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AN EXPLORATION OF THE TRANSITION TO GRADUATE SCHOOL IN MATHEMATICS

A DISSERTATION APPROVED FOR THE DEPARTMENT OF MATHEMATICS

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To my Grandfather, who always knew I'd make it to this day

—but would have been proud of me even if I didn't.

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Chapter 1: Introduction

In Fall 2009, 2590 U.S. citizens began their first year of full-time graduate study in mathematics in the United States (Cleary, Maxwell, & Rose, 2010). For a number of personal and professional reasons, these students chose one from among 390 schools recognized as granting graduate degrees in mathematics (American Mathematical Society, 2011). What did these students expect as they entered this new chapter of their academic lives? Were they academically prepared for the rigors of graduate work? What can graduate programs do to promote success among these new graduate students? This work explores the transition to graduate school in mathematics—students' academic struggles and strategies, professors' expectations, and more. The implications of the findings for graduate programs as framed by the social theory of legitimate peripheral participation (Lave & Wenger, 1991) are also discussed. To begin, however, an introduction to the transition to graduate school in mathematics and to the department under study in this work is provided.

Problem

The academic transition from undergraduate to graduate school is undoubtedly a significant one in even the best of circumstances. Students find themselves adjusting to a new geographic location, forging new personal and professional relationships, and acclimating to the idiosyncrasies of their new academic program. Beyond this, they face higher academic standards, such as more demanding or increasingly abstract classes, and an ever-increasing reliance on their own study habits to master new material. Students also encounter new professional expectations, including attendance at conferences and department seminars, enthusiasm for a particular focus within their discipline, and motivation to study independently via reading courses. (See Chapters 3 and 4 for further information on the graduate students in this study and their transition experiences.) Furthermore, in many mathematics departments, graduate students are also expected to teach or assist in undergraduate courses as graduate teaching assistants. Park (2004) noted that graduate teaching assistants can struggle with their new dual status as both learners and instructors.

Beyond changes in coursework and professional responsibilities, students entering graduate programs in mathematics often experience an "abrupt change of status" during this transition (Bozeman & Hughes, 1999, p. 347). While their undergraduate records may be exemplary, these students often have trouble adjusting to the rigorous new environment of graduate school in mathematics. Setbacks, such as insufficient prerequisite knowledge or an inability to discern or meet a professor's expectations, may generate diminished self-esteem or even a desire to drop out of the program; this is particularly true when students lack the self-confidence, relationships, or skills to overcome these initial setbacks (Bozeman & Hughes, 1999; Portes 1998). These students must attempt to "find a place" in this new academic setting and overcome issues with content, relationships, and their own perceptions of their situation.

These issues impact departments as well: Students' struggles with the transition to graduate mathematics may negatively affect program recruitment, as admissions committees are less likely to admit applicants with similar backgrounds in the future. Retention of students is also impacted across the discipline as promising students may incorrectly assume they lack mathematical ability and leave the field forever. Finally, these struggles can affect the representation of women and minorities in such programs, as these groups are less likely to find the support structures they need to survive graduate school (Bozeman & Hughes, 1999).

Motivation

As issues relating to this transition can impact recruitment, retention, and representation, a better understanding of this transition is an important issue to departments, universities, and mathematics educators in general. After my own challenges with the transition to graduate school and several years of watching other graduate students struggle with this transition, I have realized that, despite current administrative efforts, the transition from undergraduate to graduate school in mathematics is an overwhelming one for many students to make. So, in addition to the need for this study shown through institutional data and research literature, I was also motivated to conduct this research based on my own and others' transitions to graduate school in mathematics.

Personal experience. Technically speaking, my transition into a graduate program in mathematics was relatively easy. Many of my cohorts were in my courses, so I easily fell into a built-in support system on campus. My officemate was also a member of my cohort (and had a background similar to mine), so we were able to discuss lectures and assignments outside of class without undue effort. However, because my undergraduate degree was in mathematics education and from a smaller university in a different state, I was uncertain of my academic preparation for graduate school. During my first year of graduate school, I seized the opportunity to take senior-level courses for graduate credit. While some material in these courses repeated things I had learned as an undergraduate, much of it was new to me. The reduced cognitive load in these courses did not make them “easy” for me; however, it helped me adjust to the other demands on my time and energy, such as my teaching assignment, during my first year of graduate school.

My defining experiences with the transition to graduate school actually came when I began taking coursework towards my Ph.D. qualifying exams during my second year in the graduate program. One of these course sequences (Sequence A) was similar to and a reasonable extension of a prerequisite sequence I had taken. Thus, the courses in Sequence A ended up being quite manageable for me with the support of my classmates and the instructor. However, the other sequence (Sequence B) was quite a shock to me. Although I had taken a prerequisite sequence during my first year of graduate school, I had not seen some of the foundational knowledge in other areas that Professor B expected. I spent the first several weeks of Sequence B incredibly frustrated with the course, afraid to go ask questions of Professor B due to my very limited understanding of the course material. My officemate was in a similar position. We tried to help each other as much as possible but quickly realized we had only marginally more understanding together than we had separately.

Fortunately, things eventually turned around, and I survived that year. More experienced graduate students helped me understand what Professor B’s expectations for homework and exams were, and I was able to work to meet them. As I got to know my classmates better, I was able to meet with those who better understood the course material and get assistance, sometimes in exchange for helping them in Sequence A. An advanced graduate student interested in this area even offered to tutor my officemate and me. By the end of that second year, I knew what it meant to utilize all possible resources to achieve what had seemed like an impossible goal—surviving Sequence B.

Although I had worked diligently as both a high school student and as an undergraduate, nothing had prepared me for how hard I would work during my second year of graduate school. I was fortunate to have friends and other contacts in the department who could offer their assistance and support during my struggles. However, I knew that many others in my program encountered these Ph.D. qualifying sequences during their first year in graduate school. I began to wonder how other students coped with the challenges of these courses—or if they even felt challenged at all—and I started paying closer attention to these new students and their transition experiences.

Others' experiences. As I observed and had informal conversations with new graduate students in my department, I noticed that they seemed to have wide-ranging transition experiences. While specific issues that caused my research participants to struggle during their transition are detailed in Chapter 4, in this section I will share my perceptions of my fellow students' experiences, which played a great role in motivating this research.

Some new graduate students had completed their undergraduate work at our graduate institution, so they were familiar with the prerequisites, professors, and other people and policies in the department and at the university. Their transitions appeared easier than most other students' to me. New students from schools of similar size, mission, and geographic area also seemed to have a relatively smooth transition into their graduate work. However, many students, particularly from smaller schools, seemed to really struggle with the transition to graduate mathematics at this university.

Lack of prerequisite knowledge became a problem for some students when their undergraduate prerequisites were not comprised of the topics or rigor expected by their graduate professors.

In addition, some students were advised to take nine credit hours (three courses) during their first year in addition to their teaching assistantship responsibilities. These students often struggled with the load of these courses during their first year. Other students felt like small fish in a very large pond; they craved the personal attention and departmental relationships they had known as undergraduates. Still others were over-confident in their abilities due to inflation of their undergraduate successes; the academic realities of graduate school often became too much for these students to bear. On top of all these factors, students' success seemed to be affected (at least in part) by the particular instructor they encountered in each course.

I watched all of these issues (among others) impact the success of many of my colleagues in the graduate program. I was disturbed by their hardships and tried to find ways to help where I could—offering advice, my old course materials and textbooks, and other resources and recommendations. Thus, when I was contemplating potential research directions, I realized that these transition experiences were precisely the phenomena that I wanted to explore more thoroughly. Through "a systematic investigation…designed to develop or contribute to generalizable knowledge" (Basic HHS Policy for Protection of Human Research Subjects, 2009), I could actually *do* something to help future students by utilizing current students' experiences with the transition to graduate school as motivation for my research.

Research Site

For this study, I conducted interviews and collected other data from both students and faculty in the Department of Mathematics at a large Midwestern research university (see Chapter 3). While the data collection site's identity is being concealed to protect the confidentiality of participants, relevant background about the department is provided in this section. The information contained herein comes from both institutional sources (e.g., the departmental webpage) and human sources (e.g., faculty and staff) in the department; however, in order to preserve anonymity, these "local" sources will not be cited throughout this document.

University structure. This university operates on a semester schedule, and courses are identified using a four-digit number. The first of the four digits in a course number indicates the expected class-year level of the course; that is, courses with 1000-level numbering are designed at a freshman level, 4000-level courses are designed for seniors in a major or minor, 5000-level courses are designed for master's students, and so forth. A standard semester-long course in mathematics earns three hours of credit. Graduate students with a teaching assistantship appointment are required by the Graduate College to enroll in a minimum of 5 credit hours per semester. (Other requirements in the program make six hours per semester the standard minimum enrollment for mathematics graduate students.)

Department structure. The Department of Mathematics sampled in this study consists of (at the time of data collection) 33 faculty members, nearly 70 graduate students, seven staff members, nine lecturers, and eight post-doctoral associates/visitors who instruct over 10,000 undergraduate students each year. The department's 33 faculty members are classified into 24 at the rank of Full Professor and nine combined at the Associate Professor and Assistant Professor ranks. Graduate students in the department represent a variety of U.S. states and other countries; in fact, international students account for about 39% of the graduate student body. Approximately 38% of the students in the department are female, while only three of the 33 faculty members (or approximately 9%) are female. The majority of the department's graduate students are supported as graduate teaching assistants (GTAs) in the department. Graduate students have also created and currently run several seminars in the department and have an active social, mentoring, and advocacy presence in the department via a graduate student organization.

Over the past 11 years, the graduate program in this department has grown in size from just over 20 students to just under 70 students. This growth was the result of concerted efforts by Graduate Directors and other departmental personnel to recruit students more aggressively, as well as the willingness of the Dean of the department's college to allow greater flexibility in the use of university funds to support graduate students. One component of these recruitment efforts has been a two-day event for prospective graduate students that includes mathematical talks, program information, interaction with current graduate students, and other activities. The department also provides a two-day orientation for new graduate students before the beginning of each Fall semester.

Now that the number of graduate students in the department has stabilized (due to physical space and budgetary restrictions), the department's focus in the graduate program has been on student retention and quality of life issues. In an effort to address these matters, administrators have conducted a series of surveys designed to assess graduate students' perception of key quality of life concerns. Administrators have worked to address issues identified in these surveys, such as fairness of workload in various teaching assistant assignments. The department has also increased its efforts to provide graduate students with professional development opportunities by encouraging seminar talks aimed at job searches, conference attendance, or professional skill-building. Finally, the creation of a graduate student organization has helped students have a sense of ownership in departmental activities and has provided informal mentoring through a teaching assistant evaluation program.

Graduate programs. This department offers three graduate degrees: a terminal master's degree program for students not planning to obtain a Ph.D. in mathematics, a Ph.D.-track master's degree consisting of core courses in preparation for the Ph.D. Qualifying Examinations, and a Doctor of Philosophy (Ph.D.) degree for students who enter with a master's degree or have completed the Ph.D. Qualifying Examinations. Students pursuing a Ph.D. in this department are required to pass three separate Ph.D. Qualifying Examinations in the areas of Abstract Algebra, Real Analysis, and Topology. Each exam (at the time of data collection) is offered twice per year (May and August) and is based on material from that year's 5000-level, two-semester sequence in the given area. These six "core courses" form the basis for the Ph.D.-track master's degree, as well as the common experience of participants in this study. Each "core sequence" rotates among selected faculty in that area of specialty. The faculty member in charge of a core sequence in a given academic year writes the corresponding qualifying examination for the subsequent May and August exam sessions.

Incoming graduate students are advised by a departmental advisor upon acceptance to the program: Students pursuing a terminal master's degree have a faculty advisor, while all other (Ph.D.-track) students are advised by the Graduate Director. Both student and faculty participants in this study described the difficulty of correctly placing incoming graduate students into the correct level of coursework (either the 5000-level coursework preparing students for the qualifying examinations *or* the prerequisite senior-level coursework for graduate credit) in each core area of study. While students may have the necessary prerequisite courses on their undergraduate transcripts, each university views the content associated with these courses in different ways. Thus, it is very difficult for a graduate admissions committee to determine what material a student has seen in their undergraduate work. (See Chapter 4 for more details about advising issues.)

Once students have passed all three qualifying examinations, they are allowed to form a Ph.D. Advisory Committee consisting of a Ph.D. advisor in their chosen specialty as well as other (mostly mathematics) faculty. The Ph.D. advisor takes over advising matters for the student for the duration of his or her degree. From this point forward, the student is considered to be part of one of two tracks for the Ph.D.:

- The *traditional option* of the Ph.D. program encourages students to pursue original research in mathematics, culminating in a dissertation representing these contributions to the field.
- The *Research in Undergraduate Mathematics Education (RUME)* option of the Ph.D. program encourages students to pursue original research concerning

an area of undergraduate mathematics education, culminating in a dissertation representing these contributions to the field.[1]

Before defending the dissertation, students must pass a second set of exams, called the General Examination, as mandated by the Graduate College. The number and format of these exams vary somewhat based on which Ph.D. track a student has chosen. However, in all cases, the General Examination consists of a written exam (or exams) and an oral exam, which is based on the content of the written exam(s) plus other course or research content as determined by the student's Ph.D. Advisory Committee. While these exams are not directly relevant to students' transition to graduate school, knowledge of this portion of the Ph.D. program will shed light on some student and faculty comments (as revealed in Chapter 4).

Prior Work

Many academic transition points, such as the transition from secondary to tertiary mathematics, have been studied extensively as stakeholders have tried to narrow the achievement gaps among various groups of students. For instance, Selden (2005) discussed this transition to collegiate mathematics, noting that new college students must often reconceptualize ideas from previous mathematical training (such as the idea of a tangent line) in order to incorporate them into the new, demanding educational structure they have encountered. As another example, Kajander and Lovric (2005)

[1] The "RUME" acronym is nationally recognized as a designation for mathematics education research pertaining to undergraduate and graduate students. Programs of research in RUME may be housed in either a Department of Mathematics or a College of Education, depending on the institution, and these programs also carry a wide variety of names. The generally accepted acronym is used here to protect the confidentiality of the institution under study (Special Interest Group of the MAA on Research in Undergraduate Mathematics Education, n.d.).

detailed McMaster University's efforts to address this transition through surveys of students' mathematical backgrounds, course redesign, and provision of a departmental review manual to enable students' voluntary preparation for their mathematics courses. They noted that students' motivation, ability to delve beyond surface learning, and secondary school preparation in mathematics were all key to the transition process. Transferring the ideas from these two studies to the transition to graduate school in mathematics identifies several potentially relevant issues in this transition process: undergraduate preparation, ability to both reconceptualize prior knowledge and dig deeply into new mathematical material, and a "bridge" review process prior to graduate work. However, other factors may impact the transition to graduate school that are not found in this body of work.

Despite research on other transition points and recent work devoted to the new mathematics graduate student as a mathematics instructor (e.g., Border, 2009; Luo, Grady, & Bellows, 2001; Speer, Gutmann, & Murphy, 2005), little work has been done with other areas of the transition to graduate school, such as the impact of academic or personal issues on the transition experience. Related work has been done by Carlson (1999), who explored the mathematical beliefs and behaviors of "successful" graduate students; she found that persistence, high levels of confidence, and the presence of a mentor during key periods of mathematical development all played a role in these students' "success." However, while factors affecting retention and student success certainly impact students' experiences in the first months of a graduate program, they are not sufficient to define the transition to graduate school. More recently, Duffin and Simpson (2006) reported on interviews with Ph.D. students designed to explore the transition from undergraduate to graduate work in mathematics in the United Kingdom's educational system and concluded that both undergraduate and graduate education could be modified to smooth this transition for different types of learners. Despite this work, no clear picture of the transition to graduate school in the United States exists.

One theoretical lens through which to view research on graduate students—legitimate peripheral participation (LPP) in communities of practice (Lave & Wenger, 1991)—shows great promise. Lave and Wenger (1991) provide LPP as "a descriptor of engagement in social practice that entails learning as an integral constituent" (p. 35). They also describe LPP as "the process by which newcomers become part of a community of practice" (Lave & Wenger, 1991, p. 29). In 2002, Herzig applied this framework to a qualitative interview study examining persistence in graduate school in mathematics. In this case study of one mathematics department, Herzig interviewed both current students in the doctoral program and some who had left the program, as well as faculty members in this department, to investigate factors influencing doctoral student persistence and attrition. Herzig found that legitimate peripheral participation both in departmental life and in the field itself encouraged persistence in a doctoral mathematics program. Although this framework promises to enlighten research on graduate students more broadly, further work is needed to determine the phenomena involved in the graduate education of mathematics students. Additional details about the studies mentioned above are provided in Chapter 2.

Research Questions

Building on the aforementioned work, the goal of this current study is to establish a clear picture of what happens during the transition to graduate school in mathematics in the United States so that further research can be done on the impact of various aspects of (or changes to) this process. Accordingly, the purpose of this case study is to investigate the transition new mathematics graduate students make from undergraduate school to graduate school in mathematics—the struggles they face, the expectations they must meet, and the strategies they use to deal with this new chapter in their academic experience. In particular, answers to the following exploratory research questions are sought:

1. *What happens during the academic transition from undergraduate student to graduate student in mathematics?* As shown above, the field of undergraduate mathematics education research needs a multi-faceted, holistic description of students' experience with the transition to graduate school. Exploring this transition through the eyes of graduate students and faculty members will shed light on the events, feelings, and resources impacting graduate students' transition. Specifically, I will look at how students' levels of preparation, expectations, observations of classroom environment, and access to and quality of assistance programs play a role in shaping this picture.

2. *How do professors' expectations of new graduate students' mathematical knowledge affect students' success?* Do the ways in which students determine and meet their professors' expectations play a crucial role in the level of success they attain in their first few months of graduate school? How do professors' expectations align with the undergraduate training students have received? To what extent does a failure to

comprehend or to be equipped to meet expectations can cause frustration for students and/or faculty?

3. *How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies?* What strategies, aids, or other support systems do new graduate students employ to adjust for a lack of background knowledge? How do other people play a role in helping these students adjust to their new academic environment? What strategies are most helpful or successful in the transition experience?

4. *How do attitudes, beliefs, and relationships play a role in the success of new graduate students in mathematics?* How does the transition to graduate school affect things or people outside students' "academic world"? What attitudes or beliefs are most helpful (or harmful) during the transition? How do relationships within or outside of the department affect the transition experience?

My intention with this research is to fill in some of the gaps in the literature about graduate student preparation for and experiences with the transition to graduate school in mathematics. With this increased understanding, we can then work to modify resources and policies for prospective and current graduate students accordingly to help make this critical transition as smooth as possible.

Conclusion

To summarize, while much research has been conducted regarding the transition from high school to undergraduate mathematics, very little knowledge exists about the transition mathematics students make from undergraduate to graduate work. This study is presented as a "first step" toward this knowledge. Based on the given motivation, I explored the transition to graduate school in mathematics in the case of the department described above in order to answer four research questions. In the next four chapters, I will lay out the details of this work.

In Chapter 2, I provide deeper connections between this study and relevant literature, as well as detail the theoretical framework of legitimate peripheral participation, which I later use to interpret the results of this study. In Chapter 3, I detail my research methods, discuss survey and interview materials, and specify measures taken to protect participants' privacy and confidentiality. In Chapter 4, I present data and resultant themes. Finally, in Chapter 5, I discuss the implications of and recommendations stemming from these themes—for prospective and current graduate students, faculty members, and mathematics departments.

Chapter 2: Literature Review

As noted in Chapter 1, the literature regarding the transition to graduate school in mathematics has been considerably limited. This chapter presents related work from a number of areas, including the general transition to graduate work across fields. Beyond this, the chapter explores relevant work from another transition point in mathematics education—the transition from high school to college mathematics—in order to identify aspects of this transition that may be related to the transition to graduate school. Next, key parts of the growing body of literature on graduate students as instructors are presented in order to explore this key non-academic factor in graduate students' transition processes. Then, the chapter looks more deeply into the few existing studies on mathematics graduate students' academic development and demonstrates that there is still a gap in the literature which will be addressed in part by this work. Finally, I discuss the framework of legitimate peripheral participation and the role it plays in the interpretation of my results (see Chapter 5).

Graduate Student Persistence

For many of the best and brightest college graduates, embarking upon a graduate degree has been identified as a new form of intellectual challenge not dissimilar to that of the beginning of undergraduate study (Lin & Humphreys, 1977). However, not all students who complete a bachelor's degree continue on to graduate study. According to Mullen, Goyette, and Soares (2003), students with more highly educated parents have had a greater likelihood of attending graduate school. Furthermore, the quality of a student's undergraduate academic performance (as measured by grade point average [GPA]), the choice of undergraduate major, and the type of undergraduate institution attended have also been identified as important factors in whether a student enrolls in a graduate degree program (Mullen, Goyette, & Soares, 2003).

However, the focus of my work is on the transition to graduate school—not how students are selected or which students are chosen, but *what happens* after they arrive at graduate school. The primary literature on graduate student persistence identifies several key factors that impact doctoral students' retention in or attrition from their graduate programs: personal characteristics, aptitude and achievement, financial support, and institutional involvement.[2]

Personal characteristics. Many individual attributes have been suggested as factors in students' persistence in their graduate studies. Attiyeh (1999) considered the effects of age, gender, ethnicity, and U. S. citizenship status on graduate persistence in the fields of biochemistry, economics, English, mathematics, and mechanical engineering. Although his data showed minor results within particular fields, he acknowledged that, across the population of graduate students from all five fields, "persistence seems to be more consistently linked to student aptitude/achievement characteristics and to financial support than to demographic characteristics" (p.38). Others have also considered the impacts of gender, age, and race on graduate students' persistence (see, for example, Bowen & Rudenstine, 1992; Girves & Wemmerus, 1988; and Tinto, 1993). Family background factors—such as socioeconomic, marital, and parental statuses—could also have played a role in retention and attrition (Girves & Wemmerus, 1988; Lovitts, 2001).

[2] The structure for this section is adapted from that used by Attiyeh (1999).

In addition to demographic characteristics, students' dispositions toward their field of study and the graduate school experience can also affect their persistence. For example, Lovitts (2001) found that "drive, passion, curiosity, love of the subject and one's research, dedication, and perseverance" (p. 27) were frequently listed by her participants as factors contributing to students' persistence. Beyond these characteristics, several authors have noted that the compatibility of the degree sought with students' goals and intentions in the field is also important (Bowen & Rudenstine, 1992; Lovitts, 2001) because these orientations set the context for all interactions during the degree program (Tinto, 1993). Furthermore, students' attitudes and interactions have been known to change over time, particularly as external factors, such as finances, health concerns, or family situations, clamor for students' attention (Lovitts, 2001; Tinto, 1993). These factors could affect whether students enroll with full-time or part-time status, another factor that has been associated with degree progress (Girves & Wemmerus, 1988).

Aptitude and achievement. Several authors have found that students' ability and prior academic achievements also affect their graduate education (Attiyeh, 1999; Lovitts, 2001; Tinto, 1993). Ability has been measured by undergraduate GPA, as well as quantitative, verbal, and analytical scores from the Graduate Record Examination (GRE; Attiyeh, 1999; Bowen & Rudenstine, 1992; Girves & Wemmerus, 1988; Lovitts, 2001). Achievement has been quantified using variables such as whether a master's degree was held at the beginning of doctoral study and the average score on the

Scholastic Aptitude Test of the student's undergraduate institution[3] (Attiyeh, 1999). Attiyeh (1999) found that, although students' undergraduate GPA did not play a major role in their graduate persistence, "it is apparent that the GRE General Test scores measure student characteristics that play a role in determining persistence" (p. 35).[4] Possession of a master's degree before beginning a doctoral program also identified students likely to persist in their doctoral study (Attiyeh, 1999). Furthermore, students who rank high for achievement and aptitude factors have tended to have greater financial support for their degree program, another key determinant of success (Attiyeh, 1999; Lovitts, 2001).

Financial support. Completion of a doctoral dissertation typically requires the candidate to expend much focused effort over an extended period of time. According to some authors, when a student's finances are limited, financial concerns (such as the need to work externally for support) have been known to inhibit the student's persistence toward completion of the degree (Bowen & Rudenstine, 1992; Girves & Wemmerus, 1988; Lovitts, 2001; Tinto, 1993). Attiyeh (1999) examined how the net amount of financial support (total support provided less tuition and fees paid by the student) and the form of that support (fellowship versus research or teaching assistantship) impacted students' persistence toward the Ph.D.; he found that these variables had "an important influence on a student's persistence independent of any role that a student's personal characteristics might play" (p. 37). Although Attiyeh (1999)

[3] According to Attiyeh (1999), this variable was "intended to serve as a measure of the quality of the student's pre-doctoral education" (p. 16).
[4] However, Bowen and Rudenstine (1992) did not find a strong correlation between GRE scores and completion rates in their study of doctoral students in the fields of English, history, political science, economics, mathematics, and physics.

found that the importance of the form of financial support varied among the different fields he sampled, Girves and Wemmerus (1988) and Tinto (1993) claimed that a research or teaching assistantship may be more beneficial to a student than a fellowship, particularly during the first years of graduate study. The interactions with faculty or other graduate students necessitated by the assistantship's responsibilities have also been known to play a role in degree progress (Girves & Wemmerus, 1988; Lovitts, 2001; Tinto, 1993). However, several authors have noted that because a fellowship allows a student to focus exclusively on research, these awards can have a particularly positive impact on students' persistence through the dissertation stage of the degree program (Bowen & Rudenstine, 1992; Tinto, 1993).

Institutional involvement. In his study of graduate student persistence, Attiyeh (1999) also considered characteristics of the graduate program, such as student/faculty ratio, the program's national rating, and the average GRE score of students in the program. He suggested that, other things being equal, students were more likely to persist in a more prominent or selective program (Attiyeh, 1999). However, others have found that objective characteristics of the program or institution are not the only "institutional" factors which contribute to doctoral students' success (see, for example, Lovitts, 2001; Tinto, 1993).

For instance, one crucial institutional or departmental factor that has been found to contribute to the retention or attrition of graduate students is the nature of the interactions the students encountered there (Lovitts, 2001; Tinto, 1993). In fact, Girves and Wemmerus (1988) found the level of involvement in the degree program—defined as "student participation in projects and other activities outside the classroom with faculty and with fellow graduate students" (p. 167)—to be related to degree progress. Moreover, Lovitts (2001) noted that, beyond having necessary interactions with other students and faculty members, graduate students must feel they are participating members of a *community* during graduate school. This membership also helped students obtain the tacit knowledge about departmental culture, identities, and values they may need to succeed in the program (Lovitts, 2001). However, several researchers have noted that this community has two facets: It is both academic and social in nature (Lovitts, 2001; Tinto, 1993).

Integration into the academic community has traditionally been a key focus of graduate education. Several authors have claimed that this integration is impacted by academic interactions with both peers and faculty in the department, including the relationship with the academic advisor (Bowen & Rudenstine, 1992; Girves & Wemmerus, 1988; Lovitts, 2001; Tinto, 1993). In fact, in her sample, Lovitts (2001) found that the support of both an involved, enthusiastic advisor and a community of graduate student peers contributed to these students' persistence. Bowen and Rudenstine (1992), Girves and Wemmerus (1988) and Tinto (1993) also noted that a student's advisor can contribute greatly to a student's persistence, since "faculty are the gate keepers to the scholarly professions. . . . They impart the norms and expectations" (Girves & Wemmerus, 1988, p. 171).

Researchers have also claimed that integration into the social community, while not requisite for obtaining the degree, can affect students' satisfaction with their experience in graduate school, the level of "fit" they feel with the field of study, and consequently, their decisions of whether to remain in the field (Lovitts, 2001; Tinto, 1993). Tinto (1993) claimed that the two types of community are inextricably linked and that both help doctoral students obtain skills needed to successfully complete the degree and enter the profession. Tinto (1993) further asserted that these interactions "serve to mold individual perceptions not only of community membership (i.e., integration), but also of the desirability of that membership and its value for one's career goals" (p. 239).

Although considerably more has been written on the impact of communities and interaction on graduate education (see, for example, Tinto, 1993), Lovitts (2001) offered the following summary regarding doctoral persistence and interactions with institutional communities:

> Graduate student attrition is a function of the differential distribution of structures and opportunities for integration into the prevailing community. The more structures and opportunities a community provides its members to interact and engage in the professional tasks of the discipline, the more bonds the members will have with each other and with the community, and the less likely its members will be to leave. (p. 49)

While some general research has been done regarding the transition to graduate school, very little has been done for the transition to graduate work specifically in mathematics. However, some transition points in mathematics have been studied extensively. The most familiar and relevant of these is the transition from high school to college mathematics. Below, some recent literature on this transition is explored. The aim in this section is to identify some recent developments in this area that may transfer to the current study[5] rather than to provide a comprehensive review of this transition.

Transition to Tertiary Mathematics

Researchers have claimed that the transition from secondary to tertiary mathematics is problematic for a majority of students (see, for example, De Guzmán, Hodgson, Robert, & Villani, 1998). In 2001, Leigh Wood proposed three key types of adjustments from secondary to tertiary mathematics: mathematical content, teaching and learning style, and personal and interpersonal adjustments.[6] Here, each of these areas of adjustment is visited briefly.

Mathematical content. Luk (2005) noted that there is a change from "elementary" to "advanced" viewpoints at the secondary–tertiary transition and that mathematical language, rigor, and abstractness become increasingly more present in this "advanced" mathematical study (see also De Guzmán et al., 1998; Gueudet, 2008). Selden (2005) also acknowledged that "not only are incoming students less well-prepared, the pace faster, and more rigour expected, but also at university, students frequently encounter new ways of conceptualizing previously well-known concepts" (p. 134). In response to students' increasingly varied levels of preparation for tertiary mathematics (De Guzmán et al., 1998; Kajander & Lovric, 2005), some universities have instituted bridging programs or courses to help students prepare for the "academic concepts, skills and attitudes" (Wood, 2001, p. 89) they will need in tertiary mathematics. McMaster University in Canada has even offered students the opportunity

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[5] While some of these issues may translate to the transition from undergraduate to graduate work, other issues affecting graduate students are likely unique to their specific transition (see, for example, Lin & Humphreys, 1977).

[6] De Guzmán et al. (1998) noted a similar set of concerns for the international audience.

to voluntarily prepare for university mathematics via a review manual mailed to them the summer before classes begin (Kajander & Lovric, 2005).

Teaching and learning style. Several authors have asserted that most new university students have "surface" approaches to learning mathematics, although those students with "deeper" learning approaches have more success with tertiary mathematics (Crawford, Gordon, Nicholas, & Prosser, 1998; Kajander & Lovric, 2005; Selden, 2005). In other words, these authors have found that students need to be able to reason flexibly about mathematical objects in numerous ways (Gueudet, 2008; Kajander & Lovric, 2005). These two approaches to learning have also been linked to students' views of instruction, learning, and the learning environment (Crawford et al., 1998), which affect student learning outcomes (Anthony, 2000). However, many university mathematics instructors have not been trained in pedagogical arts and have tended to consider mathematical preparation to be sufficient for effective instruction (De Guzmán et al., 1998). Nevertheless, researchers have called for "university teachers to be aware of the ways students experience the total learning context rather than just focusing on the mathematical content and presentation of their course" (Crawford et al., 1998, p. 466).

Personal and interpersonal adjustments. Upon entering a university, many students find themselves in a new place, with newfound freedom, without the friends they have bonded with for years, and amid "the anonymity of a large university campus" (De Guzmán et al., 1998, p. 755). Furthermore, they have to adjust to new relationships with their mathematics professors (De Guzmán et al., 1998; Luk, 2005), learn to work with their peers (Anthony, 2000; Luk, 2005), and overcome any prior negative experiences with mathematics (Crawford et al., 1998; Kajander & Lovric, 2005). Universities have long offered orientation programs to help new students adjust personally and socially to college life (Wood, 2001).[7] These programs have provided some factual information pertinent to university life and academic study but have typically been geared toward the affective, rather than the cognitive, domain (Wood, 2001).

Although much research has been conducted regarding the transition from secondary to tertiary mathematics, very little work has been done concerning new mathematics graduate students. However, one area in which the mathematics graduate student literature has grown considerably over the last two decades is in the study of these students as graduate teaching assistants. Here, some of the key findings from this body of literature—both inside and outside of mathematics—are presented, particularly as they pertain to the experience of the *new* graduate teaching assistant (i.e., the new graduate student in one aspect of transition).

Graduate Students as Teaching Assistants

The academic transition from undergraduate to graduate school is undoubtedly a significant one in even the best of circumstances. However, in mathematics departments, many graduate students have also been expected to teach or assist in undergraduate courses as graduate teaching assistants (Friedberg, 2005; Speer et al., 2005). For most new graduate students, this was their first experience with teaching, and it occurred in the environment of undergraduate mathematics, an important component of postsecondary education (Speer et al., 2005). Furthermore, many

[7] De Guzmán et al. (1998) posited that these orientation activities could take place in the secondary school or even in the university mathematics classroom.

beginning graduate students have not given much consideration to the role they will hold as mathematics teachers (Friedberg, 2005). While most universities provide training for teaching assistants to help them prepare for their role as instructors, this training has not always been discipline-specific, its duration has varied widely from a few hours to a required semester-long course, and it has included topics ranging from generic teaching skills to analysis of teaching assistants' videotaped lessons (Friedberg, 2005; Park, 2004). Exploring the aspects of this transition to teaching is an important issue to departments, universities, and mathematics educators in general.

Experiences across fields. Despite current administrative efforts, the transition from being solely a student at the undergraduate level to teaching for the first time as a new graduate student is still an overwhelming one for many students to make. Park (2004) agreed that graduate teaching assistants can struggle with their new dual status as both learners and instructors. This ambiguity of status has often created difficulties for teaching assistants as they have worked to balance being both instructional employees and research apprentices at the university (Nyquist et al., 1999; Park, 2004). In general, even their roles as teaching assistants have been somewhat nebulous: Teaching assistants have performed duties ranging from grading papers with no student contact to running an independent section of a course (Luo et al., 2001; Speer et al., 2005). Furthermore, graduate assistants' assignments have not always been determined with due consideration of the teaching assistant's background, content knowledge, or prior teaching experience (Park, 2004).

While some professional development opportunities for teaching assistants have tended to be available in a number of disciplines (Friedberg, 2005; Lowman & Mathie, 1993; Speer et al., 2005), Nyquist et al. (1999), in their multi-site study of doctoral and masters students, observed that "graduate students report that they would like additional forms of support for their professional development as teachers" (p. 24). Indeed, it has seemed that after learning to use classroom resources, to communicate effectively, and to demonstrate very basic instructional competence, no "uniform next topic" exists in teaching assistant development (Friedberg, 2005, p. 843). Gaff and Lambert (1996) have called for a more formalized mentoring system for graduate teaching assistants as well as discipline-specific professional development seminars to build on the common "one-shot" teaching assistant preparation programs (p. 42).

With stakeholders holding institutions increasingly accountable for undergraduate education, the quality of teaching assistant training has become more important for universities and their reputations for undergraduate education (Austin, 2002; Lowman & Mathie, 1993; Luo et al., 2001). Moreover, many of today's faculty members served as teaching assistants, and this experience was often their primary preparation for their instructional roles as faculty (Lowman & Mathie, 1993; Speer et al., 2005). Since the teaching practices adopted by graduate students during their assistantships may guide their teaching for years to come (Speer et al., 2005), several authors have claimed that the future of undergraduate mathematics education will be shaped by current teaching assistant development (Lowman & Mathie, 1993; Speer et al., 2005). On one hand, teaching assistant experiences have tended to provide opportunities to support and guide the teaching assistant's instructional practices. On the other hand, without proper preparation, teaching assistants have had negative initial teaching experiences that can have a lasting impact on their attitudes toward teaching, instructional skills, and job satisfaction (if they continue in instructional roles; Lowman & Mathie, 1993; Speer et al., 2005).

Experiences in mathematics. Beyond commonalities across disciplines, some studies have examined the role of the specific discipline of mathematics in determining instructional roles and teaching strategies. For example, Luo et al. (2001) found that instructors in "hard" disciplines, such as the natural sciences, mathematics, and engineering, tend to adopt a more formal instructional style and emphasize facts, principles, concepts, and knowledge acquisition (as opposed to knowledge application) more than their "soft" discipline counterparts, such as English, political science, and education. Teaching assistants in different disciplines have also differed in the problems and concerns they experience with respect to their teaching (Luo et al., 2001). Because mathematics has often been seen as a "critical filter" (Sells, 1978, p. 28) that serves as "a gateway to technological literacy and to higher education" (Schoenfeld, 2002, p. 13), it seems important to examine the mathematics graduate teaching assistant as a separate entity from other disciplines' graduate teaching assistants.

Some of the issues confronting mathematics graduate teaching assistants are analogous to those confronting graduate teaching assistants in other disciplines. Mathematics teaching assistants have played key roles in undergraduate mathematics instruction, particularly at larger universities, and they are the principal source of future mathematics faculties (Speer et al., 2005). As with other disciplines, "mathematics will do better if the next generation of mathematicians on university faculties are excellent teachers" (Friedberg, 2005, p. 842). However, mathematics instructors (including graduate teaching assistants) have faced additional challenges such as the decline in degree production in STEM (science, technology, engineering, and mathematics) majors and the weak mathematics skills many freshmen bring with them to college (Thiel, Peterman, & Brown, 2008). Furthermore, many graduate students in mathematics have had few experiences with students unlike themselves – that is, "students who study mathematics for different reasons than they did or, even more strongly, students who find mathematics frightening or uninteresting" (Friedberg, 2005, p. 843). Without this ability to relate to students, forming the relationships with students needed for effective classroom communication is next to impossible. Friedberg (2005) argued that a key part of teaching is "what you say and how you say it" (p. 843), that teaching and communication skills are of concern in all of the "hard" disciplines (i.e., the sciences, mathematics, and engineering), and that discipline-based efforts were likely to be the most effective way to address this concern.

Whereas literature on the development of K-12 mathematics teachers is both broad and deep, the current literature on mathematics graduate teaching assistants is still relatively sparse, and not much is known about the "teaching practices, beliefs, challenges, needs, and understandings of mathematics and teaching" that teaching assistants possess (Speer et al., 2005, p. 75). Mathematics graduate teaching assistants are often assigned to lower-division courses, so they serve a wide range of the university population, thus impacting many aspects of the university community's experiences with mathematics (Speer et al., 2005). The importance of graduate teaching assistants has not been entirely overlooked, however: In the past two decades, mathematics educators have begun studying teaching assistants and creating preparation and development experiences for them (Friedberg, 2005; Speer et al., 2005).

Consequently, the mathematics education community remains hopeful that future research can help resolve some significant concerns related to mathematics graduate teaching assistants and, by association, the transition to graduate school in mathematics.

Transition to Graduate Mathematics

While research on graduate students as instructors continues to increase considerably, very little research has been reported on the academic success, cognitive processes, and other transition issues of the graduate student as *student.* However, the key related studies in this area are presented in some depth this section, since they are most closely related to this research. These studies typically fall into one (or both) of two categories: graduate students' interactions with mathematical content or graduate students' interactions with the mathematical community they encounter in graduate school. This section addresses both types of work.

Interactions with content. In the United States, doctoral programs in mathematics have typically begun with one or two years' worth of foundational coursework before any research is attempted.[8] Thus, investigating students' interactions with mathematical content has been considered as one way to get a glimpse into their transition experiences. Carlson (1999) did this by observing the problem-solving behavior of six graduate students on five untimed mathematical tasks. Interviews with these students also addressed their histories with solving problems, their mathematical knowledge, and their plans for continuing study in mathematics. Included among

[8] Bass (2003) outlined a traditional path to a doctoral degree as consisting of all or most of the following: one or two years' worth of foundational coursework, qualifying examinations, further (elective) coursework, selection of an area of focus, a preliminary research examination, doctoral research, foreign language reading proficiency, and the dissertation defense. He noted that this process typically takes four to seven years to complete.

Carlson's (1999) findings were the beliefs that: "mathematics involves a process that may include many incorrect attempts; . . . individual effort is needed when confronting a difficulty; [and] students should be expected to 'sort out' information on their own" (p. 254-255). In their interview exploration of three advanced mathematics graduate students' mathematical practices, Smith and Hungwe (1998) also noted the importance of "disciplined guessing" (p. 45) or the process of conjecturing and verifying, as part of this multi-attempt-driven mathematical progression.

The idea of independence evident in Carlson's (1999) work was also echoed in Duffin and Simpson's (2005, 2006) interview study of thirteen Ph.D. students' transition to independent graduate study in the United Kingdom. Although the graduate school experience has been quite different in the United Kingdom than in the United States,[9] the transition from undergraduate to graduate work has still involved adapting to the learning expectations of the new environment. Duffin and Simpson (2006) discussed the effect this had on two types of "undergraduate" cognitive styles—natural and alien—identified in their sample; they also noted that cognitive styles seemed inextricably linked to the levels of cognitive empathy displayed by their participants (Duffin & Simpson, 2005). They further argued that departments should work to lessen the differences between the undergraduate and graduate experience in order to smooth this transition for students of all cognitive styles. In particular, Duffin and Simpson (2005) proposed that providing opportunities for students to work together during their

[9] Duffin and Simpson (2006) note that traditional Ph.D. programs in the United Kingdom often have no coursework requirements. Students spend three years working independently to produce a "single, substantial dissertation of no more than 100,000 words" (p. 236).

undergraduate experiences can help them develop both cognitive empathy and a cognitive style that is better suited for independent graduate work.

Another key finding in Carlson's (1999) work was that the successful graduate students in her study all possessed "exceptionally strong persistence" (p. 255) and "high mathematical confidence" (p. 256). They were also willing to spend the necessary time to complete complex mathematical tasks. Herzig (2002, 2004a) noted that authentic participation in the academic and social communities of the department was critical to achieving this persistence—particularly among women and other minorities in the field. She also explained that "students' tendency to persist is decreased when they are faced with failure that they perceive to be beyond their control" (Herzig, 2002, p. 204). Thus, the persistence linked to successful graduate students can be contingent upon a number of things in a graduate student's circumstances and community.

Interactions with community. Herzig (2002, 2004a, 2004b) emphasized the importance of community in the mathematics graduate school experience in her reports of interview data collected from 18 graduate students and 10 faculty members at a large, public research university. She noted that graduate student cohorts that had bonded more closely had lower attrition rates than their counterparts (Herzig, 2002). Furthermore, Burton (1999) found that mathematicians emphasized collaboration in their own research practices; thus, a sense of community in graduate school has been proposed as a way to help prepare students for their graduate research experiences and/or post-graduate careers (Chan, 2003). Relationships with more advanced graduate students have also been suggested as an aid to new students who are learning to navigate the graduate school culture (Chan, 2003).

Beyond relationships with their peers, relationships with faculty members have also been considered crucial to students' success (Bozeman & Hughes, 1999; Carlson, 1999; Herzig, 2004b). In particular, several articles (e.g., Carlson, 1999; Chan, 2003; Herzig, 2002, 2004b) have emphasized the importance of faculty (or other) mentors to students' success. Chan (2003) noted that faculty mentors could help "train both the researcher and the scholar" (p. 901) by offering career advice along with tips for approaching independent research. Even mentors encountered before graduate school have been found to have a positive impact on students' problem-solving abilities or interest in mathematics (Carlson, 1999). Moreover, while a supportive mentor has been considered a positive influence in a student's decision to persist toward an advanced degree in mathematics, an unsupportive or incompatible relationship with an advisor or mentor has been presented as a common cause of attrition (Herzig, 2002, 2004b).

However, forming individual relationships during the graduate school experience may not be sufficient. Herzig (2002) claimed that "student *participation* in mathematics and their *integration* into the mathematical community are important to their success" (p. 198). At first, graduate students may not be able to participate in the most advanced functions in the mathematical community (such as active engagement in faculty-run seminars), but their participation can increase and evolve over time (Herzig, 2004b). More importantly, as they increasingly become part of the professional culture in mathematics, they are in a position to acquire the "tacit knowledge" or "unspoken norms by which the discipline operates" (Herzig, 2004b, p. 389). Bass (2003) additionally observed that a Ph.D. mathematician is expected to have "a professional identity founded on a deep enculturation into the intellectual traditions of the discipline"

(p. 773), but he also admitted that most graduate programs do not provide sufficient professional development in the skills and attitudes necessary to form this professional identity. He further noted that mathematicians belong to communities of researchers in their areas of specialization, communities of colleagues in university mathematics departments, and other communities within the “larger society” (p. 774), so mathematicians need a wide variety of skills, knowledge, and attitudes to be effective members of all of these communities. Students’ participation in the mathematical community, then, is a complex endeavor: They must prove themselves in some areas (such as coursework) before being allowed access to other areas (such as research; Herzig, 2002). Thus, in an interesting cycle of integration, students’ participation in a mathematical community allows them greater access into that same community. However, without participation in such a community, they might lose opportunities to develop the skills needed to participate in that community. This idea is discussed further in the next section.

Despite the work with mathematics graduate students detailed above, the key phenomena in the transition to graduate school have not yet been clearly identified. One goal of this current research has been to explore those phenomena and to delineate the key features of this transition. However, a somewhat more practical application of this research could involve using those findings to suggest changes or improvements to facilitate the transition to graduate work. To make these findings more palatable to departments and administrators, and more relatable to the broader field of educational research, I will interpret these findings through the framework of legitimate peripheral participation (LPP) in Chapter 5. For convenience, however, I will detail the theory of LPP in the section below.

Legitimate Peripheral Participation

The concept of legitimate peripheral participation (LPP) was popularized in 1991 with the publication of the book *Situated Learning: Legitimate Peripheral Participation* by Jean Lave and Etienne Wenger. This work sought to expand upon the apprenticeship model of learning into a more general social theory of learning. The theory of legitimate peripheral participation, then, was developed to address "the process by which newcomers become part of a community of practice" (Lave & Wenger, 1991, p. 29). Since all activity—including learning—is somehow situated among the participant's social knowledge, Lave and Wenger (1991) claimed that true learning "occurs through centripetal participation in the learning curriculum of the ambient community" (p. 100) rather than through simply gleaning the factual knowledge or skills necessary to function within a domain. That is, the focus in the theory of LPP is on the individual as a participant in social practice, rather than on the individual as an exemplar of cognitive processes.

Basic components. The term "legitimate peripheral participation," as it describes individuals' involvement in a community, can be understood by examining its component words (Lave & Wenger, 1991): First, a learner, or apprentice, must be allowed to truly take part—legitimately participate—in his master's craft. He must do things relevant to the task at hand, but the key is that he must *do* things—not just watch the master or learn important facts. Certainly, an apprentice is not skilled to do all aspects of the master's work; this is where peripherality comes into play. The learner must be allowed (or taught, depending on the nature of the craft) to do some small tasks which are legitimate components of the goal to be achieved. These tasks may be peripheral to the ultimate goal (such as the finishing stitchwork on a tailor-made suit), but the learner should participate nonetheless. Lave and Wenger (1991) noted the following:

> Newcomers' legitimate peripherality provides them with more than an "observational" lookout post: It crucially involves *participation* as a way of learning—of both absorbing and being absorbed in—the "culture of practice." An extended period of legitimate peripherality provides learners with opportunities to make the culture of practice theirs. (p. 95)

One significant aspect of LPP is that it functions as a way for apprentices to become members of the community of the master practitioners as well as participating in the activities of that community. It is this community which ultimately confers legitimacy on the apprentice through its acceptance and interaction (Lave & Wenger, 1991). So, increased involvement with legitimate tasks leads to greater acceptance from the members of the community; indeed, full membership in the chosen field "involves not just a greater commitment of time, intensified effort, more and broader responsibilities within the community, and more difficult and risky tasks, but, more significantly, an increasing sense of identity as a master practitioner" (Lave & Wenger, 1991, p. 111). Thus, learning and identity are inseparably intertwined in the theory of LPP.

Communities of practice. After this seminal work by Lave and Wenger, the idea of an apprenticeship model within communities of practice began showing up more frequently in a number of settings. In particular, the importance of community in graduate education began to be emphasized in the years following this work (see, for example, Tinto, 1993). However, the key explication of the ideas surrounding communities of practice within this social theory of learning was given by Wenger (and colleagues) subsequent to the emergence of LPP.

Lave and Wenger (1991) defined a community of practice as "a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" (p. 98), whereas Wenger, McDermott, and Snyder (2002) claimed that "communities of practice are groups 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" (p. 4). In either definition, however, the main idea is that of interactions or relationships between people and the activities, tasks, or facts at hand. Communities of practice could even include commonplace examples, such as a family unit or technical society, that individuals experience each day but may not consider as opportunities for learning. Yet, Wenger (1998) noted that "learning is. . . . part of our participation in our communities and organizations" (p. 8) as tacit knowledge is passed among members through informal interactions. Thus, a community of practice can be viewed as an institution of learning, where the learning process occurs through social interaction and participation within the community.

Wenger et al. (2002) stated that a community of practice consists of three main elements: "a *domain* of knowledge, which defines a set of issues; a *community* of people who care about this domain; and the shared *practice* that they are developing to be effective in their domain" (p. 27). Together, these elements form an architecture for creating and disseminating shared knowledge within this community. Furthermore, when these three components are all functioning correctly, both "newcomer" and "old-timer" participants in the community have a place to participate legitimately and contribute to the practice at hand (Wenger et al., 2002).

Communities of practice also help individuals progress toward future full membership in and identification with the community; that is, the sharing of information and interactions serve as "an investment of a community in its own future, not as a reproduction of the past through cultural transmission, but as the formation of new identities that can take its history of learning forward" (Wenger, 1998, pp. 263-264). Wenger (1998) further argued that the transmission of skills and information is secondary in importance to this process of identity formation among community members. However, identity and learning do work together, he claimed: Knowledge becomes part of (and manifests itself through) a learner's identity within the context of participating in the community (Wenger, 1998). More experienced community members can help this identity formation by fully engaging with the community and inviting new members to participate.

Applications to graduate mathematics. While the concept of legitimate peripheral participation within a community of practice has been applied to numerous settings in business and beyond, it has also been linked to graduate education (Tinto, 1993) and even the specific experiences of mathematics graduate students (Herzig, 2002, 2004a, 2004b). This section focuses on the work of Herzig and how the applications of LPP and communities of practice may influence the interpretation of results in my research. In these applications, the graduate student is typically considered the "apprentice" or "learner" from above, and faculty members generally fill the role of the master practitioner. The domain in question is mathematics, the community is the mathematics department (or the profession at large), and the practice is that of professional mathematics (teaching and scholarship).

In learning to conquer mathematical content, understand the norms of professional mathematics, and fit in to the mathematical community, Herzig (2004b) claimed that graduate students needed to learn to "*think, act*, and *feel* as mathematicians do" (p. 389). In accordance with LPP, she asserted that access to legitimate mathematical experiences was crucial to opening the discipline of mathematics to more students (Herzig, 2004b). Through participation in these social and academic practices, students learned more of the tacit knowledge about how to "be" a mathematician (Herzig, 2002, 2004a). However, many graduate programs in mathematics have been configured so that students begin the degree by completing coursework and exam requirements and are only exposed to research (a key component of professional mathematics) much later in the degree program. This practice "limits [the students'] ability to learn to be mathematicians" (Herzig, 2002, p. 204), since becoming a full participant in the chosen community is key to full integration into and identification with that community (Herzig, 2004a; Lave & Wenger, 1991).

Herzig (2002, 2004a) further noted that some students' attrition from graduate mathematics could also be related to community interactions: If students are unwilling or unable to meet the implicit expectations placed on them by mathematical culture, or if they cannot reconcile these expectations with those of another community (such as a family or other outside organization), students may not persist through a graduate degree. This has been especially problematic for students from underrepresented groups who try to fit into a mathematical culture that has not been structured around their specific needs (Herzig, 2002, 2004a). However, “experiences that enhance students’ membership in the social and academic communities of their programs strengthen their goals and commitments, which in turn increase the likelihood that they will persist” (Herzig, 2004a, p. 176). The goal, then, seems to be to provide students access to such experiences as soon as possible after entry into a graduate program.

Conclusion

Because research in mathematics education beyond the K-12 level is a relatively new field, many of its phenomena have had little systematic study; the transition to graduate school is no exception. As evidenced above, very little is known about this transition, although some work has been done in related areas, such as the transition to graduate school across various fields, the transition from secondary to tertiary mathematics, and graduate students’ roles as new instructors. In the interest of closing this gap in the knowledge of the field and of better understanding this transition through the words of those who have experienced it, an exploratory qualitative study is needed. In Chapter 3, the methods and materials used to conduct such a study are presented. The results from this study are laid out in Chapter 4, and a discussion of these results, using the interpretive framework of LPP (as detailed above), follows in Chapter 5.

Chapter 3: Methods

As discussed in Chapters 1 and 2, very little work has been done regarding the transition to graduate school in mathematics, despite work done for other critical transition points. So, in order to study this key educational transition more thoroughly, the transition experience must first be thoroughly explored. Because key phenomena have not yet been identified, an exploratory qualitative study was chosen in order to “uncover and understand” those phenomena (Strauss & Corbin, 1990, p. 19). Participants’ words—from more than one perspective on the transition—were crucial to the understanding of this transition experience. The rest of this chapter details the methods and materials used in this study and provides rationale for using these tools to explore the transition to graduate school in mathematics.

Research Design

For this project, a case study design was chosen in order to focus on a single “bounded system,” or case, through “detailed, in-depth data collection involving multiple sources of information” (Creswell, 2007, p. 73). The bounded system in Creswell’s definition refers to the boundaries that limit the case, such as time and place, as well as the interrelation of the parts of the case to form a unified system of experience of the issue at hand—in this case, the experience of the transition to graduate school in mathematics (Creswell, 2007). The case selected for this study is that of the Department of Mathematics at a large Midwestern research university, specifically focusing on those members of the department who have been involved with graduate student induction and retention in recent years. This includes students who have enrolled in certain standard Ph.D.-track, or “qualifying,” sequences of courses, as well as faculty members involved with these courses or with graduate-student-related administrative roles. This case study is also considered to be what Stake (2000) calls an "instrumental case study," because this particular case is being explored to "provide insight into an issue," not because it has specific intrinsic characteristics (p. 437). To examine my subjectivities related to this particular case, please see Appendix A.

An exploratory single-case study was chosen to delve into the in-depth meanings of one mathematics department's experiences with the transition to graduate school. To fully explore these experiences, several types of data pertaining to the transition to graduate school were collected: student surveys, student and faculty interviews, and program information. The student surveys collected basic data on potential participants' gender, year of program entry, and educational experience at this university to determine an appropriate sample with whom to conduct interviews. Using student interviews to ask specific questions about participants' transition experiences, as well as faculty interviews to provide a complementary perspective on this process (following Herzig, 2002), helped elicit a variety of viewpoints regarding students' transitions to graduate school. These varied viewpoints provided the most comprehensive look at students' experiences in this department in order to best understand the transition to graduate school in mathematics. Finally, the program information was used to provide a frame of reference for the department, graduate programs, students, and faculty encountered in this study.

While a case study of one department prohibits cross-case comparisons on a "case" scale, individual participants' experiences and observations can be compared and contrasted to create a more holistic picture of the "typical" transition experience in this department. In keeping with a post-positivist stance, the “truth” derived from participants’ accounts will not be absolute, but the data can still show how student participants describe and perceive aspects of their transition experiences and help construct a valuable portrait of this experience to aid admissions, advising, graduate student life, and other aspects of mathematics departments and universities in preparing for and supporting new graduate students in mathematics.

A case study design meshes well with a post-positivist philosophical stance in other ways as well. In order to uncover the full extent of participants’ experiences, interviews and other supporting data were used to allow student participants to share their personal recollections and feelings about their transition to graduate school. Faculty data supplemented and offered new perspectives on issues raised by students. This in-depth collection of data related to participants’ experiences as new mathematics graduate students will provide a holistic, rigorous portrait of participants’ views and experiences in this area. While, in a manner consistent with the constructionist epistemology, the participants’ recollections will be colored by their personal views of these experiences and the meanings they have constructed based on those experiences, these recollections are the only way to obtain the type of useful information needed to get a “true” picture of these experiences. These, and other constructed meanings regarding educational phenomena, are particularly useful in creating theories, informing stakeholders, and shaping policies and procedures—aspects of this area of study that are currently deficient in the literature (see Chapter 2).

Participants

This study was designed as a reasonably small case study in order to focus on gathering in-depth information from each of the individuals interviewed. Thus, the sample size was kept low (13 graduate students and eight faculty members) and focused on particular participant characteristics during the sampling process. This process is detailed below.

Students. To recruit graduate student participants for this study, an email was sent (Appendix B) to all mathematics graduate students at this university inviting them to participate in a brief online survey related to this project (Appendix C). This survey served to collect basic demographic and academic data about potential interview participants as well as gauging students' interest in participating in this study. A follow-up email (Appendix B) was sent to remind students of the opportunity to participate in this study and of the survey completion deadline. Once the survey completion deadline passed, survey responses were examined to select potential interview participants.

Interview participant selection was focused on domestic graduate students in order to avoid the confounding issues that international students can face when transitioning to graduate school in the United States (such as the language qualification process required of non-native English speakers at some universities). Furthermore, in an attempt to establish a common or similar "transition" experience among all participants, all potential participants had to have taken one or more of the Ph.D. qualifying courses in the department. Beyond these exclusion and inclusion criteria, the goal was to purposefully select a sample that would ensure maximum variation (Creswell, 2007) of the possible participants along characteristics such as gender, year of program entry, and degree sought (Attiyeh, 1999; Carlson, 1999; Herzig, 2004b). This was done to increase "the likelihood that findings will reflect differences or different perspectives" (Creswell, 2007, p. 126) so that any commonalities could be more likely attributed to the transition experience rather than to a particular professor or subgroup of students. Thus, one aim of such variation was to determine that any results gleaned from the interview data were as generalizable as possible within the population chosen at the selected university.

In all, 20 mathematics graduate students completed the survey. Of these, six identified themselves as international students, while 14 self-classified as domestic students. Because domestic students were the focus for this study, survey responses for these 14 students (six male, eight female) were analyzed further. The years of program entry for these 14 students ranged from 2003 to 2010. All students had either completed a Ph.D. qualifying sequence *or* (for newer students) were in the process of completing these sequences at the time of data collection. Survey responses indicated that all 14 of these students met stated selection criteria. Furthermore, the survey responses for year of program entry and year that qualifying sequences were taken were sufficiently varied to justify issuing interview invitations to all 14 "domestic" respondents. Each of these students received a personal email (Appendix B) inviting them to participate in an individual interview, and all 14 agreed to participate.

However, during the interview process, one participant confirmed that her previous educational experiences had taken place in a foreign country; that is, her survey response had incorrectly classified her as a domestic student. While this interview was very interesting and could inform future work in this area with international students, this interview data was not considered during the analysis or discussion of this study. Thus, study results are reported for 13 domestic graduate students (six male, seven female). Based on information collected during interviews, six of the 13 interview participants (four male, two female) had completed at least a bachelor's degree at the university where they were currently enrolled as mathematics graduate students. All of these students had intentions to pursue a Ph.D. at some point during their graduate study; however, one of them had decided to pursue a terminal master's degree by the time of data collection.

Faculty Members. Faculty invitations to participate were generated from a list of 21 faculty members who had taught a Ph.D. qualifying sequence in the previous seven years and/or had held an administrative position relating to graduate students (such as Chair, Associate Chair, or Graduate Director) during that time. Since these were the faculty members who had worked most closely with current graduate students, they should have the best insight into these students' transition experiences, thus creating an effective source of data triangulation. Unfortunately, time and IRB limitations prevented conducting interviews with each faculty member on this list. Thus, interview invitations were issued via personal email (Appendix D) using a priority system as follows:

1. Of the 21 faculty members on the original list, two had neither taught a qualifying sequence for any of the student participants nor served in one of the specified administrative positions. A third faculty member was removed from the list of potential participants for administrative purposes, which cannot be disclosed due to confidentiality concerns.

2. From the 18 remaining faculty members, 10 “first-round” interview invitations were issued to those faculty members who had held administrative positions *or* had taught more than two of the student participants in a recent Ph.D. qualifying sequence. Eight of those faculty members responded positively to the invitation, although ultimately only seven interviews were scheduled.

3. Hoping to elicit more faculty data, “second-round” interview invitations were issued to two faculty members from the remaining eight. These two faculty members were chosen because they were either discussed often in student interviews or because they held a status or position in the department that was relevant to graduate student life. One of these two faculty members scheduled an interview within the data collection window.

So, of the 21 faculty members on the initial list (or of the 18 whose input seemed particularly appropriate for this project), eight ultimately participated in interviews. These faculty members included five Full Professors and three professors at the rank of Assistant or Associate Professor at the time of data collection. The median length of employment in the department was 11.5 years. Each of the “areas” in which qualifying exams are required—Algebra, Analysis, and Topology—was represented by two to three faculty members so that results should not be specific to any given area within the department. These eight participants contained several current and/or former administrators in roles such as Chair, Associate Chair, and Graduate Director. (Specific numbers and status for each position are withheld to protect participants’ identities.) Gender information is withheld to protect the small number of female faculty in the department as either participants or non-participants; however, since the majority of faculty in this department are male (see Chapter 1), male pronouns will be used in all cases when reporting faculty data (as done by Herzig, 2002).

Data Collection

Data for this study consisted of basic demographic and personal history data collected in an online survey (for student participants only), as well as interview transcripts from interviews with both students and faculty members. Various documents were used to supplement these data and to provide background for participants' comments. Each of these data types is detailed below.

Survey. Graduate students who were interested in participating in individual interviews were invited to complete an eight-item online survey (Appendix C). The survey took a median length of less than three minutes to complete. The first page of the survey contained key elements of informed consent, although a waiver of signed consent was granted by the institution's IRB for this component of the study due to its online nature. The first four questions on the survey were designed to collect some basic academic history information—semester entered, degree initially pursued, degree currently pursuing, and semesters that qualifying sequence courses were taken—on each respondent. These questions were designed to ensure that the interviewees selected had taken qualifying sequence courses and otherwise represented a variety of students in the department.

The next two items on the survey collected participants' gender and international student status. As mentioned above, the decision was made to exclude international students from the pool of potential interviewees due to additional complicating factors that they often face during the transition to graduate work at this university. In order to obtain a sample of interview participants that was reasonably representative of the proportion of female graduate students in this department—which, at approximately 38%, is higher than the most recent [Fall 2009] approximate national average of 29% (Cleary, Maxwell, & Rose, 2010)—the gender item was crucial. The seventh item gave students the opportunity to indicate their willingness to continue on to the interview portion of the study by entering their email address in the space provided. The eighth item simply allowed students to elaborate on any of the previous items they felt needed explanation.

Student interviews. I conducted 13 semi-structured individual interviews (Esterberg, 2002) with current graduate students over the course of 41 days (26 of which were available for this data collection). These conversations ranged in length from 36 to 84 minutes with a median length of just under 62 minutes. Each participant completed only one interview, which was recorded with a digital audio recorder. (However, one participant requested to pause audio recording for a few moments during the session after becoming emotionally overwhelmed by the recounted experience. Thus, one interview was completed in two audio segments within the same sitting.) I also took field notes to record participants' gestures, brief synopses of their responses (to support the selection of probing questions), and my own reactions to their responses. These notes aided active listening (Esterberg, 2002), helped smooth interview transitions, and promoted the flow of conversation. All interviews were conducted in the building that houses the Department of Mathematics, although participants were invited to select from any location on the university campus. This option was offered so that all participants would have the freedom to discuss their experiences in a “safe” (by their own selection) environment.

Interviews were structured around an interview protocol (Appendix E), which was designed to align with the study’s research questions. Additional topics of interest not appearing on the interview protocol were discussed as the interviewee brought them into the conversation. Furthermore, after the initial set of interview questions, the order in which the sections were discussed varied with the flow of conversation with each interviewee. At the end of the interview, participants were given the opportunity to ask further questions about the study or to add further comments about anything that seemed relevant to interview topics. I provided interviewees with my contact information and confirmed that email was an acceptable mode of communication with them in case questions arose in the future.

Each interview began with a reassurance to the interviewee that his responses would be kept confidential. In addition, interviewees were asked to read a consent form containing information about the study, to ask any questions they had related to the study, and to sign their consent to participate in the study. Participants were given a copy of this form to keep for future reference in case they had later questions regarding the study. They were also informed that they could skip any question at any time during the interview. This conversation helped interviewees to know their rights during the interview as well as what their responses were helping to achieve.

The first set of questions on the interview protocol re-collected some of the basic information from the survey. Asking straightforward, demographic questions at the beginning established a comfortable rapport and also helped the participant to feel at ease with the interview setting and with me as the interviewer (Creswell, 2007; Esterberg, 2002). For sections II-V in the protocol, I typically asked participants the key question for the section and allowed them to talk freely on the topic in whatever direction they saw fit. Based on their responses, probing questions were selected from the lists on the protocol to bring into the conversation. While follow-up question selection varied somewhat among participants, many questions were asked of most or all participants (see Appendix F).

The second set of student interview questions focused on the research question "What happens during the academic transition from undergraduate student to graduate student in mathematics?". These questions helped each interviewee develop a description of their transition experience—first broadly, then focused on specific follow-up areas as indicated above (Esterberg, 2002). Discussions relevant to this question looked at students' academic preparation for and expectations of graduate school, the differences in classroom environment and work habits from undergraduate to graduate school, the types and quality of assistance available to students during this shift in academic status, specific occurrences or challenges that encapsulate the student's transition experience, and perceived comparisons of the interviewee's experiences with those of other students (Bozeman & Hughes, 1999; Duffin & Simpson, 2005, 2006; Herzig, 2002). Painting this broad initial picture of the academic passage helped spark interviewees' recollection of the transition experience, thus opening up a broader set of experiences for exploration in later sections of the interview (Esterberg, 2002).

Next, interviews typically turned to professors' expectations of students' prior knowledge in an attempt to answer the question "How do professors' expectations of new graduate students' mathematical knowledge affect students' success?". Follow-up topics included how students determined professors' expectations, whether students' backgrounds met professors' initial expectations, how the course experiences were affected by these expectations, and how initial study and work strategies were developed. Knowledge of my own and others' transition experiences indicated that professors' expectations could play a significant role in this process for new mathematics graduate students (see, for example, Herzig, 2002).

The fourth set of interview questions centered on the strategies students used to compensate for knowledge and/or skill deficiencies upon first entering graduate school. These questions were designed to generate responses to the question "How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies?". Specifically, these questions delved into how adjustments were made, what tactics or people were helpful in making necessary adjustments, and what strategies would be most useful to others in a similar position. Since only current students were interviewed for this study, participants had clearly persevered in graduate school to some extent beyond the initial transition. Their strategies for overcoming any transition-related obstacles they had encountered could be crucial to the success of future cohorts (Herzig, 2002).

The final set of interview questions were clustered around the key question "How do attitudes, beliefs, and relationships play a role in the success of new graduate students in mathematics?". These questions focused on ways that factors outside of those traditionally associated with academia affected these graduate students' transition processes as well as the ways that the transition to graduate school affected other areas of these students' lives. What attitudes and beliefs were helpful to students as they went through this academic transition (Carlson, 1999; Herzig, 2002)? What relationships influenced their success (Bozeman & Hughes, 1999; Carlson, 1999; Herzig, 2002)? How did factors outside of the classroom impact their experience—for better or worse (Bozeman & Hughes, 1999; Duffin & Simpson, 2006; Nyquist et al., 1999)? Because any number of external factors could contribute to students' initial successes or struggles in a graduate program, participants were given the opportunity to explore the impact of these factors in their own experiences. Because attitudes, beliefs, and the support (or lack thereof) found in relationships can greatly impact academic success, these factors seemed crucial to an exploration of students' transition experiences.

Faculty interviews. I conducted eight semi-structured individual interviews (Esterberg, 2002) with selected faculty members over the course of 41 days (24 of which were available for this data collection). These conversations ranged in length from 45 to 104 minutes with a median length of approximately 63 minutes. Each participant completed only one interview, which was recorded with a digital audio recorder. I also took field notes to record participants' gestures, brief synopses of their responses (to support the selection of probing questions), and my own reactions to their responses. These notes aided active listening (Esterberg, 2002), helped smooth interview transitions, and promoted the flow of conversation. All interviews were conducted in the building that houses the Department of Mathematics, although participants were invited to select from any location on the university campus. This option was offered so that all participants would have the freedom to discuss their views on the transition to graduate school in a setting in which (by their own selection) they would feel comfortable. Most faculty interviews were held in these faculty members' offices, but only at their unprompted suggestion of that location.

Faculty interviews were structured around an interview protocol (Appendix G), which was similar to, but distinct from, the student interview protocol discussed above. More specifically, the faculty interview protocol was also designed to align with the study's research questions, but the interview questions were altered to elicit a faculty perspective on these student-centered issues. Additional topics of interest not appearing on this outline were discussed as interviewees brought them into the conversation. Furthermore, after the second set of interview questions, the order in which the sections were discussed varied with the flow of conversation with each interviewee. At the end of the interview, participants were invited to add further comments about anything that seemed relevant to interview topics and to ask further questions about the study. As with the student participants, faculty interviewees and I exchanged contact information in case questions arose in the future.

As with the student interviews, each faculty interview began with a reassurance to the participant that his responses would be kept confidential. In addition, interviewees were asked to read a faculty-focused version of the consent form containing information about the study, to ask any questions they had related to the study, and to sign their consent to participate in the study. Participants were given a copy of this form to keep for future reference in case they had later questions regarding the study. They were also informed that they could skip any question at any time during the interview. This conversation helped interviewees to know their rights during the interview as well as what their responses were helping to achieve.

The first set of questions collected some basic, demographic-type information in order to better define the faculty member's involvement with graduate students over the last seven years. This context helped clarify how current the faculty member's knowledge about graduate student life was and how deeply the faculty member was entrenched in working with students that were in the early years of graduate school. These questions also helped establish a rapport so that the interviewee would feel at ease in the interview setting (Creswell, 2007; Esterberg, 2002). For sections II-V in the protocol, I typically asked the participant the key question for the section and allowed him to talk freely on the topic in whatever direction he saw fit before bringing selected probing questions into the conversation. While follow-up question selection varied somewhat among participants, many questions were asked of most or all participants (see Appendix H).

The second set of faculty interview questions focused on describing the transition experiences of graduate students in this department in order to address the research question "What happens during the academic transition from undergraduate student to graduate student in mathematics?". Topics addressed in this part of the interview included students' level of preparation for graduate work in mathematics, students' expectations of the graduate program, changes in classroom environments and students' work habits from undergraduate to graduate school, resources available to graduate students during this transition, and comparisons among various students' (or groups of students') transition experiences. Working in parallel with the student interviews, this set of faculty interview questions helped paint a first, broad impression of the transition experience from faculty members' points of view. In addition to addressing the primary research question, these interview questions helped open up a broader set of experiences for exploration in later sections of the interview (Esterberg, 2002).

After they completed an initial description of students' transition into graduate school, faculty members were asked to address the question "How do professors' expectations of new graduate students' mathematical knowledge affect students' success?". We discussed topics such as these professors' expectations of new graduate students, whether students' backgrounds and in-class performances met those expectations, whether students' performances struggled as they initially sought to determine those expectations, and how students might determine survival strategies for graduate school. Knowledge of these professors' expectations of new graduate students would provide for insightful comparison and contrast opportunities with student interview responses. This triangulation helped to validate findings based on student data (Creswell, 2008).

Next, interviews turned to the ways new graduate students adjust to graduate school and address prior knowledge deficiencies; specifically, we addressed topics related to the research question "How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies?". Faculty members gave recommendations for compensation strategies to help new graduate students and for people who are good resources during the adjustment and compensation processes. Again, using these faculty responses as triangulation for the student responses was designed to increase the authenticity and trustworthiness of the study's findings (Creswell, 2008).

The final section of the interview explored the question "How do attitudes, beliefs, and relationships play a role in the success of new graduate students in mathematics?". Faculty members were invited to share their views on how graduate students' attitudes, beliefs, and relationships with others—both within and outside of the department—affected these students' initial successes or struggles in the program. Identifying faculty members' perceptions of these issues provided an additional dimension to the portrait of the transition experiences of students in this department and allowed for deeper, more meaningful interpretations of student data (Creswell, 2008).

Program information. In addition to student and faculty interview data, information about the Department of Mathematics and its graduate program was also collected. These objective data—such as department demographics, historical background, and program details—served as an additional source of triangulation of the student and faculty interview data collected for this study. These data also provided a frame of reference for the student and faculty comments made during interviews. While some information—such as the content of qualifying sequence syllabi or graduate student recruitment criteria—turned out to have little explanatory power for either student or faculty interview comments, other pieces of data provided relevant insights into this department and this transition.

Data were provided by current and former departmental staff, students, and administrators. Some of these data were disclosed organically in the course of student and faculty interviews, while others were specifically sought in order to explain, explore, or support interview comments or results. These "program information" data included a list of recent qualifying sequence professors to use in faculty participant invitations, a list of recent administrators in positions related to the graduate student experience (again, to assist with sampling), and a list of current faculty members by academic rank to use in analyzing faculty interview comments, as well as additional information provided by publicly accessible departmental resources online.

Privacy and confidentiality. Protecting participants' privacy and confidentiality throughout the data collection process was of utmost importance. Data (if digital) were stored on a password-protected computer or (if physical) in a filing cabinet in a locked office. While digital recordings of interviews were necessary to ensure the accurate transcription, analysis, and interpretation of participant responses, audio data were destroyed after data analysis was complete. If an interview participant had opted not to consent to audio recording, he would have still been welcome to talk about his experience. However, in the interest of fairly representing both graduate students' and faculty members' experiences and views, only data that had been audio recorded and thoroughly transcribed could be used in data analysis and the reporting of findings. Fortunately, all participants in this study consented to audio recording.

In order to link multiple quotations or references to a single participant but still maintain the participant's confidentiality, each participant was assigned a unique ID code, and participant names and other identifying elements were removed from the data before analysis and presentation of results. That is, transcribed interviews were identified only by codes. The participant code was based on status (student or faculty) and a 2-digit numerical identifier. For example, the first student interviewed was assigned code S01, the third faculty member interviewed was assigned code F03, and so on. The master code list was password-protected (available only to me) and was destroyed after all data were collected and properly coded. These participant codes have been used in this work and will be used in all subsequent writings about this research to protect participants' identities. Because the proportion of both female faculty members and female graduate students are below that of their male counterparts, only male pronouns and/or pseudonyms are used when referring to participants of either gender (consistent with Herzig, 2002). This further serves to conceal participants' identities and, thus, to protect their privacy.

Due to the back-and-forth nature of setting up interview appointments, email contact was made with participants before our face-to-face interviews (see Appendices B and D for email scripts). In the exchange with each participant, the appropriate consent form was attached to an email so that potential participants would be notified in advance of the potential risks and benefits of participating in the interview process. In addition, participants were assured that their participation in the study would not affect any benefits or services to which they were otherwise entitled. However, no participant had access to the research questions or interview protocol documents before the interview session.

Data Analysis

Each of the survey, interview, and program information data types contributed to this work in valuable ways. However, uncovering the potential in each set of data involved focused analysis—in a variety of ways and to achieve a variety of purposes. These data analysis methods are detailed below for each type of data.

Survey. Survey data were used to select potential student interview participants. To analyze these data, I created a spreadsheet with a row for each survey response and a column for each piece of data provided on the survey. From this spreadsheet, counts could quickly be determined for the number of participants in any given demographic category (e.g., “female,” “entered in Fall 2005,” or “took Real Analysis sequence in 06-07 academic year”). This helped to determine whether satisfactory variation had been achieved on key participant characteristics such as gender and year of program entry. Please see the “Participants” and “Data Collection” sections above for further information on how the survey was used to identify potential student interview participants.

Interviews. I transcribed all digital audio data from interviews into text-based computer files, then listened to the entire interview while reading the transcription to check for errors. Transcripts included all words spoken by either myself (the interviewer) or the participant, plus any gestures, facial expressions, or other body language that seemed relevant to the interviewee’s comments (as noted in field notes from the interview). Page and line numbers were marked in the transcription files to facilitate smoother interactions with the data during the analysis process. Pauses, laughter, and overlaps in speech between interviewer and participant were noted in parentheses within the transcript. During the transcription process, I took brief notes of responses that recurred among multiple participants, unexpected remarks that caught my attention, and other items that I wished to pursue further at a later time. Although a more thorough analysis of the data would be conducted afterward, I knew I did not want to lose track of these initial insights during the analysis process.

Next, I read through all student transcripts completely and left “comment” annotations in the text-based computer file. These comments consisted of a word or short phrase—commonly referred to in qualitative data analysis as a “code” (Creswell, 2007; Ezzy, 2002)—attached to an interview excerpt, which captured what the participant was discussing in that section. The interview transcripts were “coded” in two ways:

1. For a participant’s response to a particular interview question, which often lasted for multiple pages of the interview transcript, a code was attached that related to the question being answered. While these codes, by nature, were not part of the inductive analysis discussed below, they were useful in locating various statements later on in the analysis and writing processes. For example, for a question such as “How do professors’ expectations of new graduate students’ mathematical knowledge affect students’ success?”, the question and subsequent conversation (until a new interview question was introduced) were coded as “Professors’ Expectations.”

2. The second round of codes focused on the theme, or concept, in each excerpt of the interview (Ezzy, 2002). The length of one of these excerpts varied from a phrase to multiple pages depending on the openness of the participant to share on that topic, the relevance of that concept to the question the participant was answering, and any follow-up questions that were asked. Often, more than one thematic code was applied to one excerpt, or multiple codes might overlap across one or more excerpts. For example, this quote from S05 was coded for both “mentoring” and “isolation” since it re-emphasizes S05’s earlier feelings of isolation upon arriving at graduate school and also recommends a mentoring system in the department:

> I've heard people talk about this, but I haven't seen it in place. . . , but doing some sort of mentoring program where you match a graduate student with an older graduate student and possibly a professor. . . so that maybe graduate students don't feel quite so alone when they start.

As I read through the first interview transcript for each group and marked its text with codes, I began to assemble a master list of codes used for each of the two groups. When coding subsequent transcripts in that group, codes from previously coded transcripts were utilized as much as possible. However, when a section of a transcript did not fall into one of the previously listed categories, an existing category was modified to include the concept in that section or a new code was created to suit the concept presented. Once a new code was created, previously coded transcripts were checked to determine whether the newly created code should have been applied in earlier coding. This iterative process continued throughout both sets of transcripts. In both sets of interviews, I ultimately reached a saturation point in the coding—that is, a point in the process at which creating additional codes was no longer necessary, because the current set of codes comprehensively addressed all the concepts found in that set of transcripts.

Between the two coding processes, two lists of codes were determined—one for student interviews and one for faculty interviews. These lists are provided in Appendix I. (It is worth noting that while some code names are shared among the student and faculty lists, the interpretation or application of these shared codes often varied between these two groups' interview transcripts.) Upon reviewing the list of codes and investigating what participants had said regarding various codes, some similar codes were grouped together to emphasize broader themes in the interview data. These themes, or commonalities among codes, formed the basis of the results for each set of interview data (see Chapter 4). Using demographic data from surveys, interviews, and program information, these themes were inspected from the perspectives of different groups of participants (e.g., female students, junior professors, or students who completed bachelor's degrees at "large" universities) to identify similarities and differences within the sample.

This thematic coding process is often referred to as analytic induction (LeCompte & Preissle, 1993) or thematic analysis (Ezzy, 2002). Coding thematically with no pre-conceived idea of categories or themes is also an idea found in grounded theory research designs, where theory is "inductively derived from the study of the phenomenon it represents" (Strauss & Corbin, 1990, p. 23). While this study was not on a large enough scale to be considered a grounded theory design, the ideas of open and axial coding employed by grounded theory (Creswell, 2007; Strauss & Corbin, 1990) were useful in building themes in this data.

Program information. While the program information data obtained were not directly analyzed for themes related to the transition to graduate school, these data played a key role in the analysis process. Program information data served to put participants' comments in an institutional context, as well as to help identify characteristics of participants (such as professor rank) that were useful in the interview analysis process. In this way, the analysis of program information data was simply a means for achieving a more salient analysis of the interview responses (particularly those of faculty members). Please see the "Data Collection" section above for further details on the role of program information in this study.

Conclusion

Because Research in Undergraduate Mathematics Education (RUME) is such a young field, its phenomena and frameworks are still emergent at best. Thus, allowing participants to tell us their stories and describe their experiences in their own words is the most effective way to determine, describe, and explore the issues in this field. This case study sought to do just that by utilizing student and faculty interviews to explore the transition to graduate school in mathematics. These 21 interviews, along with survey and supplementary documentation data, provided the basis for thematic interview coding and analysis, which shed light on several themes within the transition to graduate school in mathematics at this university. These themes are detailed in the next chapter.

Chapter 4: Results

Using the coding procedure described in Chapter 3, the codes listed in Appendix I were obtained for the 13 student and eight faculty interviews. I carefully observed patterns among codes and in interview excerpts for each group of participants in order to inductively determine the themes presented in this chapter (with supporting quotes[10] and descriptions of key phenomena). In this chapter, student interview themes are presented first, followed by themes gleaned from the faculty interviews. These results will serve as a basis for a deeper discussion of similarities and differences between student and faculty results in Chapter 5.

Themes from Student Data

In the interview excerpts presented below, student quotations are tagged with codes of the form S*yz*, where the "S" indicates a student interview and the two-digit number *yz* gives the identifier assigned to that participant. In this way, individual participants can be followed throughout the quotations presented. Within the student interview data, four main themes emerged and are discussed below: Isolation vs. Community, Academic Relationships, Role of the Department, and Realizations of Self.[11]

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[10] Throughout this work, interview excerpts have been edited by removing verbal pauses, proper names and/or titles, and (sometimes) repeated words or phrases in order to increase clarity and readability, enhance brevity, and maintain confidentiality. Every effort was made to maintain the participant's original meaning within the excerpt.

[11] Themes from the student data were presented at the 2011 Conference on Research in Undergraduate Mathematics Education and were subsequently submitted in a proceedings paper for this conference.

Isolation vs. Community

This section presents three ideas related to the contrast of isolation and community. Several student participants, including some who had completed their undergraduate studies at the same university where they were completing their graduate work, identified a feeling of isolation upon transitioning to graduate school. All participants mentioned the impact of the academic and social community of their fellow graduate students. The idea of competition also played an interesting role in the sense of community that students experienced during graduate school.

Unexpected isolation. Seven of the 13 students reported experiencing an unexpected sense of isolation upon their entrance into this graduate program. For some students, this isolation was social in nature: “Especially in the first year, I would go home every couple weekends. . . . That was probably the biggest change for me, just being away from home, not having all my friends right there, like in college” (S02). Other students made similar comments: “The place that I came from was very stable, very supportive. I had tons of friends. I had a church where I knew lots of people. They supported me. . . . And I didn’t have that here. I didn’t know anybody” (S13). These students explained their isolation as a function of the loss of the proximity of support structures such as family, friends, or other social systems. Ironically, even three students who had done their undergraduate work at the same institution where they were completing their graduate work also reported experiencing some social isolation upon entering this new academic chapter.

However, other students experienced a sense of isolation that could be better classified as academic in nature. For instance, when discussing a struggle with coursework during the first year of graduate school, one student made the following comments:

> I didn't expect to fall so far behind so fast. I wasn't used to that. When that had happened in previous courses, like in undergraduate courses, there were always a few people that were right there with me. I could talk to people in the class. . . And in grad school, I didn't see other people getting really, really confused. That's not to say that there weren't people getting really, really confused, of course. For some reason, I got the impression that everyone else was pretty up to speed with what was going on, so that made it more difficult. (S14)

This student went on to describe how this feeling of academic isolation was followed by lower grades, lack of confidence, and an unpleasant feeling toward graduate mathematics.

Role of community. In contrast to the isolation felt by some, most student participants emphasized a specific role that community had played in their graduate experience. This role was often academic:

> I would recommend just developing relationships with your classmates to support each other with your classwork. It helps a lot. . . to just talk about the material with them, and you'll learn a lot. Some of you might understand some things, and you'll learn a lot just explaining those things to the other students. . . I'd recommend developing that as early as possible. (S04)

Another student went so far as to make the following claim: "I work in groups so much now. . . I rely on other people, and that's been a significant change. I know I could not get through graduate school by myself" (S05). Certainly, for a student pursuing a

Ph.D.—and thus, likely very talented in the field—such an admission speaks volumes toward the importance of community in the graduate school experience. Overall, the interviewees perceived that having peers with whom to work through assignments and other content was crucial to their success.

However, community also fulfilled another important function—that of emotional and social support during the rigors of graduate school. One student commented on experiences with this dual role of community:

> Study groups are great, because if you know something, you know it better by teaching it to someone else, or explaining the problem to someone else, and if they know something, then they can explain it to you. . . . And so, it helps to work out the kinks with other people. And you also get that camaraderie of "Yay! We're all in this together.". . . That was one of the biggest things, I think, that really helped me get through a lot of the courses was just having that support circle of the study group. (S11)

Despite emphasizing this community support, some students also used the language of competition to describe their graduate school experiences.

Competition. Without prompting, five students specifically mentioned "competition" or "competitiveness" when relating their initial experiences in graduate school. However, these students were only rarely referring to actual competition between students for grades, attention, or any other endowment of status. More often than not, they were referring instead to the enhanced level of mathematical quality exhibited by their new peers.

> There would be, even though we're not competing against each other in a real competitive way, the competition as far as where you are in the class, you kind of realized that that was going to be, not so much like it used to be. . . We were probably all surprised that we weren't at the top of the class when we were used to being at the top of the class. (S08)

> There was actually a spirit of competition for the first time when I started grad school. It was very subtle. It wasn't like everybody was fighting for grades or anything, but you can actually sit around and talk about, 'How did you do on this thing?' and 'What did you guys do?' and I think for the first time I was actually immersed in a mathematical culture. . . . For the first time I was actually sitting around having conversations with people about mathematics. (S01)

Clearly, these students had to adjust to the new "mathematical culture" they were experiencing, but they generally seemed to embrace this culture whole-heartedly.

However, for one participant, the idea of competition was all too real:

> The competition in the classes with the other students was different [than in undergraduate]. . . Where I came from. . . the students were more supportive. There was a big study group. I had six or seven people who were in most of my classes as we all went through math majors together. And when we sat down and did homework, there were a minimum of four or five of us working on any given homework set at a time. And here, it could happen that way, but the people who were involved in these study groups here were the cream of the crop from where they came from. So, egos kind of got in the way a little bit more. . . . It gets a little harder. The study groups didn't come together as well. It gets a

> little more competitive. Especially in one of the particular classes that I took that [first] fall, the professor. . . would rank everybody's grades based on what they had done, and whenever there was a natural break, those would be the A's, those would be the B's, and if there was a big natural break somewhere else, those were the C's, and so it really was a competition. If you wanted an A, you really had to beat everyone else. (S13)

Interestingly, S13 was the only participant in this study who was no longer pursuing a Ph.D. in this department, despite spending the first few semesters of graduate school enrolled in core Ph.D. coursework.

Academic Relationships

Beyond relationships with their peers, students also encountered other relationships during their first few months in graduate school that had a great impact on their transition experiences. This section discusses the role of students' relationships with content and with their (instructing) professors, as well as the ways in which these relationships affected students' overall transition experiences.

Relationship with content. Eleven of the 13 student interviewees discussed the increased difficulty they experienced in their initial coursework in graduate school. For instance, one student commented that "the amount of work expected from each of the courses is a little bit more than you might see in undergrad, either in the level of difficulty of the problems, or just the number of problems" (S11).

Furthermore, while all students acknowledged that they had expected graduate school to be "hard," many of them also emphasized that they could not have anticipated the exact nature of the difficulty with which they were presented. One of these students addressed this phenomenon: “I anticipated an advanced difficulty level. I don’t guess you can really prepare yourself for that, though, until you actually do it” (S12).

For some, the new intellectual challenges presented by graduate school were exhilarating:

> I remember my first week being very exciting, and very positive, because I got to be immersed in math, and go to all these different seminars, and hear all these words I’d never heard before, and see people talking about all these interesting things. (S10)

However, for others, this difficulty was overwhelming or burdensome, and they felt that professors’ expectations played a role. Student S08 mentioned lying awake at night, worrying because “sometimes I think [professors] thought that I should know more than I did.”

Other students had to compensate for specific prior knowledge deficiencies: “There were a few topics that I had to look up myself and teach myself in other courses because the professor expected that we already knew that, and I didn’t necessarily know that” (S11). But, sometimes lack of preparation spanned an entire course area (most notably, topology):

> I had never seen any topology at all, so having to come in to a graduate level sequence in topology, that was kind of a big shocker. I tried to prep myself with the undergraduate topology. . . the semester before I knew I was going to start that sequence, and it was a lot to try and prep yourself for. So, I didn’t really feel prepared in that area at all. (S13)

Students discussed compensating for under-preparation in content areas such as topology, linear algebra, and complex analysis. While most students found some way to cope with a lack of prior knowledge—using the Internet, supplemental textbooks, peers, or instructors—these initial struggles with course content played an important role in students' impressions of their transitions to graduate school.

Relationship with professors. Content was not the only area in which graduate students had to forge new academic relationships, however. Often, experiences with content were compounded by relationships—either actual or perceived—with (instructing) professors:

> I don't think it was the material at first that was difficult, it's just, it took me a while to adjust to new people. Back at my old university, I knew all the professors, and I knew what to expect. . . . I knew the style of my professors. . . . My biggest transition has been adjusting to the people. (S07)

> I got the impression that everyone else was pretty up to speed with what was going on, so that made it more difficult. It made it so that I felt like the only person who could help me would be the teacher, and some professors are less approachable than others. Let's just put it that way. (S14)

In the first quote, the transition to graduate school was compounded by the lack of familiarity with faculty at a new institution. However, in the second example, a sense of academic isolation among peers deteriorated into a true academic struggle when professors were not "approachable" to this student. And while many of the relationship difficulties centered on mastering the mathematical content, other students struggled with the loss of interpersonal contact with professors which they had experienced as undergraduate students:

> I was very used to working closely with my professors at [school], because it was such a small school, which was quite a change when I came here. . . At [school], I would be in their offices every afternoon talking to them about things, and here I don't go to my professors' offices all that often. . . . We were kind of friends, so that was quite a change, too. (S05)

Ultimately, nearly all students mentioned the importance of relationships with professors or the need for adapting to professors' teaching styles as a factor in their eventual success in graduate school.

Role of the Department

While professors certainly play a large role in setting the department's cultural standards and expectations, other aspects of the department also impact students' experiences in graduate school. The department's administrative roles—such as handling quality-of-student-life concerns, advising students, and assessing degree progress—also have a great impact on students' experiences with the transition to graduate school. While some of these roles are dependent upon the particular people or departmental policies involved, others, such as those discussed below, are general enough to have potential relevance outside of this specific department.

Informing. All participants mentioned that they would have liked to have more information regarding issues ranging from tuition costs to teaching responsibilities, from paychecks to degree requirements, from health insurance to the amount of time and effort a doctoral program would require. Many students framed these comments in the context of course advising, saying things such as: “For the first two or three years, it just feels like you’re kind of floating around. ‘Well, everybody takes these courses, so I’m just going to take these courses’” (S01). These students often failed to see how to build their own degree plan around departmental criteria. Several (especially more experienced) students wished information regarding these requirements had been more readily available or had been emphasized during mandatory advising appointments.

The lack of information was also strikingly felt in the area of research expectations. Several students wished that the idea of research, an explanation of the procedures and types of work involved, and the length and depth required by the research process had been introduced earlier in their degree. One student summed up these feelings this way:

> If you’re going to get a Ph.D., you need to want to do research. And, I don’t know how that could be communicated, mostly because people coming out of an undergraduate [degree], they have no idea what it means to do research. That’s an unknown. And I don’t know that you could even instruct them as to what that is at that point. But, I think that needs to be communicated as quickly as possible to graduate students. . . so they can make the decision if they want to do it, or if they want to stop at the master’s. (S06)

Other students were surprised at the active seminar culture in the department, their role in attending and presenting in these seminars, and the process of finding a research advisor. Many students indicated that they felt the departmental and university-wide systems of disseminating information could have been improved.

Mentoring. While students felt strongly about the importance of community during the graduate school experience, several wanted a more official program to combat the sense of isolation they felt and the lack of information they received regarding the navigation of the graduate school experience:

> I've heard people talk about this, but I haven't seen it in place. . . doing some sort of mentoring program where you match a graduate student with an older graduate student and possibly a professor so that maybe graduate students don't feel quite so alone when they start. (S05)

Another student suggested that this mentoring arrangement need not be terribly formal: "Not that we would need a mentoring program, but it would be nice to know someone that you could ask, or that was kind of assigned to you to talk to, or something" (S03). These students felt that a mentoring program for graduate students would have helped them with their transition to graduate school.

Realizations of Self

In addition to commenting on aspects of the department, culture, and content that impacted their transition experiences, many participants also commented on their own perspective changes or personal growth through the graduate school experience. While these took many different forms, two key realizations—dedication and searching for a place—are discussed below.

Dedication. Eleven students emphasized the importance of being committed to and persevering through their degree program:

> You have to decide you're going to do it. If you're wishy washy, it's over. I think that, just making the decision, "I'm going to do this, and I'm going to

> finish it regardless," that's probably what you have to do, because it is going to be difficult, and if you're at anything, thinking, "I don't want to put up with this kind of difficulty," then you're not going to do it. (S06)

One student described his perseverance this way: "Once I've committed to doing something, it's very important to me to follow through on it. So, if I encounter difficulty with something I've committed to, then I'm going to do my best to keep with it and succeed" (S04).

Although dedication to the experience was important for all students, one student highlighted the primary role that perseverance played in his ultimate success in graduate school: "If you really want to do this, perseverance is probably the biggest thing. I never would have been able to do this if I hadn't been resigned to figuring it out at some point" (S14). This student went on to say that "I didn't get by because of my knowledge of mathematics. That had absolutely nothing to do with it. . . . That was just kind of a by-product of the persevering" (S14).

Searching for a place. In addition to realizing the importance of sheer dedication to the degree, students also stumbled upon new perspectives on their relationships with academics and with life. When discussing their place within the "mathematical culture," students made comments such as this:

> In undergrad, I was the top one or two or three students in the class, and then I felt like I was middle of the pack or less in graduate school. . . . When everybody is interested, and everybody's knowledgeable, it always happens that you kind of fall more towards the middle or bottom. (S03)

Other students had to adjust their definitions of "academic achievement" or "success" in order to satisfy their intellectual drives or academic perceptions of themselves:

> My attitude has changed a little, but I still have the attitude that, "Well, I might not be able to do as well as they do, but I can do enough to get through this and really learn and do well." (S08)

> I think of myself very much as an academic person. . . . Throughout my entire life, I've always defined myself by my success in school. . . . I think that determination to keep that part of what defines me, to not let that go, helped me keep saying that I had to succeed. . . . The definition of doing well has gotten tweaked a little bit. . . . I stopped building everything on an A. To me, doing well didn't necessarily have to correspond to the grade anymore. But, I still need to do well. There's still that drive there. (S11)

For some students, graduate school meant defining a purpose or role in the greater world outside of academia:

> Graduate school felt like a waste of time at the beginning. It was like, "I'm just doing math. Who cares? What does this matter?" So that, figuring out my place in society, I felt like I wasn't quite as useful as I could be. (S05)

This student went on to realize that graduate school did not have to serve as a placeholder between an initial degree and an ultimate career, later stating the following: "I've realized that my life is happening right now. I don't have to wait for it to start. It is going on, and I can find satisfaction and purpose in whatever I'm doing" (S05).

This sense of purpose was echoed in other interviews. Over half of the student interviewees explained that their lives outside of mathematics helped keep them grounded or allowed them to balance out the stresses of graduate work. One student seemed to take this idea to heart particularly strongly:

> The one thing that I have to keep coming back to is that this doesn't define who I am. . . I think a lot of people who are talented academically face that, like, "Are we defined by our performance, or what? Who am I?" So, keeping it in perspective that this is not my entire life… that's helped a lot, because when it's not so all-consuming, I'm less stressed about it, and I'm able to learn and perform a lot better when I'm less stressed. (S12)

Although these students' realizations of themselves, their attitudes, and their level of commitment to their mathematical careers were not limited to their immediate transitions to graduate school, comments regarding these "realizations of self" were prolific in the student interview data.

Summary

The student interviews conducted for this study revealed 13 unique perspectives on the transition to graduate school in mathematics at one university. However, these interviewees agreed on the importance of community in combating isolation and a sense of competition in graduate school. They also discussed a common perception of an increased difficulty level in the academic demands they faced, as well as a decreased level of "close" interaction with departmental faculty, compared with their undergraduate experiences. Despite requesting an increase in support via mentoring and the dissemination of program information, these students were able to make key realizations about themselves and their "place" within mathematics.

Themes from Faculty Data

In the interview excerpts presented below, faculty quotations are tagged with codes of the form F*yz*, where the "F" indicates a faculty interview and the two-digit number *yz* gives the identifier assigned to that participant. In this way, individual participants can be followed throughout the quotations presented. Within the faculty interview data, four main themes have emerged and are discussed below: Nature of Mathematics, Preparation, Community, and Professional "Place."

Nature of Mathematics

Each faculty participant discussed the nature of mathematics during his interview. These conversations focused on both the difficulty inherent in obtaining a graduate degree in mathematics and the professional culture surrounding mathematicians and the practice of mathematics.

Difficulty. Interviewed faculty members detailed the difficulty students encounter with mathematical content when they transition from undergraduate to graduate work. One of these faculty members simply expressed that, "Just from my own personal experience, I realize that it's hard. Math is hard" (F01). However, other faculty members elaborated on the relationship between students' expectations of difficulty and the realities they faced in their graduate work:

> I think there's a big jump in the level of difficulty between undergraduate and graduate school, and some students have been clued into that fact, and some have not. And, I think some students have a real shock at just how much harder it really is. (F08)

Other faculty members acknowledged that students might expect an increased challenge in their graduate work, but they might not fully anticipate the exact nature of what they experience:

> They expect it to be hard, certainly, but. . . I think many underestimate just how different it is from being an undergraduate. . . . The material is harder. It's at a more advanced level. . . . They have to think much more actively about the material, and they have to understand it at a much deeper level. (F04)

Faculty participants also noted that students might not foresee the time and effort that would be required by their studies:

> When they're coming in, many of them do not realize how much time it would take to prepare for just one course. They might think, "Well, I only have to take two courses, so it should be easy." However, there's a great multiplying effect in those courses. If you really want to learn those subjects, you have to work very hard. (F05)

Mathematical culture. In addition to the difficulty of course content, the culture surrounding mathematics as a field of study also had a great influence on students' transition experiences. For instance, faculty participants noted that the difficult problems encountered and the diligence needed to tackle those problems required students to adopt a new mindset toward their academic pursuits:

> Instead of working two days and getting the homework done, it might take two weeks, or you might not get a certain thing done for a month—or more. This requires a different attitude and a different mindset. And, I think that's the strength of mathematics. People study things very deeply, and not superficially.

> There are no quick answers, typically, and sometimes there are no answers. (F05)

Some faculty members also recommended that students learn to question their own understanding and honestly explore any deficiencies:

> You have to have a sense of, "What's bothering me?" as a student. . . . You have to have a sense of, "I don't understand this." . . . It's a certain self-awareness. It's almost a psychological trick. You have to be honest with yourself and admit to yourself there is something you don't really understand, and then try to correct that. (F01)

Beyond aspects of mathematical culture related to content difficulty, faculty members also mentioned several pervasive tendencies and attitudes in mathematical culture. One of these attitudes is the aversion to admitting struggles or insecurities. One faculty interviewee mentioned that, "There's … this sort of male, macho culture, where everything is easy. 'Oh, I spent 15 minutes preparing my lecture,' . . . or whatever. There is this attitude, and that can be intimidating" (F03). Another faculty member commented on this cultural attitude as well:

> There's a culture in math, and I've never been able to understand it, but it's there, somehow, like, if you act like things are hard, that means you're not very smart. And, so, one has to put on a persona as if things are not hard. (F08)

Another professor mentioned the tendency of many faculty members to be extremely demanding of their students:

> It's dying away to a degree, and that's a good thing, but there's been a culture of, you sort of throw everything at the students, and you throw all these rocks at

> them, and the people who are still standing up at the end, those are the strong students. (F04)

Faculty participants indicated that these cultural mindsets and tendencies played a role in students' transitions to graduate school in mathematics.

Preparation

Certainly, faculty members and department administrators have programmatic and personal criteria for incoming graduate students' academic preparation. However, during the interviews, it became clear that they had expectations well beyond content that students might have explicitly seen in a mathematics classroom. As one faculty member put it, "'Prepared' is a strange word. It's not just about how many math classes you've taken" (F08). Faculty participants' views on both the academic and the psychological side of students' preparation is presented below.

Academic preparation. What undergraduate courses best prepare students to succeed in graduate school? One faculty participant made the following comment:

> Everybody's got an idea of what a student ought to have studied before they start graduate school. Everybody can tell you something about that, and, then, in the end, probably we would all agree that we don't really know. We have no idea. (F05)

Despite disparities among their views of undergraduate preparation, many faculty members commented on specific topics or areas where students at this university seemed particularly ill-prepared. According to five of the eight faculty participants, linear algebra was one such area: "There are certain areas where it's really obvious that something's lacking. One of the areas is linear algebra, and that can be shockingly bad"

(F01). Another participant added complex analysis to the list of areas of insufficient prerequisite knowledge: “When I feel like a conspiracy theorist, I think there is a conspiracy against. . . complex analysis [in students’ preparation]” (F07).

Beyond material from specific courses, the faculty interviewees were also concerned with students’ general mathematical preparation: “Things like understanding how sets and functions work—this could be one of the major things that students have to overcome in order to begin to be able to do mathematics at a higher level” (F05). Two faculty members specifically mentioned the common, yet elusive, idea of “mathematical maturity.” One commented that, “We have this weird phrase, ‘mathematical maturity,’ that has to do with when you’re given something to do, how you tackle it. And, that ability is what really determines success or not” (F08). Another claimed that students were under-prepared in the area of:

> Mathematical maturity, the ability to write mathematical argument, . . . to say something that logically follows from the previous sentence, to carry an argument through, so, that’s not any one course. It’s just having been exposed to enough . . . proof-based courses that they’ve got the sort of language of mathematical arguments down. (F03)

One concern among faculty interviewees was that of admissions criteria. Regarding applicants, one professor commented that, “There’s essentially no way to know what their background has been just looking on paper at what they’ve taken. So, it says they’ve taken Linear Algebra, but you don’t know what that means, actually” (F06). However, some faculty participants believed that these students could still succeed in their graduate studies:

> If they . . . know how to write mathematics. . . and how to think about things, and how to organize their time, and things like that, they can do spectacularly well. They can do a lot better in the long run than somebody who comes in with. . . a lot more background. (F03)

> A lot of holes and gaps, things that you skipped over, or things that somehow didn't quite make the impression that they should have, one can make up for in graduate school. . . . Of course, if you have a lot of background missing in a lot of areas, then you are playing catchup on too many fronts, . . . and that's going to be harder. (F07)

Although these students would face an uphill battle for success in their graduate studies, they could overcome prior knowledge deficiencies—*if* they were willing to persevere through their struggles.

Psychological preparation. Despite the importance of various types of academic preparation for graduate school, most faculty indicated that academic preparation alone was not sufficient for a successful graduate experience: "It's not just academic preparation. It's some sort of maturity, as well, and a sort of willingness, a perseverance, a willingness to sort of just keep at it even though things may seem overwhelming" (F03). Another faculty participant noted that:

> You have to have a certain aptitude to do a Ph.D. in Mathematics, but aptitude is one thing, and desire is a second thing. I've seen students who are very good, but just not so focused, and they just don't have a hunger to learn this material. And, you won't learn it unless you really make a commitment to learning it. It's not something you can do casually. (F04)

However, commitment and perseverance were not deemed as sufficient by all faculty members. Several faculty participants mentioned that depth of involvement with the material was also a key component of success:

> I think much of this transition to grad school probably has to do with psychology. . . . You have to have a certain attitude towards the subject. It's really something you have to get into. You have to immerse yourself. . . . You have to have this mindset, and it's really often a psychological thing. (F01)

Other faculty members advocated the need for students to think and work independently—both within and beyond the structure of the coursework itself:

> What we need is for [them] to be independent of us. So, at the beginning levels of the graduate experience. . . try to read the book and learn from it. And, the more [they] can do that independently of the teacher, . . . the better job [they're] doing. (F06)

> I would expect students to be more independent than they need to be in undergraduate classes, in the sense that I expect them to read more on their own, maybe. I don't assign homework every day, so that they get guided by the hand all the time and know exactly what problems to do. . . . It's a higher level of maturity that one would expect from graduate students. (F01)

Faculty members often thought that the increased sense of maturity they expected was associated with the different academic and social environment, or departmental culture, in which new graduate students found themselves. A richer description of this sense of community is given below.

Community

All faculty participants emphasized the importance of community in making the transition to graduate school as smooth as possible for new students. They noted that graduate students' peers were crucial to their academic and social survival. Some professors also discussed the importance of mentoring within a student's own personal community (either inside or outside of the department).

Peers. Every faculty participant highlighted the importance of peers in a student's graduate experience. For example, F04 emphasized that, "The students themselves are their own best resources. They can help and support each other, and they can learn together. . . . by discussing material they're trying to absorb." Others echoed the importance of graduate student collaboration:

> I think many students have not really gotten used to working collaboratively with their classmates. And, I think that's really important when you're in a graduate course. I think you learn a lot from your peers. . . . Some of them have [worked collaboratively] before, but some of them really haven't, and I think it can really be powerful when they learn [to do] it. (F08)

Beyond the academic, however, many faculty members also stressed the social role peers played in students' successful adjustments to graduate school. For example, F02 noted the social interaction among graduate students, saying, "I think that, actually, in our department, in particular, the atmosphere among grad students is very nice. The graduate program is not too large, so people get to know pretty much everybody right away." F04 expanded on this idea by explaining how the department encourages this social interaction among the graduate students:

> We have things like [seminar for graduate students], and the teas and so on. . . . The students form their own community. These are just ways of getting students together in a room. . . . A lot of it's independent of whatever formal things are put in place.

According to other faculty members, this interaction was not merely a superfluous outflow of physical proximity; rather, it was critical to students' success:

> First-year graduate students are expected to come to the [seminar for graduate students]. They are expected to participate in activities like departmental picnics, teas, etc. And, this is not like just going to class, taking notes, and then showing up for the exams. It's this interaction, both with the faculty and with their peers, which I think is crucial. (F07)

Furthermore, one faculty member noted that graduate students "almost become" peers with faculty members. This new level of relationship changes the social atmosphere from what a student would have known as an undergraduate:

> As a graduate student, you almost become a member of the faculty. You become an integral part of what's going on. So, the faculty members are expecting that the graduate students are going to become some type of colleagues. . . . So, there's a whole different social atmosphere of, say, faculty members towards the graduate students, compared to the relationship between a faculty member and an undergraduate student. (F05)

These relationships with faculty (and even with more advanced graduate students) played a key role in helping students get the support and mentoring they needed to successfully navigate graduate school.

Mentoring. Six of eight faculty participants discussed the idea of "mentoring" and the important role experienced graduate students can play in a new student's transition to graduate school. F08 put it this way: "I think older graduate students are a huge resource, and I think now that there's [graduate student organization] and all of these other ways of interacting with more experienced graduate students, I think that's just really, really valuable." Another faculty member explained why these relationships were so valuable:

> I think one of the biggest resources they have would be graduate students who came before them, who can explain to them a lot of things that are going on, and what could be expected of them. . . . I think that the experienced graduate students are able to help the newer ones adjust to the whole situation, the entire thing, which includes the duties that a graduate student usually has. (F05)

One faculty member emphasized that the existence of a mentoring relationship was far more important than the mentor's title or departmental affiliation:

> I think any sort of mentoring relationship that you can find is good. . . . It doesn't have to be somebody in the department. . . . Somebody that you respect their opinion, and somebody who can listen to you. Part of mentoring is not always, "Oh, this is the right way to do things." It's somebody that allows you to sort of articulate out loud something that you're having difficulty with, and you're trying to figure out a way of dealing with. (F03)

According to faculty participants, these relationships with peers and other mentors could help new graduate students adjust to the new culture they would find in graduate school.

Professional "Place"

Faculty participants often referred to the professional role that new graduate students take on as members of a mathematics department. This role encompasses tasks such as preparing for a career in mathematics, balancing personal and professional life, and finding a niche in the broad world of mathematics.

Career preparation. Many faculty participants discussed the function of graduate school in helping students prepare for academic (and other) careers. Several of them noted the increase in seriousness and maturity among graduate students, as they are "thrown into a bunch of responsibilities and expected to be more mature and adult" (F07). Another faculty member noted:

> You're now beginning to put your roots, sink your roots into something that will probably be your career for the rest of your working life. . . . so you become very serious about it. It will tend to absorb all your time. (F05)

Some faculty members stressed preparing students for the range of job opportunities they could face, not just "pumping out clones of [themselves]" (F08):

> I think recognizing that you can take mathematics in a lot of different directions is beneficial towards people being able to see themselves with a future in mathematics. . . . I think getting that message early, that you're not on a path that only leads to sitting where your professor is sitting now. You're on a path that can take you a lot of different places, and there are a wide range of skill sets that can work in this. (F08)

According to some faculty participants, this broad preparation must be emphasized to incoming students who "probably really underestimate how frightfully, scarily bad the job market really is" and need to be "proactive" about their future careers from the beginning of graduate school (F03).

Balance. Seven of the eight faculty participants noted that since most graduate students work as teaching assistants in the department, they must learn to balance these professional responsibilities with their own studies:

> They have responsibilities of teaching, which is also quite helpful. . . . They get a very different perspective, and they start appreciating certain things that they may not have appreciated so much as undergraduates. It helps them to mature, . . . but, of course, that cuts into their own work, also. So, it's a balance. (F07)
>
> You take these classes, and you feel like you don't know anything, and then you could teach, and, yes, this was another pull on your time, . . . but it was also a place to take on. . . the role of the person who knows things, the person who's helping somebody else to learn things. And, I found that balance to be encouraging [as a graduate student]. (F08)

However, beyond this balance within the professional realm, students also had to find a way to balance their university commitments with the rest of their lives. As one professor put it, "Persistence and commitment are the most important things. But, you also need a little bit of a life" (F04). Another professor echoed this sentiment, saying, "I think that getting too much into studying, psychologically, is very bad. So, one should always realize that studies are studies, life is life, and one should not allow one to affect the other too much" (F02). Some faculty members claimed that incorporating non-academic activities into graduate student life actually *helped* graduate students succeed:

> So, you get to grad school, and you think, “Okay, I just have to do everything.” And, you can do that for a while and have no life, but at some point, you just can’t do it anymore. . . . Part of the first-year adjustment process is realizing that even though you’re stressed, . . . getting a little bit of time to [take a break will] help your brain be able to come back and focus. . . . There’s a [lesson] about just how much time you can spend thinking about math and making sure that you figure out a way to also have some down time. (F08)

Yet, it is important to note that while many faculty members advocated this “balanced” approach to graduate school, others recommended full immersion in the academic experience:

> I didn’t have much time for anything else during grad school. . . . I basically put all my effort into getting this Ph.D. for a couple of years. . . . This is not everybody’s attitude. Many people think you should still have a life even if you are in grad school, but. . . . if you don’t have these distractions, you get this academic reward. You really have more time for studying, for interacting with professors, and it’s not like you’re losing anything. You’re just gaining depth in this specific area, which is. . . a good thing. (F01)

For this faculty member, the tradeoffs made for academic depth were well worth the costs incurred. Ultimately, most faculty members agreed that students had to decide whether they were willing to devote the necessary time and energy to graduate study.

Finding a place. As discussed in the “Themes from Student Data” section above, some students embraced the challenges of graduate school, while others decided that their life goals would be better served by taking another path. Faculty participants acknowledged these difficult decisions:

> By the time a person goes into a graduate program in mathematics, they've at least had some background in the subject. . . so they're not doing it frivolously. However, some people find, after a semester or two, that this isn't it. . . . They typically will drop out and move to something else in their lives. By the way, there's nothing wrong with that. (F05)

> We want everybody to feel like we think that they can be successful. We also want them to know that if they decide that the price of success isn't worth it, and they want to do something else, then that's fine, too. I mean, it's hard work getting a math Ph.D., and it's not something everybody wants to do. And, it may be that as they find out more about the job market and think hard about how they really see themselves in the next five or ten years, they may decide it's not what they want to do. And, then, it's our job to help them figure out some options. (F08)

Faculty members also noted that, for some students, "finding a place" involved settling in to the new academic and social environment in which they found themselves. Several faculty members commented on the difficulty of this transition process:

> Students are coming from a place where they were one of the best, and. . . oftentimes, they're not one of the best anymore. . . . And so being in the middle of the pack, or maybe even slightly towards the back of the pack, is a brand new experience. And, that's hard. That's a hard adjustment. (F08)

According to some faculty participants, students transitioning from smaller regional universities often experienced the greatest "shock":

> We have students who come from the immediate area, who've not had very challenging courses, and are used to being far and away the strongest students in their setting, who suddenly are placed in this very different environment where there are students who are much better trained than they were. I think that's a shock for some of those students, and also, suddenly, they're meeting material that's, if not difficult, it's being presented at a pace that they're not used to. . . .It's a difficult transition, I think. It's too much for some students. (F04)

While students from different backgrounds may have had different struggles with the transition, several faculty members acknowledged that all mathematicians struggle to find their place in the subject. One faculty member offered students this sage piece of advice:

> Everybody thinks they're a fake, and an impostor, and that everybody else is just so cool. . . . Everybody thinks that. And, to realize that and don't let it beat yourself up, I think that's advice. (F03)

Summary

The faculty interviews summarized here provided the views of eight "seasoned veterans" on the transition to graduate school in mathematics. These faculty members emphasized the role that mathematics itself plays in the transition process, as well as the importance of sound academic and psychological preparation for the challenges of graduate study. Graduate students' peers—especially those with more graduate experience—helped students acclimate to a new academic and social setting. Finally, faculty members noted that students must work to find their place in professional mathematics through preparing for their careers, achieving personal and professional balance, and finding their "fit" in the field.

Conclusion

Although students and faculty agreed on the importance of community, the need for graduate students to find a personal and professional "place," and the increased academic level of difficulty associated with graduate school in mathematics, their perspectives on the consequences of academic under-preparation, relationships between faculty and graduate students, psychological characteristics' role in graduate student success, and the focus of a graduate program varied widely. In Chapter 5, these similarities and differences, as well as the student and faculty results presented above, will be examined in light of their impact on the students' ultimate transitions to graduate school. The usefulness of these results to graduate programs, departments, and the profession will also be explored through recommendations and suggestions for future research.

Chapter 5: Discussion

While many factors related to mathematics graduate students remain unexplored, this case study took a qualitative look at the transition to graduate school in mathematics. Chapter 4 presented thematic results from interviews with both graduate students and faculty members in the mathematics department of a large, Midwestern research university. This current chapter considers implications. First, the similarities and differences of results between those groups are discussed within the context of legitimate peripheral participation (LPP; Lave and Wenger, 1991). Then, the results are examined again using the research questions presented in Chapter 1 as a guide. Next, some recommendations for this and other mathematics departments interested in improving this transition process are laid out. Finally, I propose directions for future work in this currently under-researched area.

Similarities

The results presented in Chapter 4 utilized students' and faculty members' own words to describe key aspects of the transition to graduate school from both of these points of view. Student and faculty perceptions appeared to be similar for some aspects of the transition to graduate school: the importance of community, the search for a "place," and the increased academic load encountered in graduate study. This section uses the theoretical lens of LPP—the social theory of learning in which learning is situated in participation in a relevant community—to frame these similarities in relation to previous work.

Community. Student and faculty participants all stressed the instrumental role that the academic and social community of their peers played in students' ability to thrive in their initial graduate work (and in their ultimate success in graduate school). Students and faculty both indicated that a lack of interaction could isolate new graduate students. One faculty participant stated this eloquently: "Mathematicians tend to interact less than they should, both scientifically and socially. I would hope it is better for graduate students than it is for faculty, but I suspect math interaction is below average, or much below average" (F07). These participants indicated that community support could aid both academic achievement and social acclimation for new graduate students. In fact, the one participant who felt as though graduate school had been a truly competitive experience, rather than a community effort, was also the only participant who had decided not to pursue a Ph.D. While this evidence is circumstantial at best, it does seem to emphasize the importance—at least, for some students—of a sense of support among the mathematical community in graduate school.

Many students further relied upon both the academic and the social support of their community of practice[12] (here, the mathematics department at their university) to overcome the unexpected sense of isolation they had experienced early in their graduate careers. This conclusion is consistent with Herzig's (2002) findings that "participation in the academic and social communities of the department is a critical factor in doctoral student persistence" (p. 206) since initial success based on this community support would likely promote continued persistence in the program of study (and, thus, continued membership in the supportive community). Furthermore, Lave and Wenger's (1991) theory of LPP maintains that newcomers to a community of practice need to

[12] Wenger et al. (2002) identify communities of practice as "groups 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" (p. 4).

engage both with other members of the community and with tasks relevant to that community's work. In this framework, both collaborating with peers on assignments or discussions of course material (tasks relevant to the mathematical community's work) and socializing with those peers (or engaging with members of that community) are a necessary part of the transition into the new academic community of graduate school.

Faculty members also appeared to believe that interaction with other graduate students was the best resource for new graduate students to learn how to overcome initial struggles in their graduate programs. Within the academic community, most of this support came from students' classmates, as well as other peers in the graduate program, who could assist with new content through collaboration and friendly, motivational competition. Faculty members further noted that more experienced peers helped students adjust to the "ins and outs" of their new roles as instructors and to the expectations (academic and otherwise) of department faculty. These interactions with peers and graduate student "mentors" helped new students establish themselves as part of the professional mathematical culture they had recently joined. Moreover, students and faculty agreed that the presence of any mentor—whether a more experienced graduate student, a faculty member, or someone completely outside of the department—would be beneficial to the development of these new students.

Incorporating intradepartmental mentoring, which has been related to success in mathematics (Carlson, 1999), connects incoming students to the departmental culture via a vertical (advanced graduate student or professor) sense of community. These connections, combined with the sense of community among peers (discussed above) and the relationships with professors (discussed below), could help students navigate the transition into graduate school more smoothly. Certainly, student participants indicated that by putting community to work in even this relaxed (but intentional) way, their needs during the transition to graduate school could have been met more effectively.

Finding a place. In addition to involvement in a community, both student and faculty participants noted that students had to identify their place in both professional mathematics and in the world beyond mathematics. Both groups emphasized the personal commitment necessary to pursue and complete an advanced degree in mathematics as well as the struggle some students faced in adjusting to the "competition" level of their newfound peers. Many students and faculty also agreed on the importance of finding a balance between their commitment to mathematics and their personal lives outside of mathematics.

Among other personal realizations, students observed that as they progressed through their graduate careers, their attitudes toward success, personal purpose, and the balance between academia and personal life often changed dramatically. They also implied that these realizations of themselves and their levels of commitment to mathematical study would have made a great impact on their transitions to graduate school if discovered sooner in their academic experience. Some faculty members noted that these types of realizations ultimately led many students to "find a place" outside of advanced mathematics—a decision respected by these faculty members.

Despite the fact that overcoming the inevitable obstacles of difficult material, research struggles, multiple sets of responsibilities, and a new social and academic environment was quite a challenge for some student participants, the graduate students in this study had managed to persevere toward their graduate degrees. And, while mathematical aptitude is important to obtaining an advanced degree in mathematics, the students interviewed for this project emphasized that their dedication to, or persistence with, their graduate work often played a more important role. Carlson (1999) also found that “persistence was the trait most frequently cited [by graduate student interviewees] as facilitating… mathematical success” (p. 244). Herzig (2002) noted that participation in “the academic and social communities of the department” (p. 206) played a key role in whether students persisted in their pursuit of a graduate degree.

As noted above, the sole interviewee who had decided not to continue pursuing a doctoral degree was one who had several negative things to say about the lack of community during his transition into the graduate program. While this could be viewed as an isolated case, researchers should also consider the role that transition experiences play in whether students persist toward the doctoral degree. Furthermore, for mathematics graduate students who do leave academia, a faculty who are equipped to share a variety of relevant life and/or career goals can help these students find their “place” within mathematics.

Academic load. Even though perseverance and a supportive community were key factors in student participants’ success, these characteristics are not sufficient for success in a graduate program; students must also master required course content. Accordingly, many students and faculty members alike stressed that an important part of the transition to graduate school was negotiating increasingly difficult and abstract mathematical content. Students and faculty alike acknowledged that new graduate students did not anticipate the true level of difficulty they would experience in terms of course content and the time and effort required to succeed in courses. Of course, some increase in difficulty was expected by students, and several of them even mentioned looking forward to this aspect of graduate school. But, as noted by Martin, Hands, Lancaster, Trytten, and Murphy (2008), “students actually seem to prefer courses that challenge them as long as they also perceive those courses as doable” (p. 111). For students whose prior knowledge was lacking in one or more areas, the challenge presented by some graduate courses was outside the scope of their capabilities and was thus a source of detrimental frustration—not a healthy challenge.

As indicated by Duffin and Simpson (2006), new graduate students often have to determine new ways to study and to process course material beyond those they used as undergraduate students. So, coping with this increased level of difficulty took some adjustment on the students’ parts. Both students and faculty noted the additional time, depth of engagement with material, and collaboration with peers that were needed to succeed in graduate classes as opposed to undergraduate classes. New students’ struggles with this academic load were particularly intense if their undergraduate preparation in certain areas was not up to the graduate program’s expectations. However, as discussed below, students and faculty members had differing views about the impact of prior knowledge deficiencies on students’ ultimate success in graduate school.

Differences

Although faculty and graduate student interviewees had congruous accounts of a number of key aspects in the transition to graduate school, these two groups’ perceptions, presented in Chapter 4, also diverged on a number of topics. This section focuses on student and faculty differences regarding students' academic preparation for graduate school, relationships between graduate students and professors, students' psychological preparation for this new academic experience, and the focus of the graduate program. As with the discussion of similarities above, these results will also be tied to related work in the field.

Academic preparation. Both students and faculty members noted that while graduate students may have transcripts showing requisite undergraduate coursework, some still struggle with key areas in graduate school. Prior knowledge deficiencies were noted in students from smaller, regional, or private universities, but these deficiencies certainly were not limited to students with these backgrounds. Even some students who had done their undergraduate work at the institution under study admitted to struggling with issues of preparation for graduate school. Although students and faculty members agreed that this lack of academic preparation exists, they disagreed about its impact. Faculty participants indicated that prior knowledge deficiencies were fairly trivial in students' experience, with one professor noting that these deficiencies do not affect graduate students' success "very much if it's just a knowledge deficiency" (F03). In contrast, several student participants noted that this lack of preparation caused noticeable stress: In addition to being frustrated at not being able to understand course material or homework assignments, they also had the additional burden of independently working to compensate for their lack of prior knowledge.

Due to the lack of understanding of the precise nature of prior knowledge expectations for graduate school, student participants had no standard way to know whether their undergraduate experiences had prepared them for the demands of graduate school. Without such information, students who struggled may have felt that there was no way to have been better prepared for graduate school. Moreover, Herzig (2002) notes that “students’ tendency to persist is decreased when they are faced with failure that they perceive to be beyond their control” (p. 204), so the lack of a consistent body of prerequisite knowledge may have ultimately resulted in a lack of motivation to persist (in addition to academic difficulty). Some programs—such as the National Science Foundation’s Research Experiences for Undergraduates, as well as numerous summer programs for women and minorities in mathematics (see, for example, Bozeman & Hughes, 1999)—have been developed to help students combat a lack of “mathematical maturity,” research experience, or specific content preparation. However, because they cannot address the specific expectations of faculty members in the student’s future graduate institution, and because they reach only a proportion of undergraduates, these programs may not be sufficient to overcome this difference in graduate student and faculty perceptions of the transition to graduate school.

Relationships with professors. In addition to the impact of under-preparation on students’ success, faculty and students also disagreed about the preferred nature of student-faculty relationships in graduate school. Many students noted that an important part of the transition to graduate school was negotiating new relationships with professors (or at least adjusting to professors’ teaching styles). These students typically viewed the change in relationships as negative; that is, the diminished personal contact (or approachability) from the relationships they had encountered as undergraduates negatively impacted their academic experiences in graduate school. Interestingly, these views of change were shared by students who had come from a variety of undergraduate institutions—including students who had completed their undergraduate degrees at the university under study! So, this sense of loss in interpersonal relationships with faculty members was not limited to students from any particular type or size of undergraduate institution. Furthermore, these comments came in response to questions about professors' expectations, the ways in which courses had changed since undergraduate school, and even compensation strategies. Thus, professors seemed to play an integral role in multiple facets of the academic experience for many students.

Despite students' generally negative perception, faculty mostly viewed these changes as positive. They noted that graduate students often work independently with a professor and thus receive more personalized attention than undergraduates in larger classes do. Furthermore, some faculty seemed to immediately view these new graduate students as "mathematicians in training," regarding them as "almost" faculty members and expecting them to participate in the larger department culture. Beyond the sense of community with their peers mentioned above, students also need a sense of community with faculty members, such as the sense that is established when they are treated as "junior colleagues" (Herzig, 2002, p. 201) by these faculty members. Spending time around these gatekeepers of the mathematical community helps students achieve both the mathematical ability and skill necessary to excel in the field as well as the social and cultural knowledge needed to feel like a true member of the professional mathematical community (Lave & Wenger, 1991). However, when faculty members and students see these relationships differently (in particular, when one group thinks relationships fulfill these community roles and the other doesn't), neither group is sensitive to the other's needs and expectations. Furthermore, since the quality of these relationships with faculty is a key component of students' success (Herzig, 2004b), these conflicting goals and perceptions may hinder students' progress toward a graduate degree.

Psychological preparation. Just as many students were not fully prepared for the impact of their changed relationships with faculty members, many also were unprepared for other psychological or emotional changes they would experience in graduate school. Furthermore, some faculty members mentioned a number of facets of psychological preparation for the demands of graduate school that student participants did not acknowledge. For instance, student and faculty participants agreed on the importance of dedication to the degree. Carlson (1999) also found that graduate students "both reported and were observed possessing strong persistence and high mathematical confidence" (p. 256). However, some faculty members also emphasized the need for a willingness or a desire to be immersed in mathematics that was not mentioned by student participants. While students did expect that increasingly difficult problems would require increasing amounts of time to complete (and, thus, seemed willing to commit to immersing themselves in this work while earning their degree; Carlson, 1999), very few of the student interviewees for this study mentioned the level of excitement for mathematics that the faculty participants seemed to convey.

Some faculty members further stressed the importance of independent work and outside reading as crucial to students' progress, although most students only mentioned consulting outside resources in the context of addressing a particular knowledge deficiency—not as a habit they were forming. This is consistent with Herzig's (2002) observation that faculty members "may assume that their students are as independent as they were," regardless of whether or not students saw this as a priority (or, even, a necessity).[13] Faculty participants also noted that graduate students must be more mature than undergraduate students (both personally and mathematically), a characteristic not mentioned by graduate student participants.

Program focus. Beyond psychological under-preparation, students also seemed ill-prepared for the culture and expectations that surrounded the graduate program. Students and faculty members seemed to have disparate views of what the focus of the graduate experience should be: Student participants seemed to expect an emphasis on department-level issues, such as degree plans, research expectations, and other issues crucial to their academic success, while faculty members saw the graduate program as a step on the road to membership in the wider mathematical community. Student participants wanted mentors to help them navigate the graduate degree; faculty participants trumpeted mentoring's ability to help in broader aspects of professional life. Thus, these two groups seemed to have divergent expectations for the focus of the graduate students' experiences in this program.

However, as noted in the LPP literature, to be truly successful in graduate school and beyond, students must learn the "ins and outs" of succeeding in graduate school and in mathematical culture more broadly. Realistic expectations of the nature of the degree path (e.g., sets of departmental exams to be passed, paperwork required by various campus offices, average time to graduation) and of the research process can be gleaned while students participate in the community in legitimate, peripheral ways. Unfortunately, many graduate programs in mathematics expect students to master

[13] Although students may not have viewed independence to be as critical to mathematics as their advisors did, Carlson (1999) did note that most mathematics graduate students are not afraid to independently work through given information.

prescribed content through coursework rather than encouraging them to "*think*, *act*, and *feel* as mathematicians do" (Herzig, 2004b, p. 389). For instance, Herzig (2004b) noted that, for the women students in her study,

> 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. (p. 390)

Thus, some students in transition from undergraduate programs do not have access to the authentic forms of participation that reveal these key bits of cultural knowledge. Students can feel lost and may go to great lengths to try to be successful within a system they do not truly understand, while faculty members assume that cultural knowledge is passed along with lectures about content. As explained below, informing realistic expectations for both students and faculty can help make this process of cultural transmission more effective for both groups.

Looking Back

In Chapter 1, I established that the purpose of this case study was to investigate the transition to graduate school in mathematics and to explore four research questions: What happens during the academic transition from undergraduate student to graduate student in mathematics? How do professors' expectations of new graduate students' mathematical knowledge affect students' success? How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies? How do attitudes, beliefs, and relationships play a role in the success of new graduate students in mathematics? Now that I have presented the relevant literature, methods used, results found, and implications for this work, I will revisit those questions to see how this research has contributed to the body of knowledge regarding mathematics graduate students.

What happens during the academic transition from undergraduate student to graduate student in mathematics? When student and faculty participants were asked this question, they gave a wide range of responses, including requests for a more specific question! Based on participants' initial and subsequent responses, I have composed the following list of concerns common to many students' transitions to graduate school and/or many faculty members' perceptions of these transitions:

Students felt academically overwhelmed. Although students expected an increased level of difficulty in graduate school, both students and faculty members felt the difficulty students experienced far exceeded their expectations.

Students were academically under-prepared. Student and faculty interviewees agreed that students were often under-prepared for graduate school. However, students claimed that topology was the area in which they were least prepared, whereas faculty members identified a key deficit in linear algebra.

Students felt socially isolated. Even those students who had stayed at the same university from undergraduate to graduate school mentioned feeling isolated. Others had to combat social concerns such as navigating a new town, adjusting to a new school, overcoming distance from their established support system(s), and finding new ways of functioning within the university.

Students found themselves teaching for the first time. Although most students commented favorably upon their teaching experiences, both students and faculty members discussed the adjustment these students went through to be comfortable on the "other" side of a classroom. This additional adjustment compounded the academic transition process.

Students wanted more information. Students specifically mentioned wanting more information about the pay process, health insurance, enrollment, and many other issues as they prepared for and went through their transition process.

These and other aspects of the transition are discussed in more detail elsewhere in this work. The goal here was to summarize interviewees' first impressions of this issue in response to a very broad question. The three remaining research questions provide more specific insights into the transition process.

How do professors' expectations of new graduate students' mathematical knowledge affect students' success? Faculty participants noted that having high standards of new graduate students' mathematical knowledge was important in order to maintain high standards of quality in the program. The existence of rigorous departmental criteria was reflected throughout in both faculty and student comments provided for this study. Both groups also noted that variations in course content and quality among various undergraduate institutions make it difficult for graduate admissions committee members to discern how prepared students actually *are* when they come to graduate school. Furthermore, beyond expectations of mathematical knowledge, faculty comments revealed that they also would like new graduate students to be psychologically prepared for the rigors of graduate work. But, how do these expectations impact students' success?

Students noted that their lack of expected prior knowledge often became a stumbling block to their academic success. At one end of the spectrum, students would have to take time away from current course material and assignments to shore up deficiencies with other content; at the other end, one student mentioned lying awake at night, worrying about these inadequacies. However, faculty members typically brushed these weaknesses aside, noting that they were "just" knowledge deficiencies and implying that students should have no issue catching up in most cases. A couple of faculty participants mentioned that new graduate students without the expected mathematical preparation could take some senior-level undergraduate courses to address some prior knowledge issues. Unfortunately, several students felt that even these courses were not adequate preparation for the demands they faced in their graduate coursework.

The interviews conducted for this study provide instances where professors' expectations of new graduate students' mathematical knowledge impacted students' success much more than those professors may realize. Even when expectations were made explicit to students—and several faculty participants admitted that they do not put much effort into this task—the charge to master a (sometimes) large body of new material can be particularly overwhelming to new graduate students who are learning how to master mathematics in a more independent setting. When coupled with the stereotypical lack of interaction in mathematical communities, which might otherwise provide academic or social support for this undertaking, students can quickly feel hopeless about their potential to succeed in graduate school.

How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies? As established in Chapter 4, the transition to graduate school is accompanied by an increase in content difficulty. Students faced the need to work harder, longer, and more independently on problems that were increasingly more challenging. Beyond this, however, they encountered issues of time management as they sought to balance teaching and coursework responsibilities, as well as their personal lives outside of the university. Time management issues were further confounded for those who found themselves compensating for prior knowledge deficiencies. With all of these pressures at hand, neither faculty nor student interviewees seemed surprised that some students would opt to leave graduate school.

But, how do the students who stay adjust to this rigorous new environment? One key attribute, emphasized strongly by both student and faculty participants, is perseverance—a desire to see the degree through to completion. Students who were "resigned to figuring it out at some point" (S14) seemed to have located resources to aid them in their commitment. When professors were "less approachable" (S14) than students would have liked, they turned to scouring the library and the Internet for resources to help them conquer new topics or solve a homework problem. Peers also helped with the adjustment process, either by providing a sense of camaraderie and commiseration (if at the same experience level) or by offering sage institutional, professional, or mathematical advice (if more experienced). For at least one of the two student participants who mentioned being fortunate enough to find a more experienced "mentor" graduate student to provide these forms of assistance, the difference made by these suggestions was the difference between staying in and dropping out of a graduate program.

Finally, it is worth repeating that some students do not fully adjust to the graduate school experience, whether by failure or by choice. That is, some try but are not able to succeed due to any number of personal and/or scholastic factors. Others decide that the end result simply is not worth the effort demanded, and, as F05 put it, "there's nothing wrong with that." Part of adjusting to the demands of graduate school—whether students stay or leave—is negotiating a "place" within the profession and its idiosyncrasies. Indeed, finding this "place" seems to be crucial to students' ultimate success, whether within or outside of academia.

How do attitudes, beliefs, and relationships play a role in the success of new graduate students in mathematics? Graduate student and faculty participants catalogued a number of attitudes or beliefs that could impact new graduate students' success. Both groups noted the importance of students, particularly those from smaller schools, learning to accept a ranking in the middle of the class when they were accustomed to being at or near the top. One faculty member expressed the idea that the ability to celebrate personal strengths, rather than to be consumed with the progress of others, is a key to success:

> Being able to focus in on your success without having it be compared to everybody else's success, I think that's a helpful mental place to be, and I think the sooner students can sort of have that realization, the better, the more happy they'll be. (F08)

Of course, both students and faculty also discussed the importance of dedication to the degree, coupled with the students' belief that they could succeed if they persevered. Many students emphasized a personal desire to excel in their studies, and this helped fuel their perseverance in the face of academic or personal difficulties.

Beyond this perspective, students also had to determine what attitudes toward work, school, and outside life best fit their needs and goals. A few faculty members in particular noted that choosing an academic trajectory that was commensurate with a student's life goals was essential to the student's ultimate happiness and success. Faculty interviewees also commented that students should have an attitude of "career preparation" throughout their graduate study, as well as the motivation to think and to pursue mathematics independently.

Relationships also played a role in the success of new graduate students. Both student and faculty participants agreed that relationships with peers were highly beneficial to students' success. While both groups also acknowledged that friends and family outside of academia could offer graduate students support and encouragement, the greatest (positive) impact was always attributed to fellow graduate students. However, relationships with professors were viewed differently by student and faculty participants. Faculty participants felt that their relationships with graduate students were stronger than those with undergraduates; in contrast, student interviewees indicated that there had been a loss of personal relationship with professors since coming to graduate school.[14] Thus, while relationships with peers helped students feel that they belonged in

[14] One notable exception to this was that students at the research stage of their degrees generally praised their primary faculty advisor, with whom they had specifically chosen to work.

mathematics and encouraged them to persevere in their studies, relationships with faculty members sometimes cast a shadow upon these goals. However, these relationships, as with all aspects of the transition to graduate school discussed in this work, are prime targets for future growth in this and other departments.

Recommendations

In this section, I will present both my own and participants' recommendations for departments and students experiencing this transition process. While some of the issues presented in this discussion are unique to the department involved in this case study, others seem common to many mathematics departments (based on personal experience as well as participants' comments). Thus, some of these recommendations are specifically designed to aid this department in the induction and retention of its graduate students, and some are designed to address this problem at a broader, profession-wide level.

Encourage community. Clearly, one key aspect of a student's successful transition into graduate school is the support of his or her peers (Herzig, 2002; Lave & Wenger, 1991). Both student and faculty participants were clear that the presence of an academic and social collaboration among students was critical to these students' success. Some professors emphasized that this community exists beyond departmental structures designed to "enforce" it and seemed pleased by students' initiative in organizing seminars and social events to foster academic and social community. While a sense of community which is authentically driven by students is much more effective than one simply imposed on the students, I recommend that departments continue to monitor and encourage the development of community within the graduate student body, particularly those graduate students who are in transition. This support should even extend to the provision of resources to facilitate community-building activities as appropriate.

In addition to a community at the graduate student level, faculty emphasized that new graduate students also become a part of the larger departmental community. These layers of interaction help prepare students for later involvement in the professional mathematical community and also provide additional support within the department. So, in addition to events that support community among graduate students, departments must also initiate activities that engage the entire departmental community—both socially and academically. By learning to engage in authentic professional activity in this variety of settings with a variety of "peers," graduate students will learn how to "*think, act*, and *feel* as mathematicians do" (Herzig, 2004b, p. 389)—and will be better prepared for the variety of activities they will encounter as part of their graduate school experience and beyond.

Provide mentoring opportunities. Beyond a basic sense of community, however, some faculty participants expressed an interest in creating a mentoring system similar to that utilized in the natural sciences.[15] The system would not need to center around a disciplinary area or research focus, but rather provide a group structure or scaffold to support new students through their first year (or more) of graduate school. As mentioned above, Carlson (1999) noted that mentoring has a positive effect on

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[15] Some faculty members referred to the fact that in most natural scientific disciplines, students are almost immediately matched with a laboratory or research group upon entrance to graduate school. These groups often consist of faculty members, postdoctoral associates, and more advanced graduate students who provide the mentoring and vertical sense of community that new graduate students need in an apprenticeship-type format.

graduate students' "mathematical success and problem solving abilities" (p. 256). Furthermore, implementation of a mentoring program would tie in to the emphasis on community made throughout this work and the relevant literature (see, for example, Herzig, 2002; Lave & Wenger, 1991; Wenger, 1998).

While student participants did not make specific reference to this group mentoring structure, several of them did request some action or program by the department to address this initial lack of knowledge by creating an established mechanism whereby they could tap into their more experienced peers as resources during their graduate experience. For example, S03 simply requested "someone that you could ask, or that was kind of assigned to you to talk to, or something." Students felt that this idea of a formal or informal pairing of graduate students to impart aspects of departmental culture and institutional knowledge (Herzig, 2002; Lave & Wenger, 1991) would have helped them combat isolation and a lack of key information in the initial stages of graduate school. Others have also noted the importance of "organized mentoring" (Bozeman & Hughes, 1999, p. 348) in graduate education (see also Herzig, 2004b).

Level the playing field. In addition to wanting a mentor available to discuss aspects of graduate student life as they emerged, students also wanted a way to glean information about prior knowledge expectations.[16] Furthermore, those students who had felt underprepared upon their entrance to graduate school wished they had been provided some way to attain an appropriate level of prior knowledge before classes

[16] Although general admissions criteria are available on the department's webpage, these criteria are purposefully left vague to allow students with nontraditional backgrounds to be eligible to apply.

began. Informing students about the prior knowledge required for graduate coursework could help them decide if they were truly prepared for graduate-level work, if they needed to exercise the option to take senior-level undergraduate courses during their first year on campus, or if they would prefer not to pursue advanced mathematics at this stage in their lives.

One remedy for the stress of prior knowledge deficiencies, suggested by S14, would be to have some kind of “Intro to Graduate Math” course or review manual available during the summer prior to the beginning of graduate school. This resource could help students feel better prepared for their future courses and, hence, make their future coursework more accessible to them. Such an idea has already been piloted at the secondary–tertiary transition level (Kajander & Lovric, 2005), although Kajander and Lovric (2005) noted that students’ individual motivation to utilize review materials would play a key role in the success of such a program.

Several faculty members also discussed the possibility of a “bridging program” between undergraduate and graduate school. Such a program could help students review key aspects of prior knowledge, expose them to talented peers in a low-stakes setting, or even help establish the attitudes that would serve these students well in their graduate work. Other faculty members noted that seminars conducted during the normal semester could provide additional preparation in particular areas of prior knowledge (e.g., linear algebra) or attitudinal support for graduate students who begin to struggle after a few weeks of difficult material. Whatever the format of the chosen program, however, the key factor in all of these ideas is that they help to level the playing field for students of all backgrounds who want to pursue advanced degrees in mathematics. By making expectations for prior knowledge explicit and by helping students to achieve those targets, faculty members provide all students the opportunity to succeed.

Inform realistic expectations. Beyond the role that mentoring and academic preparation programs could play in informing students of various departmental expectations, students wanted clear, accessible statements of key pieces of information about their graduate programs.[17] Several student participants mentioned that when they first started their graduate program, they had no idea what research was, how they would go about conducting it, why it can take so long, or how to seek a dissertation advisor. As noted in Chapter 4, dissemination of these research expectations earlier in the Ph.D. process could have helped students make important decisions about their futures in a more efficient and practical way.

Although some of this information could be found by combing through university and departmental documents, many of the participants' comments were more cultural in nature. For example, students and faculty both noted that students seemed surprised by the level of "competition"—or quality of their peers—that they experienced in graduate school as well as the decrease in class rank that many experienced as a result. Other students were taken aback by the amount of commitment required to master the new, more difficult content at the appropriate depth.

[17] It is worth noting that in the years following many of these students' entrance into the graduate program, the department made efforts to improve graduate students' quality of life. One area addressed during this time was the clear dissemination of information and expectations; however, in this section, I report student and faculty ideas about what they felt could make students' transitions smoother, whether currently relevant to the department under study or not.

Psychological preparation for these and other issues[18] could help students enter graduate school with clear expectations and a full knowledge of the sacrifices necessary to succeed.

However, informing students about these and other implicit expectations they will face in graduate school is not sufficient. Faculty members also need to understand the level of stress many students are under as they transition to graduate school. Department leadership should work to better inform faculty members about the actual level of students' preparation, especially prerequisite courses taken, so that these professors can organize their courses appropriately or provide structured supplemental materials for students who need assistance in a given area. Informing realistic expectations for these faculty members can help them maintain high academic standards, because when students feel a course is manageable, they are more willing to engage with difficult content (Martin et al., 2008). By taking these (and other) recommendations under consideration, departments can help provide all new mathematics graduate students with a more equitable chance at succeeding in graduate school.

Future Research

Although much has been uncovered through the exploration presented in this work, there is still much to discover about the transition to graduate school in mathematics. Based on the progress made for the research questions presented above, I submit the following suggestions for future research in this area:

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[18] Others have presented a variety of cultural issues—such as support for women and minorities—that students may face in graduate school in mathematics (see, for example, Bozeman & Hughes, 1999; Herzig, 2004a, 2004b).

Undergraduate preparation. As noted by faculty participant F05, the proportion of academically underprepared students entering graduate school begs the question, "What undergraduate preparation is needed to succeed in graduate work?" Are specific courses key to students' success in later study? Are relationships with undergraduate faculty members more relevant than specific content? Much work has been done to address curricula that affect the transition from secondary to tertiary mathematics, but there seem to be few definitive answers for this transition point.

Professors' expectations. Professors' expectations regarding students' preparation and performance have been broadly discussed in this work. However, these could be studied in greater depth within specific areas of focus, such as linear algebra or proof-writing, for beginning graduate students. Precisely what prior knowledge items are necessary within a given area? Are these common to all faculty members, or is there a wide variation in these expectations? How are these expectations conveyed to students?

Other populations. We now have some idea of how current domestic mathematics graduate students recall their transitions to graduate school, but the struggle for a successful transition to graduate school in mathematics is not limited to this group. How do undergraduate students who might be considering graduate school as a future option view their preparation for or possible transition to graduate school? What changes would they expect or prepare for? What would former graduate students who were never able to complete an advanced degree in mathematics say about their transition experiences? Just how much different is the transition to graduate school for international students? Do they experience an entirely different set of issues, or is there overlap between the two groups? Is the transition experience in other fields similar to or vastly different from that in mathematics? How do the views of these other populations affect the way we perceive the transition to graduate school in mathematics?

Other research sites. Naturally, extension of this research to additional universities can give us a broader view of the issues that affect students collectively (and, thus, should be addressed by national mathematics organizations) as opposed to those that are delineated by local circumstances. Furthermore, types of universities beyond large research universities should also be sampled to determine if the transition to graduate school involves similar concerns for students entering a different type of graduate program (or a program with no Ph.D. option). Knowledge of these factors and of those mentioned in the directions for future work listed above can help us refine and relate the factors involved in the transition to graduate school in mathematics until we have a more holistic view of these students' experiences. Understanding this transition as thoroughly as possible will help us to be most effective in smoothing this transition for the greatest number of future graduate students in mathematics.

Conclusion

As they progressed through graduate school, the graduate students interviewed for this study had to take on more and more tasks common to life as a mathematician. According to Lave and Wenger (1991),

> Moving toward full participation in practice involves not just a greater commitment of time, intensified effort, more and broader responsibilities within the community, and more difficult and risky tasks, but, more significantly, an increasing sense of identity as a master practitioner. (p. 111)

That is, as students became more involved in the teaching, research, and service activities common to a mathematician in an academic setting, they formed their own sense of identity as a mathematician. While this identity formation happens over time as students participate in a community of practice, early experiences with the transition help shape students' views of the field and of "master practitioners" therein.

Furthermore, while some things seem to be universal to the transition to graduate school in mathematics (such as the importance of community, the need to find a "place" within mathematics, and the increased academic load), others can be viewed quite differently by graduate students and departmental faculty (such as students' levels of academic and psychological preparation, the nature of student–faculty relationships, and the focus of the graduate program). These incongruous views can cause students to stumble, expectations to go unmet, or the necessary student–professor (apprentice–master) bonds within the professional community to be dismantled. Departments, as well as the profession at large, must be aware of the potential for unbalanced expectations and must work to prepare new graduate students academically, psychologically, and socially for the demands they will experience. Then, the field can produce more graduates who are satisfied, well-adjusted, high-achieving, and ready to take their place in the world of mathematics.

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Appendix A
Subjectivity Statement

This study was designed to explore the academic side of the transition to graduate school in mathematics. In particular, I wanted to investigate and document the struggles students face, the expectations they must meet, and the strategies they use to deal with this new chapter in their academic experience. Student participants were all mathematics graduate students at a large Midwestern university who had taken (or were taking) at least one of their department's three Ph.D. qualifying sequences—Algebra, Real Analysis, and Topology. This helped to ensure some commonalities among all participants' academic trajectories. These students were also all domestic students, since international students can face other complicating issues with such a transition, including the language qualification process required of non-native English speakers at this university. Faculty participants had either taught a Ph.D. qualifying sequence in the past seven years or had held an administrative position linked to graduate student life—such as Chair, Associate Chair, or Graduate Director—during that time.

As a domestic graduate student in Mathematics at a large Midwestern university myself, I had much in common with my student participants. I had similar experiences with Ph.D. qualifying exams and with subsequent general examinations. I came to graduate school from a smaller university with less rigorous mathematical preparation, so I, too, struggled with the transition to graduate school in mathematics. I was of a similar age, ethnicity, and regional background as many of my participants. I had also balanced the academic demands of graduate school with the professional demands of a graduate teaching assistantship—a balance both student and faculty participants mentioned in conjunction with the academic transition.

My interest in the academic transition to graduate school has grown from my own experiences during the first two years of graduate school and from the experiences of other graduate students who have started their graduate careers in mathematics during my time in graduate school. Thanks to some wonderful friends and fellow graduate students, I received the academic and moral support I needed to succeed in my graduate coursework. However, the poignant feeling of being overwhelmed with the academic demands of certain early graduate classes has stayed with me. I have channeled my own experiences into a desire to be a mentor and friend to incoming graduate students and to assist them with academic resources and support whenever possible—but that has not been enough. My informal observations of other graduate student struggles within my own department have led me to expect to find that graduate students in mathematics are not prepared as well as they could be for the experiences they have in their first year(s) of graduate school. The desire to assist these students has evolved into a research direction—one I hope will shed light on graduate students' early experiences with graduate mathematics and ultimately improve the transition experiences for these students.

As a current graduate student, I hope that my personal experience and "insider's perspective" into this transition will translate into an advantageous lens through which to interpret the data. I also believe my student participants related well to me as a researcher because we already shared many common experiences. That rapport should have led to the trust necessary to elicit honest, uninhibited responses from my participants. As my true interest in this research area and my desire to improve graduate students' experiences became evident, I hope that participants felt increasingly comfortable sharing personal experiences for the benefit of future graduate students.

However, my direct connections to these transition experiences could also limit the effectiveness of this work. For instance, I might make assumptions about the participants' meanings based on our shared experiences and relationships and might miss richer interpretations that a more objective analyst would find in the data. Also, a participant may have been less comfortable with me because of our relationship apparent similarities. If a personal dislike or concern about confidentiality within the department arises, the participant would likely be less forthcoming with responses, thus inadvertently biasing or tainting the data I collected.

Whether ultimately positive or negative in their effects on my research, my experiences with the transition to graduate school in mathematics have impelled me to delve into this research area. I hope that I can bring insight to this multifaceted transition through this study.

Appendix B
Student Recruitment Emails

Email to Recruit for Student Survey

Fellow Mathematics Graduate Students:

As many of you know, I am conducting educational research in pursuit of my Ph.D. in this department. For my research study (IRB Approval Number 13156), I am looking at how mathematics graduate students make the transition from undergraduate to graduate school. I need volunteers who would be willing to complete no more than two interviews with me to discuss their experiences as they started graduate school. In order to make sure I get a good variety of people to interview, I would like to collect some preliminary information from those of you who are interested in being part of my study. I have set up an online survey for you to fill out if you are willing to participate in the study. The survey is available at http://www.surveymonkey.com/s/VNGTKYD and should take less than five minutes to complete. It will be open until Friday, October 15. If you are selected to participate in the interview portion of the study, I will contact you via email by Tuesday, October 19 with the details. If you have any questions, you can contact me at sarah.marsh@ou.edu.

Thank you very much for your time and consideration.

Sarah Marsh

The OU IRB has approved the content of this message but not the method of distribution. The OU IRB has no authority to approve distribution by mass email.

Follow-up Survey Recruitment Email

Fellow Mathematics Graduate Students:

This is simply a reminder that I am looking for volunteers for my research study (IRB Approval Number 13156), which looks at how mathematics graduate students make the transition from undergraduate to graduate school. I need volunteers who would be willing to complete no more than two interviews with me to discuss their experiences as they started graduate school. In order to make sure I get a good variety of people to interview, I am collecting some preliminary information from those of you who are interested in being part of my study. I have set up an online survey for you to fill out if you are willing to participate in the study. The survey is available at http://www.surveymonkey.com/s/VNGTKYD and should take less than five minutes to complete. It will be open until Friday, October 15. If you are selected to participate in the interview portion of the study, I will contact you via email by Tuesday, October 19 with the details. If you have any questions, you can contact me at sarah.marsh@ou.edu.

Thank you very much for your time and consideration.

Sarah Marsh

The OU IRB has approved the content of this message but not the method of distribution. The OU IRB has no authority to approve distribution by mass email.

Email to Recruit Students for Interview

Dear (Student Name),

Thank you for responding to my survey about the transition to graduate school and for indicating your willingness to participate in an interview related to the transition to graduate school. To further my research in this area, I would like to set up a one-on-one interview with you to discuss your experiences surrounding the transition into graduate school. I am attaching a consent form for my study (IRB Approval Number 13156) to this email so that you may have the opportunity to learn more about the study and what is being asked of you. I will provide you with a hard copy of this form at the interview. The interview should last approximately 45 to 75 minutes. I have interview slots available on the following days / hours:

Mondays (10/25, 11/1, 11/8, or 11/15): beginning at or after 8 AM and ending by 11 AM
Tuesdays (10/26, 11/2, 11/9, or 11/16): 12:30 PM - 4:00 PM
Wednesdays (10/27, 11/3, 11/10, or 11/17): 8 AM - 11 AM, 2:00 PM - 4:30 PM
Thursdays (10/21, 10/28, 11/ 4, 11/11, or 11/18): 8 AM - 11 AM, 3:00 PM - 5:00 PM
Fridays (10/22, 10/29, 11/5, 11/12, or 11/19): 8 AM - 11 AM

Please let me know at your earliest convenience which time slot you would prefer. If none of these times are convenient, please let me know what times you are available, and we will work to find a mutually agreeable appointment.

Thank you very much for your willingness to participate in my research.

Sarah Marsh

Appendix C
Student Recruitment Survey Screenshots

Student Data

Exit this survey

Overview

Welcome, Fellow Mathematics Graduate Students!

You are being asked to volunteer for this research study, which is being conducted at the University of Oklahoma – Norman Campus. You were selected as a possible participant because you are a graduate student in the Department of Mathematics who has recently experienced the transition from being an undergraduate student to being a graduate teaching assistant in mathematics.

Please read this information and ask any questions that you may have before continuing with the survey.

The purpose of this study is to investigate what happens during the transition from being an undergraduate student in mathematics to being a graduate student in mathematics. More specifically, I am looking at what happens academically during this transition, how professors' expectations affect students' success, how new graduate students adjust to graduate school in mathematics, and what personal factors play a role in graduate students' success. I hope that through this study the transition to graduate school in mathematics can be made smoother for future mathematics graduate students.

Approximately 70 people received an invitation to complete this survey, while a total of about 25 people will take part in the interview portion of this study. If you complete this survey, you are agreeing to allow me to use your responses to select participants for the interview portion of the study. Your responses will be used for no other purpose, will be stored securely, and will be accessible to no one but me (the primary researcher). Participation in this study is voluntary. If you withdraw or decline participation, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

The survey should take less than five minutes to complete and has no known risks associated with it. There are no benefits of being in the study. You will not be reimbursed for your time or participation in this study.

If you have concerns or complaints about the research, the researcher conducting this study can be contacted at (405) 325-6711 or sarah.marsh@ou.edu. Alternatively, you may contact Dr. Randa Shehab, faculty sponsor, at (405) 325-3721 or rlshehab@ou.edu.

Contact the researcher(s) if you have questions or if you have experienced a research related injury.

If you have any questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than individuals on the research team or if you cannot reach the research team, you may contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu.

By moving to the next page of the survey, you attest that you have read the above information, have asked questions and have received satisfactory answers, and consent to participate in the survey portion of the study.

Thank you very much for your time and consideration.

Sarah Marsh

33%

Next

Student Data

Exit this survey

Part 1 - Degree Information

Each question refers to the Department of Mathematics at the University of Oklahoma.

1. In what semester did you enter graduate school in this department?

2. What degree did you declare or intend to pursue when you entered graduate school in this department?

3. What degree are you currently pursuing in this department?

4. Please indicate the semester in which you took the following qualifying sequence courses. If you did not take a particular course, please indicate "Did not take" in the drop-down box.

	Fall (I)	Spring (II)
Abstract Algebra (MATH 5353 / 5363)		
Real Analysis (MATH 5453 / 5463)		
Topology (MATH 5853 / 5863)		

Explanation of any of the above (if needed)

67%

Previous Next

Student Data

Exit this survey

Part 2 - Other Information

5. Please select your gender:

6. Are you an international student?

7. If you are willing to be contacted regarding participation in the interview portion of my research study, please indicate this willingness by providing your email address here:

8. If you have any comments or questions about the study or about any of your answers above, please share them here:

100%

Previous Done

Appendix D
Faculty Recruitment Email

Dear Dr. (Name),

As you may know, I am conducting educational research in pursuit of my Ph.D. in this department. For my research study (IRB Approval Number 13156), I am looking at how mathematics graduate students make the transition from undergraduate to graduate school. I am planning to interview students to learn about their transition experiences, but in order to gain multiple perspectives on (and, hence, a more complete view of) this transition, I would also like to speak with faculty members who have recently been involved with various aspects of this transition. In particular, I need faculty volunteers who would be willing to complete no more than two (and very likely, only one) interview(s) with me to discuss their experiences with teaching and observing new graduate students. I have included you in this list of potential interviewees because you have taught a qualifying sequence in the last seven years or have held a key administrative position in the department during that time. The interview(s) will last approximately 45 to 75 minutes. If you are willing to participate, or if you have any questions, please contact me at sarah.marsh@ou.edu.

Thank you very much for your time and consideration.

Sarah Marsh

Appendix E
Student Interview Protocol

Introduction
Hello! First of all, I want to thank you so much for agreeing to be interviewed today. I truly appreciate your time and your willingness to participate in my study. Before we begin, I would just like to assure you that all your responses will be kept confidential. I will use a pseudonym in place of your name when I transcribe or write about this interview so that your name will not be associated with your responses. To reassure you of the nature of this interview, what you can expect, and your rights during the interview, I have prepared a consent form for you to read and to acknowledge your consent to what we are doing today. I'll give you a few minutes to read the form. Feel free to ask any questions you may have. [*Pause for participant to read; get a signed copy of the consent form; answer questions as necessary*.] During the interview, if a question seems broad or abstract, please feel free to include any details you want. I may ask probing questions based on your responses. You are also free to "pass" on, or refuse to answer, any question at any time. Do you have any questions for me before we begin? [*Allow participant to ask questions; provide responses.*] Are you ready to begin? [*Once participant assents, begin interview.*] We're going to start by going over some basic information.

Interview Questions

I. Basic Information
1. When did you begin graduate school in mathematics at OU?
2. What degree were you planning to pursue when you entered the program?
3. What degree are you currently pursuing?
4. What qualifying sequence courses have you taken, and when did you take them?
5. What degree(s) did you have when you entered this program, and where were they from?

II. Describing the Transition

Key Question:

Describe the transition you went through as a student when you started your graduate program here.

Possible Probing Categories / Questions:

1. (Preparation) How well-prepared were you for the academic demands you experienced? Were there specific topics or subject areas in which you were particularly well-prepared or less well-prepared?

2. (Expectations) What things did you correctly expect? What did you not expect? Did anyone help you know what to expect? If so, who and how?

3. (Class Environment) What changed about your classes from undergraduate to graduate school, and what stayed the same? What was the most significant difference between undergraduate and graduate work? How did these changes impact your work habits / preferences?

4. (Assistance) How did the university / the department help prepare you for this transition? How was your experience with both formal and informal advising? How could things have been done better / differently to positively impact your success?

5. (Individual Experience) Were there particularly positive or negative moments during the transition that affected your perspective on or approach toward your courses? What was the biggest challenge you experienced during this transition?

6. (Comparisons) How do you think your experiences were similar to, or different from, other graduate students in your cohort? Other graduate students in the department? Graduate students in other departments?

III. Professors' Expectations

Key Question:

As a new graduate student, how did your professors' expectations of your mathematical knowledge affect your success?

Possible Probing Categories / Questions:

1. (Determining Expectations) How did you determine your professors' expectations in your courses at OU? How explicit were these expectations? How could they have been made clearer? Were you able to ask questions to better ascertain expectations, or did the professor(s) expect you to know already?

2. (Meeting Expectations) In what ways did your background meet or fail to meet these expectations?

3. (Effects) During the time you were working to determine these expectations, how was your understanding or performance in the course affected? How was your attitude toward the course affected?

4. (Initial Strategies) What factors impacted your choice of study strategies when you first entered? What people or experiences played the largest role? Were these strategies similar to or different from those used as an undergraduate?

IV. Compensation Strategies

Key Question:

As a new graduate student, how did you compensate for any lack of background knowledge or skills in your classes?

Possible Probing Categories / Questions:
1. (Strategies, etc.) What strategies, aids, or other support systems did you use, and what role did they play in helping you adjust? How else did you adjust to the course demands in graduate school?

2. (Others' Influence) How did others (professors, classmates, older graduate students, etc.) help you find strategies to adjust to these demands? How did you ask for help, or how was help offered to you?

3. (Recommendations) How successful were your strategies? What strategies would you recommend or not recommend to others in this position?

<u>V. Other Factors</u>

Key Questions:

A. How did attitudes and beliefs play a role in your success as a new graduate student?

B. How did relationships play a role in your success as a new graduate student?

Possible Probing Categories / Questions:

1. (General Impacts) How did this transition impact other areas of your life? How did things or people outside of the "academic world" play a role in your ultimate success or failure in certain classes?

2. (Attitudes / Beliefs) What attitudes or beliefs helped you succeed, and how? What attitudes or beliefs were detrimental to your success? What, if any, attitudes or beliefs, separated you from other graduate students (positively or negatively)?

3. (Relationships) How did relationships outside of the department influence your transition? How did relationships within the department (peers, professors, other personnel) affect your success? Who was most influential, and how did this person (or people) help (or hurt) you?

<u>Conclusion</u>
Is there anything else you would like to add related to any of the topics we have discussed today? [*Allow participant to respond.*] Now that you have seen my research topic in more detail, do you have any questions about this research project? [*Allow participant to ask questions; provide responses.*] If you think of any questions at a later date, or want to contact me later for any reason, here is my contact information. [*Hand participant a follow-up contact information sheet with my name, phone number, and*

email address.] In case I need to contact you later for clarification or for additional questions, could I also have your contact information? [*Have participant write down contact information.*] Great! Thank you again for coming to participate in my research study today. Have a wonderful day!

Appendix F
Common Student Interview Follow-Up Questions

During sections II-V in the Student Interview Protocol, I typically asked participants the key question for the section and then selected probing questions from the lists that followed. These follow-up questions varied somewhat among participants, but the following questions represent topics that were discussed with at least 10 of the 13 student interview participants. I have also included the key question and follow-up categories for each section for reference.

Section II: Describing the Transition

Key Question

Describe the transition you went through as a student when you started your graduate program here.

Common Follow-Up Questions

Preparation. How well-prepared were you for the academic demands you experienced? Were there specific topics or subject areas in which you were particularly well-prepared or less well-prepared?

Expectations. What things did you correctly expect? What did you not expect?

Class environment. What changed about your classes from undergraduate to graduate school, and what stayed the same? What was the most significant difference between undergraduate and graduate work?

Assistance. How was your experience with both formal and informal advising?

Individual experience. Were there particularly positive or negative moments during the transition that affected your perspective on or approach toward your courses?

Comparisons. How do you think your experiences were similar to, or different from, other graduate students in your cohort? Other graduate students in the department?

Section III: Professors' Expectations

Key Question

As a new graduate student, how did your professors' expectations of your mathematical knowledge affect your success?

Common Follow-Up Questions

Determining expectations. How did you determine your professors' expectations in your courses at OU?

Effects. During the time you were working to determine these expectations, how was your understanding or performance in the course affected? How was your attitude toward the course affected?

Initial strategies. What factors impacted your choice of study strategies when you first entered?

Section IV: Compensation Strategies

Key Question

As a new graduate student, how did you compensate for any lack of background knowledge or skills in your classes?

Common Follow-Up Questions

Strategies, etc. What strategies, aids, or other support systems did you use, and what role did they play in helping you adjust?

Recommendations. What strategies would you recommend or not recommend to others in this position?

Section V: Other Factors

Key Questions

1. How did attitudes and beliefs play a role in your success as a new graduate student?

2. How did relationships play a role in your success as a new graduate student?

Common Follow-Up Questions

General impacts. How did this transition impact other areas of your life? How did things or people outside of the "academic world" play a role in your ultimate success or failure in certain classes?

Attitudes/beliefs. What attitudes or beliefs helped you succeed, and how?

Relationships. How did relationships outside of the department influence your transition? How did relationships within the department (peers, professors, other personnel) affect your success?

Additional Question

During my first interview, I noticed that S01 often either implicitly or explicitly offered advice to future students or constructive criticism of the department. To make sure all participants had an equal opportunity to express such thoughts, I added one question to my original interview protocol just before the conclusion of each interview. This question was phrased similarly to this: If you could, is there anything you would like to tell the department or incoming students about the transition?

Appendix G

Faculty Interview Protocol

Introduction

Hello! First of all, I want to thank you so much for agreeing to be interviewed today. I truly appreciate your time and your willingness to participate in my study. Before we begin, I would just like to assure you that all your responses will be kept confidential. I will use a pseudonym in place of your name when I transcribe or write about this interview so that your name will not be associated with your responses. To reassure you of the nature of this interview, what you can expect, and your rights during the interview, I have prepared a consent form for you to read and to acknowledge your consent to what we are doing today. I'll give you a few minutes to read the form. Feel free to ask any questions you may have. [*Pause for participant to read; get a signed copy of the consent form; answer questions as necessary*.] During the interview, if a question seems broad or abstract, please feel free to include any details you want. I may ask probing questions based on your responses. You are also free to "pass" on, or refuse to answer, any question at any time. Do you have any questions for me before we begin? [*Allow participant to ask questions; provide responses.*] Are you ready to begin? [*Once participant assents, begin interview.*] We're going to start by going over some basic information.

Interview Questions

I. Basic Information

1. How long have you been at OU?
2. What qualifying sequences have you taught in the past seven years?
3. What administrative positions having any insight into graduate student life have you held in the past seven years?
4. Have you played any other role in helping new graduate students transition into this department in the past seven years?

II. Describing the Transition

Key Question:

Describe what you have seen students go through as they transition into a graduate program.

Possible Probing Categories / Questions:

1. (Preparation) How well-prepared are students for the academic demands they experience? Are there specific topics or subject areas in which students are typically well-prepared or very poorly prepared? Are these observations consistent among all students, or are they specific to certain groups of students?

2. (Expectations) What do students correctly expect / prepare for, and what do they not expect? Does anyone take time to help them know what to expect? If so, who and how?

3. (Class Environment) What changes from undergraduate to graduate classes, and what stays the same? How do these differences and similarities impact students' work habits? How should they impact these habits?

4. (Assistance) What resources or assistance are available for students during this transition? How could things be done better / differently to help students through this transition?

5. (Comparisons) Is this transition fairly consistent among all students, or do some students struggle (or excel) more readily than others? What characteristics do the students who struggle (or excel) possess?

III. Professors' Expectations

Key Question:

How do professors' expectations of new graduate students' mathematical knowledge affect students' success?

Possible Probing Categories / Questions:

1. (Determining Expectations) How do you communicate your expectations in graduate courses? Are you explicit with these expectations, or do you anticipate that students have a sense of what to expect?

2. (Meeting Expectations) Do students typically meet your expectations? When they do not meet expectations, to what do you attribute it? Are there common characteristics among those students who do not meet expectations? How do students' backgrounds match up with your expectations (particularly in qualifying sequences)?

3. (Effects) How are students' course performances affected while they determine how to meet your expectations? How does a student's struggle with prior knowledge affect his / her attitude, work ethic, and course performance?

4. (Initial Strategies) Are there strategies for surviving graduate mathematics that are different from undergraduate mathematics? How are these communicated to new graduate students? When and by whom?

IV. Compensation Strategies

Key Question:

How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies?

Possible Probing Categories / Questions:

1. (Strategies / Recommendations) How do you recommend that students compensate for any lack of background knowledge or skills when they are in your classes at OU? What strategies, aids, or other support systems would you recommend to help students adjust to the new academic demands?

2. (Others' Influence) How do students find these support strategies? What people are good resources for new graduate students struggling to find successful compensation strategies?

<u>V. Other Factors</u>

Key Questions:

A. How do mathematics graduate students' attitudes and beliefs play a role in their success or failure?

B. How do graduate students' relationships with others (both within and outside of the department) play a role in the students' success or failure?

Possible Probing Categories / Questions:

1. (General Impacts) How does the transition affect other areas of students' lives? How do things or people outside of the "academic world" play a role in students' ultimate success or failure in certain classes?

2. (Attitudes / Beliefs) What attitudes or beliefs seem to help them succeed? What attitudes or beliefs seem to be detrimental to their success?

3. (Relationships) How do relationships outside of the department influence students' transition into graduate school? How do relationships within the department (peers, professors, other personnel) affect students' success during this transition? How do these relationships help (or hurt) students?

<u>Conclusion</u>

Is there anything else you would like to add related to any of the topics we have discussed today? [*Allow participant to respond.*] Now that you have seen my research topic in more detail, do you have any questions about this research project? [*Allow participant to ask questions; provide responses.*] If you think of any questions at a later date, or want to contact me later for any reason, here is my contact information. [*Hand participant a follow-up contact information sheet with my name, phone number, and email address.*] Thank you again for coming to participate in my research today. Have a wonderful day!

Appendix H

Common Faculty Interview Follow-Up Questions

During sections II-V in the Faculty Interview Protocol, I typically asked participants the key question for the section and then selected probing questions from the lists that followed. These follow-up questions varied somewhat among participants, but the following questions represent topics that, with one exception, were discussed with at least seven of the eight faculty interview participants. I have also included the key question and follow-up categories for each section for reference.

Section II: Describing the Transition

Key Question

Describe what you have seen students go through as they transition into a graduate program.

Common Follow-Up Questions

Preparation. How well-prepared are students for the academic demands they experience? Are there specific topics or subject areas in which students are typically well-prepared or very poorly prepared?

Expectations. What do students correctly expect / prepare for, and what do they not expect?

Class environment. What changes from undergraduate to graduate classes, and what stays the same?

Assistance. What resources or assistance are available for students during this transition?

Comparisons. What characteristics do the students who struggle (or excel) possess?

Section III: Professors' Expectations

Key Question

How do professors' expectations of new graduate students' mathematical knowledge affect students' success?

Common Follow-Up Questions

Determining expectations. How do you communicate your expectations in graduate courses?

Meeting expectations. Do students typically meet your expectations?

Section IV: Compensation Strategies

Key Question

How do new graduate students in mathematics adjust to the rigors of graduate school and/or compensate for prior knowledge deficiencies?

Common Follow-Up Questions

How do you recommend that students compensate for any lack of background knowledge or skills when they are in your classes at OU? What strategies, aids, or other support systems would you recommend to help students adjust to the new academic demands? (These questions came from the "Strategies/Recommendations" follow-up category on the Faculty Interview Protocol.)

Section V: Other Factors

Key Questions

1. How do mathematics graduate students' attitudes and beliefs play a role in their success or failure?

2. How do graduate students' relationships with others (both within and outside of the department) play a role in the students' success or failure?

Common Follow-Up Questions

General impacts. How does the transition affect other areas of students' lives? How do things or people outside of the "academic world" play a role in students' ultimate success or failure in certain classes?

Attitudes/beliefs. What attitudes or beliefs seem to help them succeed? What attitudes or beliefs seem to be detrimental to their success?

Relationships. How do relationships within the department (peers, professors, other personnel) affect students' success during this transition?

Additional Question

To parallel the question added to the Student Interview Protocol (see Appendix F), I added one question to my original Faculty Interview Protocol just before the conclusion of each interview. This question was phrased similarly to this: If you could, is there anything you would like to tell the department or incoming students about the transition?

Appendix I
Codes Used in Data Analysis

Codes Used in Student Interview Data Analysis

Codes Related to Interview Questions/Topics
Preparedness
Expectations
Negative experience
Positive experience
Ugrad changes
Most significant
Formal advising
Informal advising
Comparison
Professor expectations
Determine expectations
Understanding/attitude
Specific subjects
Study strategies
Compensation
Recommend
Other areas
Success contributors
Attitudes/beliefs
Department recommendations

Codes Related to Themes/Concepts in Student Responses
Academic struggle
Adapt to professor
Advisor
Algebra
Analysis
Anxiety
Ask for help
Community
Competition level
Coursework
Dedication
Extra math
Extra textbooks
Family
Finding a place
Gender
Generals
Grad school decision

Grading
Group
Independent
Informing
Initiative
Isolation
Job preparation
Large school
Master's support
MathFest
Mentoring
Money
More difficult
Moving
New teaching style
OU
Outside social
Paperwork
Prior knowledge
Qualifiers
Quotable
Relationship with professors
Research
Seminars
Significant other
Small school
Staff
Teaching
Technology
Time
Time off
Topology
Tuesday Tea
Ugrad materials
Workload

Codes Used in Faculty Interview Data Analysis

Codes Related to Interview Questions/Topics

Preparedness
Student expectations
Course changes
Resources
Struggle/excel
Professors' expectations
Communicate expectations
Meet expectations

Strategies
Other areas
Outside social
Department culture
Attitudes/beliefs
Department recommendations

Codes Related to Themes/Concepts in Student Responses
Additional experience
Admissions
Aptitude
Career training
Commitment
Compare OU
Difficulty
Exams
Family
Finding a place
High school
Independence
International
Internet
Leaving grad school
Library
Mathematical culture
Maturity
Mentoring
MGSA
Mindset
Peers
Program commentary
Qualifier
Quotable
Relationship with professors
Relaxation
Seminars
Specific subjects
Struggle
Student Progress
Teaching
Time
Ugrad changes
Ugrad prep
Underrepresentation
Workload