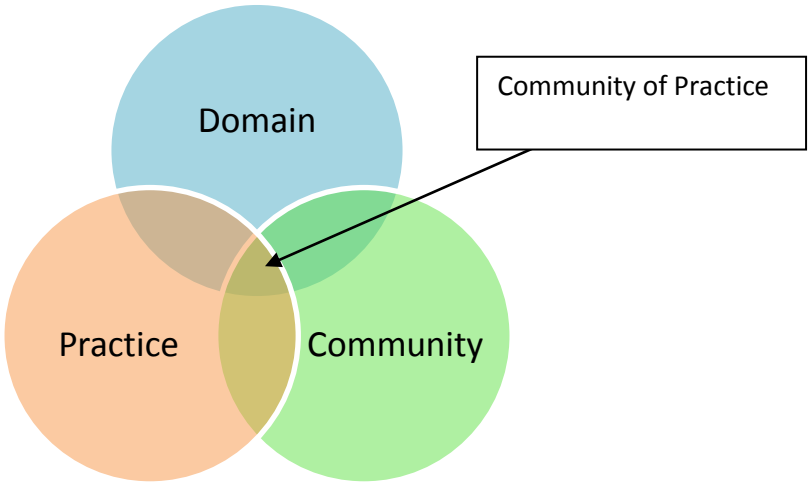

Figure 1: Relationship between Elements of a Community of Practice

A second aspect to the framework is depicted in the Carnegie Initiative on the Doctorate (CID). The Carnegie Foundation is an organization has taken an interest in the socialization process of doctorate students, particularly women. The CID is a "multiyear research and action

project to support departments' efforts to more purposefully align the purpose and practices of their doctoral programs" (Carnegie Foundation, 2006). Walker (2004) draws attention to issues that have existed for decades in improving doctorate studies in the United States. Some of these concerns have been issues for women in attaining graduate degrees in the STEM areas. For example, diversity with programs, quality and structuring of mentoring programs within departments, amount of time spent obtaining a degree, and interdisciplinary and multidisciplinary opportunities have been known and the topics of deliberations since the 1950s (Walker, 2004).

During the last few years, discussions about the state of doctoral programs in a variety of fields have been taking place (Golde & Walker, 2006). These discussions have focused on what it means to pursue a doctorate in terms of students learning both content and professionalism related to their specific fields. Leading the way in the discussions is the idea of a "steward of the discipline" (Golde, 2006, p. 9). A "steward of the discipline" is a phrase used to describe two major roles for graduate students. First, the students must know the content of the field in which they are studying, and second, the students have an obligation to pass that knowledge to others.

As a result of this discussion, several articles have been written stimulating conversation between mathematics departments across the country. In one such article, Bass (2003) explores the shifting nature of the meaning of mathematics as well as the purpose of doctoral programs in math. His discussion surrounds the subject of mathematics as a discipline versus mathematics as a profession and the effects of this difference on different student groups. Mathematics as a discipline is concerned with content knowledge and furthering mathematics research. Mathematics as profession encompasses a much larger idea; that knowledge generation, application, conservation, and transmission as well as the interaction with other areas of study

and universities within the larger society of academia (Bass, 2006). Further, Bass claims that doctoral programs should be designed to create a sense of cultural awareness of mathematics and its significance in the larger world of science and society (Bass, 2003). This is a relatively new path for doctorates in mathematics. Historically, "the doctoral program in mathematics was designed to be an apprenticeship into the research practice of an academic research mathematician" (Bass, 2006, p. 107). However, this model is not appropriate for all students. Academic institutions are the biggest employers of PhDs in mathematics, but almost on third of students take jobs outside of academia (Golde & Walker, 2006). Students that enter programs now demand career preparation as well as the skills and content knowledge necessary to become scholars in the field (Chan, 2006).

The stewards of the discipline as outlined by the Carnegie Initiative include three elements; generation, conservation, and transformation (Golde, 2006). Currently, the research has taken a turn that may suggest that these three aspects are important for the student to learn, but the responsibility lies on the faculty for preparing the students.

Research is the core of the doctoral program, therefore, generation of knowledge is essential (Golde, 2006). Some aspects of generation include:

- Make unique contributions to the field
- Ask important and interesting questions that are relevant to the field
- Conduct scholarly research
- Critically read and assess the work of others (Golde, 2006)

These features are difficult for students to complete without training. Therefore, the faculty has the difficult obligation for preparing students to conduct research, helping students gain experience by encouraging them to work on research projects within the department.

Another feature of the stewardship is conservation. Conservation is not solely concerned with preserving the knowledge of the past, but that doctoral students are aware and knowledgeable of the history of their field (Golde, 2006). Conservation includes:

- Understanding the history and basics ideas of the field
- Maintaining continuity, stability, and vitality of the field
- Mastering a balance between depth and breadth of knowledge
- Locate themselves and their work in the is the field
- Understand how the field fits into the larger span of academics (Golde, 2006)

Again, it can be argued that the faculty is responsible for teaching the students these things as well. Of course, after the graduate student has successfully completed the program they should know and be able to pass on the information in which they have learned.

Finally, transformation is the most abstract of the three categories. It states that knowledge and insight into the field have little significance alone. Students need to be able to characterize and communicate their knowledge and ideas effectively (Golde, 2006). In other words, the students will need to become teachers in their field and understand other fields and their relation to their own field (Golde, 2006). Bass (2003; 2006) expounds on the idea of transformation by describing the differences between mathematics as a discipline and mathematics as a profession. Bass (2003; 2006) defines the mathematics discipline as a body of knowledge with historical basis, language, and methods. The mathematics profession is defined as the community dedicated to the transmission of this knowledge, to creating new knowledge, and integrating this knowledge with other academic domains (Bass, 2003; 2006).

A community of practice differs from a formal department in that the goal of a formal department is to produce a product or service. In the case of university mathematics departments, the product or service would be the production of excellent mathematicians. Of special interest to this study is the production of women mathematicians. Understanding and

knowing the practices, expectations, and one's expected role in a community of practice eases one's entry into that community. Much of the knowledge about and within such communities is informal. Therefore, the information needs to be transmitted to new members by existing members (Bass, 2003; Chan, 2003; Herzig, et al., 2006; Wenger, 1998).

Each of these two frameworks, Communities of Practice (Wenger, 1998), and Stewards' of the Discipline (Golde & Walker, 2006) will be overlaid with issues concerning women's attrition from STEM fields from the literature. Table 1 outlines how these three areas will be related. Currently, the data analysis has not been completed therefore; this table represents predictions based on preliminary data collection and literature.

Table 1
Connections between the Frameworks

	Domain (Generation/Conservation)	**Practice (Conservation/Generation)**	**Community (Transformation)**
Community of Practice	Creates a common ground Makes people want to participate in the community	Socially defined ways of doing things in a specific domain Members master a shared body of knowledge	Social fabric of learning Interactions and relationships based on mutual respect
Stewards of the Discipline	Learning the practice of mathematics Conduct scholarly research Make unique contributions to the field Learn and create mathematics Balance between depth and breadth in the field		Develop identities as members of the community
Gender Issues (a prediction based on observations in the data and the literature)	Gender devaluation Career Trajectories Nature of the academic system	Women and men perform equally well at all academic levels Research does not support a difference in women and men's ability to learn to mathematics content	Advising Faculty/Role Models Nature of mathematics study Department dynamics Funding

Initially, it was felt that the three aspects of the Community of Practice and Stewards of the Discipline overlapped cleanly. However, it is believed that this is no longer the case, and the distinctions between Domain/Practice and Generation /Conservation are not so clear.

Methods

The researcher has chosen to use a collective case study design using 10 broad cases and 3 in depth cases (Stake, 2005; Tellis, 1997b). A collective case study is a "number of case studies that may be studied jointly in order to investigate a phenomenon, population, or general condition" (Stake, 2005, p. 445). This study qualifies in that the researcher is interested in the phenomenon that these university mathematics departments graduate large percentages of women doctorates. The data collection for the collective case study will allow the researcher to 'see' details within the study that otherwise she would not.

This study employs five sources of data collection: website evaluation, documents, interviews, surveys, and direct observation. During Phase I, the researcher will conduct website evaluations of the department websites looking for specific references to diversity. She will collect public documents, such as those found on the internet or college guide books, and internal documents pertaining to the departments' policies on recruitment and retention. Semi-structured interviews will be conducted with the Directors of Graduate Programs or administrative equivalents in all 10 university mathematics departments (UMDs). Phase II includes an online survey inviting all graduate students in the mathematics department to participate. Finally, Phase III involves semi-structured interviews of doctoral students and tenure track faculty members in three of the UMDs. The semi-structured interview structure will allow the researcher to be flexible and to adjust to the nature of the responses and follow different leads the participants provide (deMarrais, 2004; Fontana & Fey, 2000). The researcher will conduct three site visits to

UMDs for 2-3 weeks each. This data collection outlines a three phase process that can be viewed in Table 2. Each of the three phases is designed to elicit a different perspective of the mathematics department. During the first phase, the researcher will be examining the "public face" of the department through the website (Burack & Franks, 2006). This phase will also look at the department from an administration perspective through the Director of Graduate Programs.

Table 2
Research Design Overview

Phase I										
Collective Case Study Participants	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Data Collection	DGP Phone Interview Document Collection Website Evaluation									
Total Participants	10 Mathematics Departments 10 DGP phone Interviews									
Phase II										
Collective Case Study Participants	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Data Collection	Graduate Student Online Questionnaire									
Total Participants	≈300 graduate students Student participants will be from all 10 universities									
Phase III										
In-depth Case Study Participants	UA			UB			UC			
Data Collection	Faculty Interviews Graduate Student Interviews Non-participant Observations									
Total Participants	18 Interviews (3 men, 3 women at each university) 30 Interviews (5 men, 5 women at each university) 3 reflective journals (one for each university)									

Phase II is designed to gather information from graduate students in the mathematics about why they chose their university and degree programs. This online survey will provide a broad

sweeping glance at the university mathematics departments. The third phase was designed to gain an in-depth perspective of three of the departments.

Preliminary Observations

The data analysis has not been completed therefore only preliminary observations will be reported here. First, I will describe some observations from the online-survey, and second I will discuss some observations from the graduate student and faculty interviews from one specific department

Graduate Student on-line Survey

The graduate student online questionnaires had both multiple choice questions and open ended response questions. The first question that is important is "Why did you choose to apply and accept admission to this university?" This question had ten choices and a space for open ended responses. Each student could check as many of the ten choices as they felt appropriate or in which they considered a factor when choosing a graduate program. Currently, four universities have completed the questionnaire, two small private universities, and two large public universities. In total, 92 students have responded to this particular question (See Figure 2 for all responses). The top three choices for choosing to apply and accept admission were (1) Funding Opportunities with 77% of the students saying this was a factor (2) Location of the University was the second most chosen answer with 59% of the respondents stating this was a factor, and (3) the Reputation of the Mathematics Department with 44% of the students stated it was a factor. It is interesting to note that Funding Opportunities was the number one choice for each of the four university's graduate students. This may indicate that no matter where a student applies to graduate school funding is a primary factor in accepting admission to that institution.

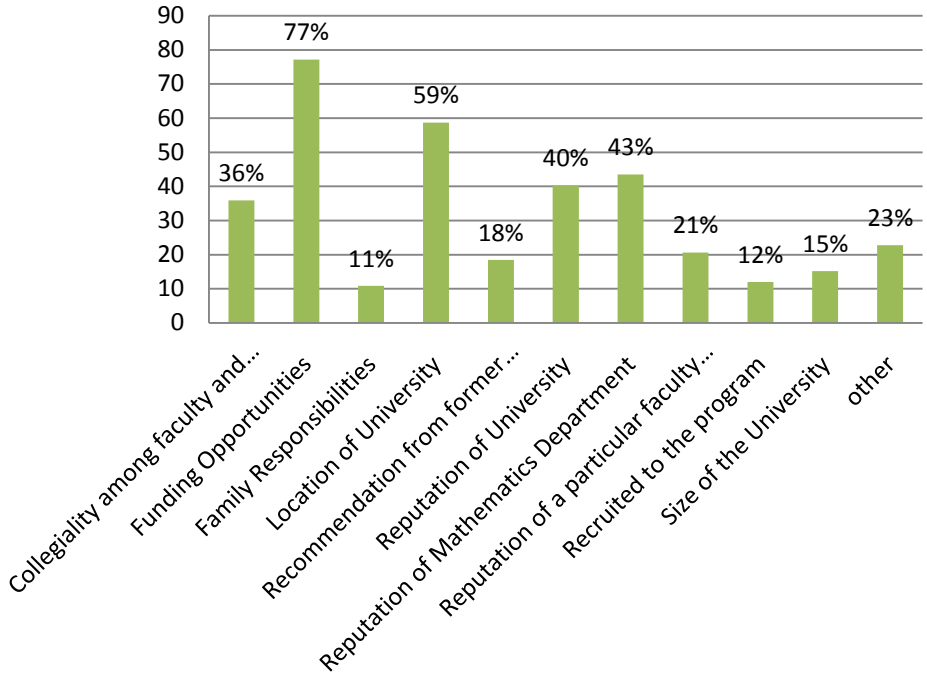

Figure 2: Question: Why did you choose to apply and accept admission to your university?

A second question with interesting conclusions asked how students felt about their decision to enroll in their current program. Answer choices included: (a) feel even more strongly that it was the right decision, (b) feel satisfied with your decision, (c) feel unsure if it was the right decision, and (d) regret your decision. The pie chart in Figure 3 shows how the students responded. It is clear that 70% of the students felt more strongly that their decision was correct or were satisfied with the decision they made. The three students who regretted their decision, only one provided a reason, "should have applied to a more difficult program". However, it seems that most of the students feel that their decision to attend their current programs was satisfactory.

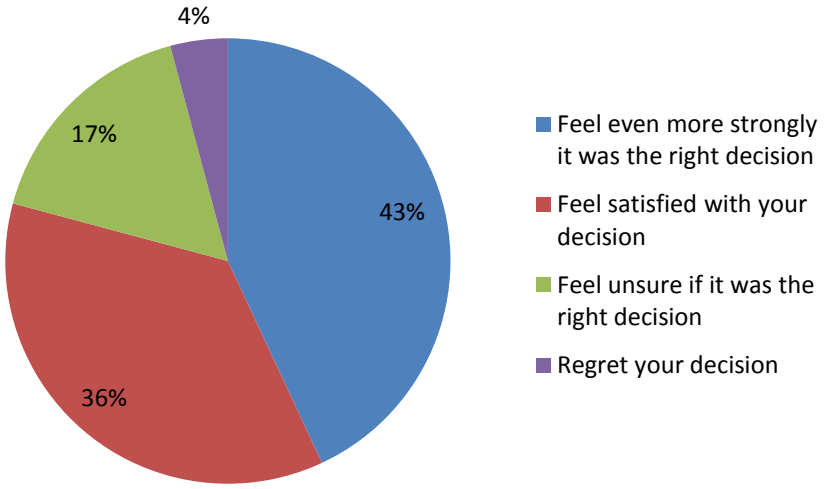

Figure 3: Responses to Decision Regarding Choice of Program

Interview Responses

Interview with 14 graduate students and 10 faculty members within a large public university has yielded five consistent themes prior to data analysis. First, the department is described as being friendly and a good fit with participants' personalities. They feel that they belong there. Second, the students state that they are collaborative among themselves. They work together, and are encouraged to do so by the faculty, on homework. The younger students also state that they seek out older students for help in courses in which the older students have already taken and might be able to explain the material differently from the professor. The students also spend time studying for their qualifying exams in groups. This collaboration helps the students to talk out problem approaches and solutions in a group setting, and to share ideas about the best methods for solving problems. Many of the faculty members also stated that they collaborated on common research projects as well. The faculty did not seem to collaborate outside their areas of expertise. However, one of the applied mathematics stated that she worked much more often with faculty outside the mathematics department.

Another common theme was that students who attended the recruiting weekend stated that it had an influence on their decision to come to this particular university. The students stated that the recruiting weekend afforded them the opportunity to meet both a significant number of faculty members as well as a large number of graduate students. During the recruiting weekend, time was afforded to the current graduate students to meet with prospective students without faculty members being present. This time allowed the prospective students an opportunity to discuss the program informally and gain the perspective of the current students. The recruiting weekend, also lets the prospective students "see" who is in the department, and get a feel for the climate of the department.

These interviews took place a large public university, in which there was a wide diversity of research interests among the faculty in both the pure and applied mathematics. The students felt that this gave them the opportunity to explore different topics either through communications with professors or during weekly seminars. This implies that the students are able to find a research topic that interests them, and a professor in which they feel comfortable working with.

Implications

Research that focuses on the positive aspects of mathematics departments and their graduation rates of women doctorates can influence several fields. The study is situated within higher education and the policies concerned with recruitment and retention of women. It is possible that this study could serve as an example for other gender diversity studies in STEM fields, improving the quality of STEM education at the doctorate level for women. Second, the study is focused on "success" stories in mathematics. This means that the results of the study could outline measures less successful mathematics departments might employ to increase the number of women in their programs.

In addition, this research can contribute to the mathematics education research by providing a glimpse of the educational environments that occur in the mathematics graduate programs with high percentages of women. This study does not look at how women learn graduate mathematics, but rather why they choose to pursue graduate mathematics at particular universities. At the graduate school level and even at the undergraduate level to some degree, mathematics becomes a choice. Women either choose to study it or they choose not to. This research will help us to understand why specific educational environments are appealing to large numbers of women choosing to study mathematics at the graduate level. If the community of practice framework is successful at the highest level of education for women, it may be beneficial to examine mathematics classrooms at the K-12 level using this type of framework for improving women's participation in mathematics.

The American Mathematics Society (AMS) reported 32% of doctorates awarded in the mathematical sciences (mathematics, computer science, and statistics) went to women during the 2005-2006 school year (Kirkman, Maxwell, & Rose, 2007). While the percentage of women earning doctorates has drastically improved over past decades (see Harmon & Soldz, 1963), there is still room for improvement. This work will provide a different perspective in the research on women in mathematics and STEM disciplines in general. Eventually, the knowledge gained here may help other departments increase their number of women graduate programs.

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