2015

Missed Connections: a case study of the social networks of physics doctoral students in a single department

BOSTON UNIVERSITY

SCHOOL OF EDUCATION

Dissertation

MISSED CONNECTIONS: A CASE STUDY OF THE SOCIAL NETWORKS OF PHYSICS DOCTORAL STUDENTS IN A SINGLE DEPARTMENT

by

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Submitted in partial fulfillment of the

requirements for the degree of

Doctor of Education

2015

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And you may find yourself living in a shotgun shack

And you may find yourself in another part of the world

And you may find yourself behind the wheel of a large automobile

And you may find yourself in a beautiful house, with a beautiful wife

And you may ask yourself, "Well... How did I get here?"
-Talking Heads, Once in a Lifetime

Acknowledgments

In some ways, conducting this study is almost like a play within a play. My own social network has been imperative to where I currently am in life. Like many people, my life is not always easy or linear. My social connections have helped make life easier and richer.

These acknowledgements cannot fully express my gratitude. These people truly cannot be thanked enough. I include people who were directly involved in this project, as well as those who have been important in other work; I feel those in the latter category must have had an effect on my perspectives and approaches, though it is not as easy to say how. My acknowledgments are as follows:

My education since my undergraduate days at Smith College has been generously supported by the **Gates Millennium Scholars** program, which is funded by the Bill and Melinda Gates Foundation. Receiving such an honor still feels like a dream, even twelve years later. While I do not wish to trivialize the financial support, which was critical for me every step of my post-high school career, the opportunities and social support they have provided mean so much. I have been fortunate enough to attend some conferences that contributed to my growth in academia and as a person. I have met some of the most inspiring and kind people in my life through this program, as well as finding friends with whom I have an instant rapport. Among the staff and scholars, I have a true community.

The **Asian and Pacific Islander American Fund** (APIASF) has provided similar community and opportunities to grow. Particularly **Prema Chaudhari**, **Reeba Monachan**, and **Jacqueline Mac**, I always felt I had somewhere to turn when life became difficult. They have provided many opportunities to learn not only about Asian and Pacific Islander Americans but also general issues concerning research.

David Campbell, professor of the Boston University Physics department, has been one of my most valuable sources of support throughout my time as a doctoral student. I consider him my mentor for my academic and professional development, but he has provided me with general support and encouragement in many areas of my life. His generosity and good will towards me is truly remarkable. Without him, this project and my completion of the doctorate would not have happened for a multitude of reasons. Many of the following contacts are thanks to him. I feel very lucky to have had someone like him in my life.

I have worked for **Bennett Goldberg**, professor of the Boston University Physics department, since I arrived at Boston University. Without hesitation, he chose to be my advisor. For that, I am forever grateful. I have learned a lot from working for him on other work at Boston University, which has been incredibly influential on how I approach research. He truly has contributed to my professional development during my time as a doctoral student. I continue to admire his tireless dedication and hardwork towards STEM education.

Laurel Smith-Doerr, professor of the University of Massachusetts- Amherst, was the mastermind behind this project. She was critical in developing this project and generally providing guidance. I always enjoyed talking with her about women in STEM issues.

Deborah Belle professor of the Boston University Psychology department, has been so generous with her time and support on this project as well as my professional development. Her insights have helped to improve upon this project, and her encouragement and warmth have helped me stay motivated and optimistic.

Laura Jiménez, professor of the Boston University School of Education, has provided useful advice as a member of my committee. I have really appreciated her insights and perspective on my dissertation work, as well as work within in the School of Education. She has been willing to make the time for me and my work, for which I am grateful.

Phitsamay Uy, professor of the University of Massachusetts- Lowell has been another supportive figure in navigating the doctoral student process. I always appreciate her empathy and concern for me, as well as her insightful and thoughtful feedback.

The American Institute of Physics' Statistical Center, particularly Roman Czujko, has warmly discussed research with me and offered any help they can. This has been much appreciated. These conversations have greatly influenced my work.

Phillip Tate, professor, of the Boston University School of Education, has been a consistent inspiration and influence for my teaching and how I approach my work in other areas of education. He always has been willing to help with any teaching questions or issues I have had. I appreciated his feedback and support on this project as well.

Eric Kolazczyk, professor of the Boston University Mathematics and Statistics, department answered my questions regarding statistics, taking the time to explain concepts and more subtle points to me. This help was much needed and much appreciated.

Erol Peköz, professor of the Boston University School of Management, provided feedback to further my statistical analysis and indulged me in research discussion.

Joel Tenenbaum, PhD alumnus of the Boston University Physics department, generously volunteered to proofread this dissertation over the summer. This service has truly been invaluable. He has been a wonderful source of support to me, always eager to discuss this project with me. His enthusiasm has kept my spirits up during some of the more challenging times.

Nagendra Panduranga and **Nima Dehmami**, personal friends of mine who are doctoral students in the Boston University Physics department, have answered my questions regarding the quantitative side of social networks. They too have been supportive and enthusiastic towards my work.

I have enjoyed working with and learned from **Reggie Jean** and **Manher Jariwala**, both of Boston University, on broad educational work. They have influenced how I approach research and made the work I do feel real. Like many of the people I have thanked, their dedication to improving education is admirable and inspiring.

My friends, from the Middle Eastern raqs sharqi community to Boston University physics graduate students and post-docs to Smith College friends, have all listened to me talking about this process and have been supportive throughout my time in the doctoral program. One needs the extra social support times, and my friends have been above and beyond supportive.

Lastly but certainly not least, I thank the **Jonas University physics department** and the student participants. The Jonas University physics department, for allowing me to conduct this study, and the participants for taking the time to be so thorough in their responses. I thank the interview participants for their candid responses and their willingness to share personal stories. I imagine it may have been difficult to be open to a stranger in a publishable study. The study truly could not have happened without them.

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ABSTRACT

Gender disparity is an issue among the many science, technology, engineering, and mathematics (STEM) fields. Although many previous studies examine gender issues in STEM as an aggregate discipline, there are unique issues to each of the fields that are considered STEM fields. Some fields, such as physics, have fewer women graduating with degrees than other fields. This suggests that women's experiences vary by STEM field. The majority of previous research also examines gender and other disparities at either the nationwide or individual level.

This project entailed social network analysis through survey and interview data to examine a single physics department's doctoral students in order to provide a comprehensive look at student social experiences. In addition to examining gender, other demographic variables were studied to see if the results are truly associated with gender; these variables include race/ethnicity, year in program, student type, relationship status, research type, undergraduate institute, and subfield. Data were examined to determine if there are relationships to social connections and outcome variables such as persistence in completing the degree and the time to degree. Data collected on faculty were used to rank faculty members; data such as h-indices and

number of students graduate over the past 5 years were collected. Fifty-five (55) of 110 possible participants completed the survey; forty-three are male, and twelve are female. Twenty-eight of the fifty-five survey participants were interview; twenty-three are male, and five are female.

Findings for peer networks include that peer networks are established during the first year and do not change drastically as one progresses in the program. Geographic location within the campus affects socializing with peers. Connections to fellow students are not necessarily reciprocated; the maximum percentage of reciprocated connections is 60%. The number of connections one has varies by network purpose, with students having more connections for the more social purposes. Students are isolated when working on their research, even in their early years. Research discussion does not occur, unless one is providing casual updates to a peer.

Findings for student-faculty networks indicate that these relationships are important but complicated. Advisor selection is often done casually, even when one is switching advisors. Faculty have a lot of influence on the doctoral students such as motivating research collaborations among students or aiding in the job search. Most doctoral students feel as though there is a power dynamic that hinders them from socializing with faculty and thus, are not close to the faculty. Opportunities to develop stronger relationships and for professional development are often missed. The total number of peer and faculty ties has significant relationships to whether a student considers leaving the program.

Analyzing the qualitative and quantitative data through demographic variables showed how complex these experiences are. All demographic variables indicated there are statistically significant differences in social experience among the groups, though the extent varies. The year in program variable showed the most differences among cohort years, primarily with those in the fifth year. While gender showed few differences, women tended to have more homophilous peer networks than men and women tended to have more connections to higher prestige faculty. The race/ethnicity, student type, undergraduate institute, subfield, and relationship status variables produced few statistically significant results. Peer networks have statistically significant differences in homophily when examining research type.

The regression model suggests that being female, having a higher year in the program, and/or completing undergraduate studies from a liberal arts college increases the time to degree. Being in a relationship (dating or married) and/or working on experimental research decreases the time to degree. Only research peer network and departmental information network variables remain in this model.

Suggestions for further research for both physics/STEM education and social network analysis are included. Suggestions for ways in which the Jonas University physics department can improve its climate are also included. Although these suggestions are written based upon the Jonas University data, they may be applicable to other physics/STEM graduate programs.

Contents

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List of Abbreviations

AAPT	......	American Association of Physics Teachers
AIP	......	American Institute of Physics
APS	......	American Physical Society
BIO	......	Biophysics
CM	......	Condensed Matter physics
d.f.	......	Degrees of Freedom
FGSA	......	Forum on Graduate Student Affairs
GPA	......	Grade point average
GRE	......	Graduate Records Examinations
HE	......	High Energy physics
HF	......	Higher Prestige Faculty
HFW	......	Higher Prestige Faculty, weighted out-ties
HLM	......	Hierarchal Linear Modeling
LF	......	Lower Prestige Faculty
LFW	......	Lower Prestige Faculty, weighted out-ties
NSF	......	National Science Foundation
PI	......	Principal Investigator
S	......	Staff
SW	......	Staff, weighted out-ties
STEM	......	Science, Technology, Engineering, and Mathematics
TFGE	......	Task Force on Graduate Education
TF	......	Typical Prestige Faculty
TFW	......	Typical Prestige Faculty, weighted out-ties
W. In-ties	......	Weighted-In ties
W. Out-ties	......	Weighted-Out ties
WOC	......	Women of Color

Chapter 1

Introduction

The term "social networks" has become part of our colloquial lexicon in recent times through the development of websites such as Facebook and LinkedIn or as career gatherings commonly referred to as "networking" events. In academic study, social networks are not merely connections created through websites or business contacts but are a way to study interactions among people or organizations. These interactions, referred to as ties or connections, help to create friendships, collegial relationships, and other forms of social support. Studying these networks provides a means of seeing how interactions and connections between individuals are a part of a larger picture. Kadushian (2012) describes social network analysis in the following way:

> We live surrounded by them [networks] but usually cannot see more than one step beyond the people we are directly connected to, if that. It is like being stuck in a traffic jam surrounded by cars and trucks. The traffic helicopter can see beyond our immediate surroundings and suggest routes that might extricate us. Network analysis is like that helicopter. It allows us to see beyond that immediate circle. (p. 4)

This aerial view can also aid in identifying patterns among members of a group, such as whether individuals of certain demographics are connected in the network but are not connected to individuals of a different demographic.

Because of this perspective, network analysis is a natural fit for studying how individuals in an institute or organization interact. Studying doctoral students in science, technology, engineering, and mathematics (STEM) fields through network analysis is a particularly good fit, due to the number of social networks in which they participate. Doctoral students in all disciplines may seek support for a variety of reasons, from personal to professional, but doctoral students in STEM fields may need to work with fellow students in laboratory settings to learn research techniques or complete coursework. Some experimental research requires teamwork; for instance, one person may need to operate a data-acquiring computer while another manually operates the microscope. Because collaboration may be a necessity to students in STEM fields, understanding their social experiences becomes even more crucial than in other fields.

Social network analysis may also be useful for studying differences in the social experiences of STEM students. These differences in social experiences include demographic variables such as gender. Women in STEM fields are frequently studied because of noticeable differences when compared to men in STEM fields. Much of the current research suggests that female STEM doctoral students, particularly those in fields where women are underrepresented, may find challenges in network participation. Some women have found that the institutional social environments exclude women (Benckert and Staberg, 2000; Rosser, 2004; Blickenstaff, 2005; Fox and Colatrella, 2006). Others more specifically have felt a lack of support from their advisors (Fox, 2004; Ferreira, 2003). These factors may culminate in missed opportunities to form strong network connections. Rather than overt sexism, these more subtle social reasons may be a contributing factor behind the national trends of low female participation in STEM fields, as well-qualified women tend to leave these fields at higher percentages than men (Blickenstaff, 2005). Using a social network analysis lens to study female STEM doctoral students and their social connections may further our knowledge on barriers women face in STEM fields.

While the study of women in STEM typically entails studying women in multiple fields, the experiences of women may not be universal across the STEM fields. Data collected by the National Science Foundation (NSF) show that while the percentages of women in STEM have increased over the past 30 years, not all fields experience the same gains. In 2008, fifty-percent (50%) of the PhDs in the biosciences (biology, molecular and cellular biology, environmental biology, and agricultural sciences) were earned by women, while women in the physical sciences (chemistry, physics, and earth science) earned approximately 30% of the doctoral degrees (NSF, 2011).

By disaggregating the physical sciences category, the percentages of individual fields show non-uniform trends. In 2003, approximately 33% of chemistry doctorates earned were held by women, while approximately 16% of physics doctorates were earned by women (Ivie and Ray, 2005). This difference in representation amongst the physical sciences suggests that women in specific fields may have very different experiences within their programs of study. Some of the challenges to participating in social networks may be more prevalent in some fields, contributing to the differences in female degree completion. Because of these STEM field differences, the study in this dissertation will only focus on one STEM field, physics. Physics is of particular interest because, while it has experienced some progress towards gender equity, the field has not experienced the same progress towards gender equity as math or other sciences experienced (NSF, 2011).

The department as a whole and other demographic variables are also examined. The department as a whole is examined to provide a general characterization of interactions within the network. Other demographic variables are considered in order to determine if what is being observed is a result of gender or another a variable.

This dissertation is organized in the following format: chapter 2 delves into literature related to women in physics and graduate student social networks. The chapter begins by reviewing the current body of research related to women in physics. While each STEM field may have a unique social atmosphere and different percentage of degree completion for women, much of the prior research that I will review focuses on women across multiple STEM fields. Similarly, a large body of research examines undergraduate women and women with PhDs in STEM. Wherever possible, I have incorporated literature that focuses specifically on graduate student social support and networks in the field of physics.

The literature review includes research beyond women in STEM. To ensure the reader is familiar with social network concepts and terminology, I have included research related to the broader field of social network analysis. This includes literature on social network data collection. This is followed by literature related to the purposes for which doctoral students may participate in networks, from coursework to research. These networks have both peer and faculty participants. Research on how an individual's identity affects network participation and departmental social climate are also included. Lastly, the chapter concludes with the research questions for this study.

Literature on other demographics is included in this chapter. Every person has multiple demographic identities, such as race and age, that may affect one's experiences. Intersectionality, a theory that looks at how multiple dimensions affect one another, may be important to understanding doctoral student experiences. Female international students may have different experiences than female students from the U.S. Relevant research on STEM working professionals is included, because STEM doctoral students are both students and employees. They are learning either in coursework or through working in labs, but they often receive modest salaries from research or teaching. I have also included research on the social networks in other fields of graduate study, because the social experiences of students or workers in non-STEM fields may be applicable to STEM graduate students. In particular, I have included literature on fields where the research suggests that the experiences of men and women are quite different from one another.

After the literature review and research questions in chapter 2, the methodology in chapter 3 is discussed. Data collection took place from September 2013 through mid-December 2013. The study site is one physics department located in the New England area. It is considered to be one of the top 50 physics departments in the United States, according to the *US News and World Reports* rankings.

This study is mixed methods, incorporating both survey and interview data. The survey and interview protocols are in the appendix in chapter 6. The survey questions are in regards to both peer and faculty connections. The questions delve into the specific reasons, such as research or socializing within the department, why students connect with various individuals. Demographic data were collected, as well as data related to outcomes, such as degree completion, and attrition. Interview questions delve into how networks form, what information is received, and any difficulties in social experiences. Data on faculty, such as the number of students advised and number of publications, were collected through departmental annual reports and online searches.

The analysis techniques are discussed in the methodology chapter. These include which network attributes are examined and which statistical analysis, such as t-tests are used and when. A regression model using the departmental report data was developed to rank faculty. Beyond traditional network attributes, such as determining how many connections participants have, network attributes are incorporated in regression models and chi-squares to determine if network behaviors are related to the time taken to complete the degree and possibility of attrition. All of these data were analyzed with consideration to various demographic variables, such as gender or whether one is an international student; this was done to ensure any observed differences are truly because of gender. My role as the researcher is also included in this chapter.

Results are displayed in chapter 4. Data are presented in order of research question. The physics doctoral students in this study are connected to one another, but there is no universal experience. Some students have more connections than other students. Students also have varying numbers of connections for purpose; for example, one student may have a different number of connections for research for socializing. Analyzing the data through demographic variables indicate there are demographic differences, including gender. The interview data provide further insight into the survey data, providing possible explanations for what is observed.

In chapter 5, the results are discussed. I provide a list of suggestions to support doctoral students in physics; this list is tailored to the department featured in this study but may applicable to other departments. Because the study has generated new questions, further areas for research are included.

Chapter 2

Literature Review

This chapter covers a variety of topics related to gender, international students, race, graduate school, physics, STEM, and networks. Each topic is important to understanding what is known and what has been done to work towards gender parity. Both pedagogical and sociological research is included, because both have been studied in the context of the afore-mentioned demographics. I include literature on social network theory and research techniques to ensure the reader understands the details of the research in this chapter. Theoretical models on student persistence and degree completion are also included. Through drawing upon the research on variables that affect degree completion, these models organize the variables in order to understand how they affect student persistence. Drawing upon all of the research discussed in this chapter, I conclude chapter 2 with the research questions and related hypotheses for this study.

2.1 Physics Pedagogy and Diversity

As noted in chapter 1, STEM fields are not homogeneous. The percentage of women who complete STEM degrees varies according to field, with physics having a lower percentage of women compared to other sciences (NSF, 2011). Comparing STEM fields to one another is important to demonstrate that certain fields, such as physics, may have barriers or challenges that hinder women.

In an article featured in *Physics Today*, Trefil and Swartz (2011) suggest that the question to ask is why are there so few women in physics compared to other sciences, rather than simply asking why are there so few women in physics. According to Trefil and Swartz, the more nuanced question compares physics to other disciplines within

STEM. This negates the arguments that claim talent and ability are the reasons why there are so few women in physics. These arguments include men having abilities more suitable for science than women, physics is too mathematical, and socialization reasons; an example of socialization is young boys may be socially conditioned to develop traits that are more suitable for science. These reasons should apply to other STEM fields and do not; other science fields have gender parity, and half of the mathematics majors are women (NSF, 2011; Trefil and Swartz, 2011).

Trefil and Swartz explain this difference by noting that multiple issues exist for women in physics. They emphasize one issue: problem sets. Problem sets in physics may include word problems that are designed to relate to the world in order to engage students. For instance, a problem on acceleration may be based on driving a car. Swartz, who was a female student in an introductory mechanics course at George Mason University, noticed that physics problem sets may include details that are unfamiliar to women. While the article is more of an opinion piece, it anecdotally reveals that problem sets may contain gender bias.

Other studies focus on addressing gender issues in the context of curriculum and pedagogy. In a literature review presented at a conference, Dancy (2004) suggests that educators change the curriculum to be more inclusive. The Force Concept Inventory (FCI), a test which was designed to test physics understanding using conceptual multiple-choice problems, may suffer from gender bias because of how the questions are worded. Several studies have shown that the FCI results vary with gender (Dancy, 2004). One study cited in this literature review shows that changing the imagery, not the physics, to be more female-friendly (using less violent imagery, for instance) has produced favorable results for women.

Research suggests there are general pedagogical barriers in physics. In *They're Not Dumb, They're Different*, Tobias (1994) studied adults who enrolled in either a chemistry or calculus-based introductory physics course. The seven adults in this study had demonstrated science aptitude in high school but chose to pursue non-STEM fields. They either had received or were pursuing advanced degrees in other fields, but they still had an appreciation for science. The participants in this study took field notes on the course material, the professor's teaching style, and the classroom atmosphere.

Tobias found that physics and chemistry curriculum and culture are set up such that these fields may exclude certain students. The coursework was found to be dull, and professors did not encourage questions from students. The class material seemed insular to the course rather than placing it in the broader context of the field. To ensure the validity of the study, Tobias' results were compared to a 1978-1983 study of 300 students from Harvard-Radcliffe. One group had high aptitude but varying in levels of interest in science, while the other group showed varying aptitude but high levels of interest in science. Tobias notes that while there are differences between the two studies, the Harvard-Radcliffe study contained similar student reactions to the course structure, pedagogy, and material. Although the sample size is seven students and in a particular context (summer school), Tobias' study does provide evidence that physics and chemistry education has particular pedagogy and culture that may dissuade some talented and interested students. What is interesting to note is that Tobias' study indicates barriers within the broad area of the physical sciences, national trends indicate that chemistry is closer to gender parity.

Since Tobias' study, efforts have been made to improve physics education. Whitten and Burciaga (2000) describe various course reforms for undergraduates developed by several universities to address issues observed in physics courses. The reforms include *Physics by Inquiry* and *Workshop Physics* (WP). *Physics by Inquiry* is aimed at non-physics majors, while WP is designed for physics majors. Both physics curricula promote an interactive learning environment. According to one study on WP, the results are mixed. While these classes enroll a larger percentage of women, respondents are unsure if they are learning the material. The respondents also disliked the amount of time active learning takes. Course reform can go beyond classroom structure and modify the way in which content is taught (Whitten and Burciaga, 2000). Thomas Moore of Pomona College created the *Six Ideas that Shaped Physics* curriculum. The series emphasizes concept development over problem-solving. The series begins with conservation laws rather than kinematics (motion without consideration of force).

The series also emphasizes modern physics (quantum mechanics and relativity) in order to be more interesting to students.

Although these efforts are concentrated at the undergraduate level, reform is needed at earlier stages. Taasoobshirazi and Carr (2008) point out the interaction of multiple variables within the gender achievement gap for physics is not addressed. For instance, girls tend to lack hands-on experience and rely on rote memorization, which can allow for success in K-12 but be problematic for college-level physics. McDonnell (2005) suggests the combination of curriculum and social factors may affect one's decision to pursue physics. From interviews with 17 high school students (9 male, 8 female) who were in an advanced physics course, McDonnell found the students perceived physics as lacking places for creativity.

At the graduate level, curriculum and pedagogy do not appear to have the innovation seen at the undergraduate level. A task force was created by the American Association of Physics Teachers (AAPT) and American Physical Society (APS), both sub-organizations of the American Institute of Physics (AIP). Calling themselves the Task Force on Graduate Education (TFGE), they examined graduate physics curriculum. Their motivation to do so was out of concern that graduate physics curriculum either weakened or became stagnant and that students were not adequately prepared for life beyond graduate school (Campbell et al., 2006).

By using both data previously collected by the AIP's Statistical Center and creating a new online survey, they studied multiple aspects of the general experience of graduate physics education. The new survey's response rate was 114 out of 186 PhD-granting departments. Information for non-responding universities was found online, bringing the total of participants to 137 departments. The TFGE additionally surveyed the Forum on Graduate Student Affairs (FGSA). FGSA is an APS organization with graduate (master's and PhD level) student and postdoctoral members in applied math and physics. The response rate for this 13-question survey was 50 responses out of 1000 members of FGSA (Campbell et al., 2006).

The TFGE found that traditional core coursework (classical mechanics, electricity and magnetism, statistical mechanics, and quantum mechanics) is required in over

75% of the programs (Nicholson et al., 2005). Standard textbooks in some courses are still heavily used. Seventy-six (76) out of 80 departments use J.D. Jackson's electricity and magnetism book. Forty-eight (48) out of 64 departments use Goldstein's classical mechanics book. However, within the past 5 years of answering the survey, forty (40) out of 96 departments had changed their course requirements (Nicholson et al., 2005). Based on the survey results, the TFGE recommended that physics departments require a core curriculum to ensure a breadth of knowledge. They also recommend offering opportunities to develop machine shop, grant writing, and public speaking skills (Campbell et al., 2006).

Physics education research has indicated curricular and pedagogical issues exist in both high school and undergraduate physics courses that not only may affect women but also may affect men. These issues are as follows: language in problem sets that excludes particular demographics, such as women; coursework that does not promote creativity and interest; and no understanding of where the course materials fits in a broader context. These issues have been addressed in various course reforms that involve restructuring the classroom environment to restructuring the order in which material is taught. The research indicates that a more innovative curriculum may encourage women to participate in physics.

Graduate physics education has not undergone similar reforms. There is little research on graduate education in physics, and the research that exists is on focused on improving the curriculum are for the general physics graduate student population. The suggestions aim to prepare students to be competitive in the job market, not necessarily to be more inclusive of students. This differs from much of the literature on high school and undergraduate physics students.

Although the research presented in this section is quite focused on curricular matters, the rest of the literature is not. The curricular matters certainly are important in learning. However, physics doctoral students have succeeded in undergraduate physics. The curricular innovations are concentrated in lower level physics courses, so physics students would eventually take courses that are taught in a traditional manner. Physics doctoral students also spend the majority of their time focused on research, not coursework. Because of these critical reasons, this study and the literature in the subsequent sections look at social issues.

2.2 General Social Network Literature

Social networks are studied across multiple fields. Statistics, physics, sociology, psychology, and education are among the fields that incorporate social networks in their fields. Different fields that study social networks use different terminology to describe some of the same concepts. For example, a person in a network may be described as a node, actor, or vertex. This section serves as a guide to the social network terminology used throughout the dissertation. By no means is this section exhaustive of all aspects of social network analysis and theory.

2.2.1 Social Network Terminology and Concepts

A network consists of the relationships among entities; a entity in a network can be a person, an organization, an object, et cetera. The most basic network is a dyadic network, which consists of two nodes in a relationship (Kadushian, 2012). As mentioned previously, the entities in a network can be called nodes, actors, agents, or vertices; for ease of understanding, I refer to entities as nodes. A relationship can be anything from a friendship to simply being in the same room. Relationships in a network are called ties, links, or edges. In this dissertation, ties or connections will be used to describe relationships. Depending on the network, multiple nodes may connect to form groups. Nodes that connect separate groups are called bridges. To illustrate what a bridge is, see figure 2·1 which displays a network depiction. There are 6 brown nodes in two separate groups. The blue node is a bridge between the two groups.

Ties may be negative or positive, depending on the relationship. Relationships can be directional, meaning that the relationship goes from one node to the other and not vice versa. For example, Ball and Newman (2013) studied friendship networks of high school students by asking them to select 5 female and 5 male friends from a list of names. The results include unreciprocated friendships, meaning that student

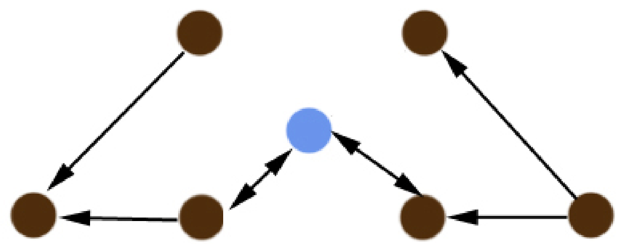

Figure 2·1: A depiction of a network. The blue dot is a node that acts as a bridge between the two groups of brown nodes. The black lines depict the ties between nodes. Each line has at least one arrowhead to portray the direction of the tie.

A named student B as a friend but not vice versa.

In this dissertation, ties are described as “in-ties” or “out-ties.” In-ties are directed towards the node, indicating that the node was selected. In figure 2·1, the first node in the group on the left has two in-ties. An example of this kind of relationship could be a financial network where renters pay their landlord; the landlord would have many in-ties to describe the direction of financial exchange. Out-ties are directed away from the node. In figure 2·1, the farthest node in the group on the right has two out-ties. An example of out-ties could be an information network where someone broadcasts an announcement over an intercom; the information would be received by others, who would be considered out-ties. Ties can be reciprocal, such as friendships or business partners. The ties to the blue node are reciprocal. In these depictions, the arrowheads indicate the direction of the tie.

Ties are described as absent (non-existent), weak, and strong. Granovetter (1973) defines strength of ties as the “amount of time [frequency of interaction and the age of the relationship], the emotional intensity, intimacy (mutual confiding), and reciprocal services [both nodes help one another]” (p. 1361). This theory draws upon positive and reciprocal ties. Weak ties are not necessarily negative. Granovetter (1973) argues that weak ties allow for information to diffuse, because one’s weaker ties exist in different social settings. The weaker ties have access to different information than stronger ties. One example that Granovetter (1973) provides is a group of people who recently changed jobs. These people predominantly found their new jobs through their weak ties, because their weak ties had professional contacts that the job seeker did not have.

Networks can be classified as egocentric, sociocentric, or open networks (Kadushian, 2012). Egocentric networks are networks in which one node is the focal point among other nodes (Wasserman and Faust, 1994; Kadushian, 2012). The focal node is called the "ego", and the connected nodes are called "alters." A business, as the ego node, and its clientele, as the alter nodes, is an example of such a network (Kadushian, 2012). Sociocentric networks are networks where there is a known boundary, such as students in a classroom or residents of a neighborhood. Boundaries can also be created by the researcher if no definitive boundary, such as a classroom, exists. The researcher must consider the research questions and data of interest when selecting a boundary (Scott, 2000). For instance, when studying student networks, one could include the classroom, or the entire school. The student networks would likely be different depending on where the boundary is drawn. Characteristics of the overall network would likely also be different. Open networks are networks where there are no clear boundaries. Kadushian (2012) uses the example of elite corporations and their networks.

The nodes within networks are often categorized in some manner, such as by gender or age. Members of a network are often similar in multiple ways; members may be people, organizations, or other entities. In social network analysis, this is called homophily. Homophily is often described using the phrase, "birds of a feather flock together" (Kadushian, 2012). Demographic characteristics such as race, class, gender, and sexuality may influence how groups form. For example, women in the sciences may prefer to socialize with their female colleagues. A common interest is also a way of observing homophily for a group of friends; people who participate on the same recreational sports teams or watch the same movies may form their own social groups.

Homophily should be considered cumulative, because social networks tend to consist of people who are similar in multiple ways. For example, chemistry doctoral students may be friends within the same social network. However, being a chemistry doctoral student may not be adequate to be included in an ego's network. Alters in this example may need to be at the same university in order to be included in the network. Race, gender, socioeconomic class, etc. may also determine who is and who is not included.

Centrality describes the relative importance or integration that nodes have in the network (Scott, 2000). There are several types of centrality that reveal different aspects of the network. Degree centrality measures how many ties a node has (Wasserman and Faust, 1994; Scott, 2000). Wasserman and Faust (1994) define degree centrality, C_D, using the following equation:

$$C_D = \frac{N_D}{g-1} \tag{2.1}$$

where N_D is the total number of ties a node has and g is the total number of nodes in the graph. Equation 2.1 considers degree centrality independent of direction; when direction is considered, the denominator is squared.

Scott (2000) notes that when possible, tie direction should be noted. As seen in the Ball and Newman (2013) paper, even friendships are not always reciprocal. The lack of reciprocity is related to the idea of prestige. Wasserman and Faust (1994) consider an actor to be prestigious if the actor is the recipient of many ties. In the Ball and Newman (2013) paper, the most popular students would be considered prestigious. To study prestige by this definition, the ties must be directional. Prestige can conceptually be described through other means, such as leadership or having a strong research profile; this is further discussed and applied in section 3.4.2.

Betweenness centrality is the measure of how frequent a node is the bridge to the shortest distance between other nodes (Wasserman and Faust, 1994; Scott, 2000). Shorter distances mean things can travel through the network faster. Things can range from information to objects to diseases. The blue node in figure 2·1 has the most betweenness centrality in the depicted network. Without the blue node acting as a bridge, the two groups of brown nodes would not be connected. For node j

and node k,Wasserman and Faust (1994) define betweenness centrality, C_B, using the following equation:

$$C_D = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}} \tag{2.2}$$

where g_{jk} is the number of shortest pathways between nodes j and k and $g_{jk}(n_i)$ is the number of pathways that include node i.

2.2.2 Social Network Data Collection and Analysis

Social network data are collected using the standard methods of collecting social science data: observations, surveys, and interviews. The difference is these methods are used to look specifically for social connections or lack thereof (Wasserman and Faust, 1994). Observations can be done in a variety of settings depending on the population. For example, to observe social interactions of doctoral students, one may attend departmental events (departmental lunches or talks), classes, study groups, or research groups. The advantages of observation are as follows: the researcher witnesses the interactions without participant bias, can collect data on both who is participating in social interactions and on the nature of those interactions (for instance, whether interactions are collegial or brusque), and does not rely on the participant's memory. Essentially, the researcher can observe the members of the department in their natural states. Observation can be useful to note details that participants may not notice or recall, such as facial expressions and pattern behaviors (Kadushian, 2012).

The primary disadvantages of observations are as follows: disturbing the naturally occurring system, being time-consuming on behalf of the researcher, and having a risk of bias in interpreting the interactions (Wasserman and Faust, 1994). Observation is challenging, because it requires the researcher to be present and unobserved; the researcher may inadvertently disrupt the system if participants feel self-conscious and behave differently. Even video may cause discomfort. In terms of time, particularly in large departments with many places to interact, observing multiple students in multiple areas may take considerable time. Selecting which students and which settings to observe would elicit the question of whether the social experiences of observed students in those settings are representative of the population or anomalies. In terms of interpreting the interactions, the meaning the researcher finds in the interactions may be different from what the student feels or experiences. The researcher may not be able to see subtle but important aspects of the interaction and would not know the prior relationship history among participants. For instance, communicating in a sarcastic manner may be perceived as hostile to an observer, but the participants may genuinely enjoy that type of communication.

Surveys are an alternative popular method for collecting social network data through either a "recall" or "roster" method (Wasserman and Faust, 1994; Kadushian, 2012). A recall method relies on participants' memories to name people in their networks. This method, referred to as a name generator, is typically used when the possible persons in the network are unknown to the researcher. An example would be a nationwide survey such as the General Social Survey (GSS), which includes a question asking participants to name their five closest friends, based solely on memory (Kadushian, 2012). For the roster method, the participant is presented with a list of names and selects the persons who best fit the question asked. For instance, if the GSS's five closest friend question were asked on a roster method survey regarding a 20-person office, the participant would choose 5 names from the provided list. The advantage of using a roster is that participants are more likely to provide accurate data; participants often forget names when using recall methods (Wasserman and Faust, 1994; Brewer, 2000). Therefore, having a list of possible choices aids participants in more accurately portraying their social networks.

Because of the possibility of forgetting the people with whom one interacts, the roster method is generally preferred (Wasserman and Faust, 1994). The disadvantages of roster methods are the availability and length of a roster. A complete roster is often not available, such as with a national survey. An example of a roster that would be available but too long is a list of all students enrolled at a large university. The participant may experience survey fatigue, meaning the participant becomes tired while completing a large survey. This could be a deterrent to survey return rates or could hinder the quality of data if participants rush to complete it.

Interviews are the third method that social science researchers use to collect network data (Wasserman and Faust, 1994; Kadushian, 2012). The purpose of an interview is to collect rich, detailed information from the participant that cannot be found quantitatively and can be used to help interpret the quantitative data. In other words, interviews help researchers to find out the *why*. For example, through conducting interviews, a researcher may learn why a student does not participant in a study group network. Interviews also provide means of explaining and interpreting the participants' experiences; experiences that are not obviously gendered or racial to the researcher may be interpreted as such by the participant. Similar to observations, the disadvantage of interviews is that they are time intensive. This limits the possible number of interviews that can be completed (Wasserman and Faust, 1994).

Data are analyzed using typical social science methods. For qualitative data, thematic coding may be used to examine topics such as network formations and satisfaction within networks (Kadushian, 2012). Quantitative data are analyzed statistically. There are many aspects one can study with quantitative data. These include the number of ties a node has, centrality, and popularity or prestige (Wasserman and Faust, 1994; Scott, 2000). Data can be analyzed using typical statistical methods, such as t-tests, analysis of variance (ANOVA), and chi-square tests (Wasserman and Faust, 1994; Scott, 2000). The researcher must be cautious when using statistical methods on datasets with relatively few participants. Other tests may need to be used, such as a Fisher's exact test instead of a chi-square test.

Data can be depicted graphically as sociograms. Figure 2·1 is an example of a sociogram. Sociograms often look like connect-the-dot pictures, where lines represent a tie. If there is no line, there is no tie or relationship between two nodes. Graphic representation in sociograms can convey multiple aspects of a network (Kadushian, 2012). As shown in figure 2·1, the ties can be depicted directionally by using arrowheads or other symbols. The lines can also be color-coded to indicate relationship type or have varying thickness to indicate the tie strength. Nodes can be color-coded or represented as other symbols to indicate groupings; in figure 2·1, the brown nodes could be office workers and the blue node could be a manager. The size of a node can indicate its centrality or prestige in the network. These are only a handful of ways that a sociogram can convey information through graphical representation.

2.3 Networks for Learning and Support

Regardless of the discipline, graduate school serves as indoctrination for doctoral students into their chosen fields. However, doctoral students must learn other skills in order to succeed in graduate school. Students are not only learning the values and practices of the field but also learning how to be doctoral students (Anderson and Louis, 1994; Mendoza, 2007; Ong et al., 2010). Being a doctoral student entails managing academic coursework, learning what is expected to complete the program, and selecting a research area and topic (Anderson and Louis, 1994). STEM doctoral students have additional responsibilities in their programs, because they typically need to select a particular research group or lab. They also frequently have teaching responsibilities. In this section, these tasks and responsibilities of STEM doctoral students are discussed in the context of social networks. Although participating in social networks has great potential to aid doctoral students toward degree completion, barriers or challenges may exist that prevent them from reaping the benefits of these social experiences.

Interaction with fellow graduate students and faculty can provide various types of support necessary for graduate students to complete their program. Research indicates that graduate students tend to interact with one another more than with faculty (Anderson and Louis, 1994; Ferreira, 2003; Sallee, 2011). Doctoral students in STEM have many ways in which they can interact with one another. They often share workspace and may work together on coursework. In the lab, students may teach one other how to use equipment or work together to collect data. These social networks provide an opportunity for newer doctoral students to learn from more veteran doctoral students, who have more experience in navigating the academic program and department as a doctoral student (de Janasz and Sullivan, 2004). Graduate programs sometimes provide formal peer mentoring, where incoming students are assigned to a mentor who is a year or more ahead of them in the program. Peer mentors can provide useful advice and support. For example, Allen et al. (1999) found that the peer mentors assigned to incoming Master's of Business Administration (MBA) students would advise their protégés on how to succeed in their classes by providing test taking strategies.

Faculty may interact less with students, but they may still provide valuable support. In Lawson and Fuehrer's (2001) interview and survey study of first-year, second-semester doctoral students in both the humanities and sciences, students reported relying on both faculty and fellow students for support. Fellow students tended to provide emotional support as well as academic advice and information, such as how to prepare for an exam. Faculty members were able to provide advice on different matters, such as clarifying fellowship agreements. Those who were highly stressed also were most satisfied with their doctoral school experiences and received the most support, suggesting that stress is not necessarily a negative experience if the person has good social support. This also suggests that a good social support network means support from multiple types of sources, not just faculty or students.

When conducting a study on chemistry and history doctoral students, Gardner (2006) also found that students relied on both faculty and students. Students felt that they could have conversations with faculty regarding any issues or problems, as well as just chatting socially with faculty. They appreciated having multiple types of interactions with faculty. However, these interactions did not occur with all faculty members. Students also were aware of which faculty members were not open to interacting.

Although the participants enjoyed talking to faculty, fellow students still were important in the doctoral student social networks. Not only did they provide friendship, but fellow students informally aided in helping others understand expectations for doctoral students and departmental rules. Although Lawson and Fuehrer as well as Gardner studied informal networks, more structured networks may be needed such as the mentoring program studied by Allen et al. Austin (2002) found that doctoral students with professorial aspirations in STEM and humanities fields wanted a more formal way to discuss research and teaching with fellow students. They were also interested in obtaining career advice, which may indicate the need for a structured information exchange.

Doctoral student socialization with faculty and students may not only be beneficial when handling current matters, such as completing the first year of the program, but also for work after degree completion. Gardner and Barnes (2007) studied professional socialization by interviewing 10 alumni and current graduate students studying higher education who were involved in a field-specific professional organization. The graduate student participants believed that developing networks with others through professional organizations aided in finding job prospects and facilitating future collaborations. Influence to join these professional networks varied. Some students reported being encouraged by faculty and fellow students to join organizations, while others reported only being encouraged by fellow students.

Gardner and Barnes found that simply joining a professional organization did not lead to many connections. More prestigious faculty members and graduate programs tend to be well known and to know influential people in their fields. Through prestigious faculty or the program staff, graduate students were introduced to important contacts. Students who were attending less prestigious programs or worked with less prestigious faculty had to work harder to acquire contacts within their fields.

The networks discussed in this section are positive or have the potential to be positive. Doctoral students participating in social networks have the opportunity to receive both social and academic support. However, network participation may have less positive effects. Lomi et al.'s (2011) longitudinal study of both Italian domestic and international students in an MBA program at an elite Italian university suggested that student academic performance depends on their friends. The social network data, taken at three different time periods, and grade data across multiple courses suggest that peers affect one's grades.

Not only do students tend to be friends with students who have similar grades, but also students tended to assimilate to the grades of their friends. This is an issue for low performing students, because their grades would be less likely to improve. This may indicate that low performing students would benefit from socializing with high performing students. However, high performing students do interact with low performing students. While high performing students are less likely to initiate friendships and are less likely to be considered friends by others, other students do seek them out for course-related advice (Lomi et al., 2011). Because the results are statistical, the researchers cannot be sure why this occurs.

2.3.1 Collaborations

To further enhance learning and productivity, graduate students may work with fellow students or faculty. Many factors determine whether a specific collaboration is fruitful, as Hara et al. (2003) found when studying the scientific collaboration of a research group working at a research center. The research center was financially supported by federal grant money, a nonprofit organization, industry, and 4 participating universities. Four research groups consisting of chemistry and chemical engineering researchers worked at the center. Hara et al. asked group members to complete a survey on their social connections within the research center. Questions included with whom and the reason they communicated, the age of the relationship, and the means of communication (telephone, face-to-face, email, video conferencing). One of the four groups did not have the same number of collaborations that the other three groups had. Hara et al. believed that studying a negative case of collaboration may provide insight as to why collaborations are successful.

The research group that was interviewed consisted of graduate (master's and doctoral) students, professors, one postdoctoral researcher, and one research associate, with representation from all four universities. Thirteen of the 14 group members participated in interviews. Hara et al. (2003) found that work styles, good communication, and levels of respect were critical for collaborations to occur. Being geographically close to group members also helped collaborations occur. Faculty and scientists tended to collaborate with graduate students who possessed high levels of knowledge and were acclimated to scientific practices.

Two types of collaboration with students were found. One type entailed acting as a mentor to further develop the student as a scientist. The second type of collaboration was referred to as "collaboration through students" (Hara et al., 2003). In this collaboration, two professors working in different fields or research areas would each guide the student. The student must possess the knowledge and ability to synthesize the work of the two professors in order for the collaboration to succeed. Video conferencing helped bridge distances between researchers and encouraged researchers to collaborate. However, Hara et al. notes that newly formed relationships may not be conducive to collaboration, because interpersonal relationships and trust have not been developed.

Blau (1974) also found that location proximity was important in a study of theoretical high energy physicists' communication networks. Although this is not an explicit study of collaboration, elements of good communication relate to collaboration. The physicists were asked to name two research conversation partners outside of their university, as well as provide demographic information such as country of residence and whether they were considered a leader in their research area. Nine-hundred seventy-two (972) ego networks were created and measured for homogeneity. Country of residence was the most important variable for these networks; high energy theorists from this study lived in the same country as their conversation partners (Blau, 1974). If the ego and its selected alter nodes had the same research specialty, being homophilous for other variables was less important. If the ego and alters had different research specialties, they were more homophilous for other variables. In other words, an ego and alter from two different research specialities would work at similar institutes or have similar personal backgrounds. If they had the same research specialties, these other variables were less important.

Homophily is also an important aspect for collaboration in authoring papers. In a study on collaboration patterns among sociologists, Leahey and Reikowsky (2008) found co-authored papers in sociology and categorized the papers by keywords from the co-authors' publication histories. A total of 61 papers from 148 authors were categorized. Authors were also interviewed. For 7 of the 10 papers where a co-author had no previous publications, the co-authors were a full or distinguished professor working with a graduate (master's or doctoral) student. Seventy-percent (70%) of the authors involved in collaboration tended to be in the same field, the same research interests, and had the same level of expertise. These collaborations developed possibly to increase research productivity, not work in novel ways. Eleven percent (11%) of the authors considered their co-author's skill set to be complementary their own.

Jha and Welch (2010) studied multifaceted collaboration by using a 2007 U.S. national survey of academic scientists and engineers from research intensive universities. "Multifaceted collaboration" is defined as collaboration where collaborators work together on multiple parts of a project. These parts include grant writing, data collection, and writing articles. The social network data were collected using a name generator method. Participants in this study provided the names of important partners for collaboration, as well as partners who provided professional advice and support.

From the survey data, Jha and Welch created gender homophily, knowledge homophily, and status homophily variables. Gender homophily is whether those in the networks had the same gender. Knowledge homophily variable was created a composite variable. The data used to create this variables includes whether the respondent had been a doctoral student with the alter and whether the respondent had a good understanding of the alter's field of expertise. Status homophily was measured using the responses from a question that asked whether the named person was junior, senior, or neither as the participant; the categories were collapsed into peer (same rank) or non-peer (junior or senior rank). In this study, approximately 33% of the relationships were persons of the same rank. Other variables included in study were emotional intimacy, and the duration of the relationship.

Data were analyzed using hierarchal linear modeling (HLM) to create regression models. One regression model consisted of variables related to the respondent, such as the field of study and status; the other model consisted of variables related to the relationship between the ego respondent and the selected alter nodes, such as the homophily variables. This statistical method was selected, because the ego's attributes could not be assumed to be independent of the relationship with the alter

(Jha and Welch, 2010). Each variable had different effects on collaboration. Status and gender homophily negatively correlated to collaboration. Knowledge homophily positively correlated to collaboration. The likelihood for collaboration increased with the amount of time that the respondent had known the alter, as well as increasing if they were close friends. These results were considered statistically significant.

Many factors must work together in order for collaboration to occur. Matters specific to the research help collaborations occur. Having shared knowledge, similar levels of knowledge, and the need to work together was important. Both Blau (1974) and Hara et al. (2003) found that having geographic proximity helped establish communication and collaboration networks. There also is typically a purpose or need that a collaboration would fulfill. The need may be a collaborator who can provide a unique contribution to the research (Hara et al., 2003) or to increase efficiency and productivity (Leahey and Reikowsky, 2008). They did not simply work together for the sake of working together. Interpersonal skills and relationships also are important. Hara et al. (2003) notes collaborators need to have similar work styles and good communication. The results in Jha and Welch's (2010) study suggest that close professional friendships that have developed over years play a major role.

While these studies agree on several aspects of successful collaborations, the relationship between status homophily and collaboration in these networks is not clearly defined. Hara et al. (2003) found that highly skilled graduate students contributed to collaborations in research. This suggests that although graduate students formally share the same status and are not faculty, an implicit hierarchy of graduate students may exist. Graduate students who have an implicitly higher status may be more likely to collaborate with faculty or other research scientists than those with a lower status or knowledge base.

Similarly, the majority of collaborations from Leahey and Reikowsky's (2008) study were not between faculty and graduate students. The sociologists in this study may have had similar statuses, because they had similar levels of expertise. However, Jha and Welch (2010) found that status homophily and collaboration were negatively related. The difference regarding status may be differences among the fields or collaboration setting. For instance, those working specifically in academia may be more likely to collaborate with students. Another possibility to account for the difference is how participants determined the rank of those selected in the Jha and Welch study. For example, suppose a participant was an associate professor. The participant could interpret an assistant professor as lower ranked or could consider the assistant professor as a peer. Similarly, the associate professor may categorize another associate professor who started at the university earlier as senior. The interpretation of this question would affect the results, as egos may have fewer homophilous ties if they are quite specific in their interpretation of what a peer is.

2.3.2 Networks for Learning and Support: Demographic Considerations

Although participating in social networks can be beneficial for graduate students, not all graduate students participate. While similarities may encourage network formation, differences can negatively affect network participation. This section considers how student type, gender, and race affect participation in social networks and how marginalized students are affected.

International students tend to experience social alienation, high levels of stress, and culture shock. Through interviewing both international and United Kingdom (U.K.) domestic doctoral students, Deem and Brehony (2000) found that international students may struggle to fit in as they are not a part of the culture because of cultural differences. They may limit their contact with students who are residents of the university's country or choose to have superficial relationships with them. Deem and Brehony found that international students did not mention informal academic networks or encouragement to attend departmental seminars as often as U.K. domestic students. Contact with students who are citizens of the university's country may help integrate international students. In a study of STEM graduate students by Perrucci and Hu (1995), interaction with U.S. domestic students was found to be important for helping international students adjust to U.S. culture, develop facility with English, and be satisfied with their academic program.

In Trice's (2004) study of international graduate students' socialization with U.S.

domestic students, interactions between international and U.S. domestic students depended on several factors. Primarily, this was the amount of time that the international students lived in the U.S. The longer the international student lived in the U.S., the greater the likelihood that the student became friends with U.S. domestic students. However, interactions with U.S. domestic students were affected by international students' concerns with how to interact with them; the more concern the student had, the less likely he or she was to interact with U.S. domestic students. Even if students share other similarities, a single characteristic, such as nationality, can hinder network participation.

Lack of interaction with U.S. domestic students can have serious implications for international students. In Dong's (1998) study on dissertation (doctoral level) and thesis (master's level) writing, international students were found to be less likely to utilize network connections to acquire the help they needed with their writing. U.S. domestic students tended to use network connections to improve their writing by speaking with their committee members or fellow students. International students also worked in isolation more so than U.S. domestic students, having fewer partners to discuss scientific writing. This was not by choice; the international students reported that they would like to have a native English speaker to help improve their writing.

Dong suggests that as a result of having fewer native English speaking writing partners, international students were found not to be producing work that could be transformed into articles. This would hinder their acceptance into their research communities. Other research suggests that international students interact with faculty less than U.S. domestic students (Weidman and Stein, 44). This indicates that international students may not receive the support they need.

Although the challenges are different, female STEM students also experience challenges in receiving academic and social support. As discussed in section 2.1, efforts have been made to improve the quality of physics education and be more inclusive of female students; other STEM fields have made similar efforts as well. These efforts include making interactive material and promoting group work. However, these efforts may be met with challenges. Laeser et al. (2003) examined group dynamics of undergraduate engineering students working on a design project. Three-hundred fifty nine (359) students participated in teams of 4-6 members. Teams were heterogeneous or mostly homogeneous (predominantly male or female) with respect to gender. Data was collected in the form of observations and a final report, which was evaluated using a rubric. The heterogeneous teams performed worse than the mostly homogeneous teams. Laeser et al. suggest this is possibly due to the students' lack of maturity to work in a heterogeneous team.

However, even older female students face challenges when working in heterogeneous environments. Women who have graduated with bachelor's degrees still encounter difficulties in social network network participation. In a literature review, Fox (2001) notes that female doctoral students in science collaborate with fewer male faculty and male doctoral students on publications and research than male doctoral students do. Ibarra (1992) studied the social networks within an advertising firm. Women tended to be underrepresented in work departments such as research, as well as being underrepresented in managerial positions. By using a roster method, Ibarra asked participants to select conversation partners for various reasons, such as workplace gossip or social support. T-tests were used to determine whether men and women had different networks.

Ibarra found that while male participants' networks tended to be homophilous across all categories, homophily in female participants' networks varied. Women tended to have homophilous friendship and social support networks, but their networks for career or workplace decisions tended to consist of men. Although Ibarra studied employees at an advertising firm, the findings may apply to doctoral students in STEM as there is underrepresentation in multiple departments. If the Ibarra study results apply to STEM doctoral students, female doctoral students in male-dominated fields may find themselves lacking social support if they do not participate in networks outside of their department. The research from Ibarra, 1992 suggests this is an effect from gender and gender homophily.

Irrespective of gender homophily, excluding women in social networks hinders their ability to gain career knowledge and affects their social and professional mobility. An example of this is provided by Pierce (1995), who observed a law firm where male attorneys and paralegals socialized outside of the work environment without female paralegals or attorneys present. Besides social camaraderie, the attorneys would provide career advice to male paralegals and encourage them to pursue law school. Because of the close relationships that developed, male attorneys would give more interesting work to male paralegals and would write letters of recommendations for them. The female paralegals did not enjoy these benefits. Women were largely ignored and relegated to tasks that did not encourage career development.

The demographic categories do not exist in isolation from one another. The intersectionality of demographic categories means that demographic groups can be further categorized. Women of color (WOC) are an example of this categorization and how categorical variables affect one another; the term includes black, Hispanic/Latina, Asian, Pacific Islander, and Native American women. Intersectionality distinctions are important to note, because the intersection of demographic variables can mean that experiences vary for a particular combination. For WOC, both race and gender should be considered, because they may be subjected to differential treatment based upon the intersection of gender and race.

Johnson (2007) interviewed and observed 16 black, Latina, and Native American female undergraduate science students. The women in the study felt that their professors were uncaring and only interested in science, rather than establishing relationships with their students. By not creating rapport, these students felt that the professor was trying to trick them when the professor would ask questions. Fellow students further alienated the participants. The two black participants observed that other students would not sit near them. They suggested that their fellow students were making a deliberate choice not to do so. One participant told Johnson that she originally sat in one row by herself but moved to another row where other students sat. The row in which she originally sat had other students, while she sat by herself in her new row.

Doctoral students may also have difficult experiences in their programs due to how their identities intersect. Gutiérrez y Muhs et al. (2012) edited *Presumed In-*

competent, a collection of personal narratives written by WOC academics. These narratives reflect upon on both their doctoral and professorial experiences. Research is interlaced throughout the narratives to provide further context. Although the term "WOC" encompasses multiple races and ethnicities, their racial, ethnic, and gender experiences vary according to which race and ethnicity they are. For instance, black women may be expected to act as a mammy (black nurse archetype from slavery stories) while Latina women may be expected to embrace a sexualized image ("spicy Latina") (Gutiérrez y Muhs et al., 2012). The narratives contained several common themes: being expected to conform to racial stereotypes by students and colleagues; being treated as a token minority; being presumed incompetent and incapable of completing their doctoral programs or working as professors by their advisors, their students, or their faculty colleagues.

Doctoral students may find other types of intersectionality hinder their abilities to participate in social networks. Green and Kim's (2005) interview study of female international Korean doctoral students depicts the complicated relationship of race, ethnicity, gender, and student type. While some of the doctoral students made an effort to befriend U.S. domestic and other international students, as well as join extracurricular activities, they still were alienated from non-Asians; although they identified as Koreans, Green and Kim noted that they also referred to themselves as Asians. Being a Korean woman also was perceived as being both negative and positive. Some participants felt that because they looked young and were petite, they were not subjected to sexual harassment. However, participants also noted that they felt that faculty and peers did not take them as seriously.

Universities could encourage and utilize student organizations to provide support for students in need. For instance, women in science organizations were created to socialize women into their fields, develop critical skills, inform members of resources (workshops, conferences), and provide community for women (Weinberger, 1992; Braselmann, 2003). These organizations often include members who are at various stages of their careers (undergraduates, graduate students, faculty members, industry professionals) in order to provide an opportunity for differentiated support.

Analogously, international student organizations may inform international students of university resources to aid in writing, help teach them about U.S. culture in order to reduce culture shock, and organize events where they can interact with U.S. domestic students.

Network participation can be affected by demographic factors. Female and/or international students in these studies were not included in social networks in the work place or at their universities. While cultural differences were considered a barrier for international students to participate in networks, no reasons were provided for why women may not be included. Although Gutiérrez y Muhs et al. (2012) focused on WOC, being perceived as incompetent may also apply to white women and prevent them from being active in social networks. Variable interactions differ according to which variables are being studied. Both Perrucci and Hu (1995) and Deem and Brehony (2000) found that the results on their studies on international students did not vary by gender. However, race and gender affected the women in both Gutiérrez y Muhs et al. (2012) and Green and Kim's (2005) work. While participants in both works shared some common experiences with white women, being WOC created additional challenges because they dealt with both race and gender stereotypes and prejudices.

2.3.3 Networks for Learning and Support: Summary

The literature in this section demonstrates the various ways in which doctoral students participate in networks. Social networks for doctoral students may include benefits such as mitigating stress, developing research and writing skills to complete the dissertation, and building network connections for future work in their fields. Fellow students and faculty are needed to provide different types of support, not only because they possess different knowledge but also because of homophily and power dynamics. For example, a peer may be able to empathize better with a struggling first-year student than a faculty member. The struggling first-year student may prefer to talk to a fellow student candidly, because they have similar status in the department and have fewer fears of appearing incompetent or facing repercussions

(Allen et al., 1999). In contrast, faculty support may be needed for navigating the department procedures and career purposes.

Literature on collaboration not only provides information on how research collaborations are created and operate, but also it reveals information on general group work dynamics. While common research interests and the need to collaborate are important factors, much of the literature shows that interpersonal relationships and skills contribute to the starting of a collaboration and determine whether the collaboration is a success. Close friends are likely to collaborate, and good communication and teamwork skills are valuable for successful collaboration to occur. While this research primarily focused on professionals, the research is likely applicable to doctoral students who may work in collaborations of various kinds.

Most of the networks discussed in this section are informal, meaning they are relationships that developed without formal mechanisms. Doctoral students were not required to participate in these networks. Even collaborations, which are more structured than a network of conversation partners, appear to be something one chooses to do. Because such networks are often informal and homophilous, support may not reach certain populations that are more marginalized such as international students and female students in male-dominated fields. Negative interactions with faculty and other students may discourage these populations from participating in these networks. Formal organizations that promote social support and connecting with others, such as student organizations or structured mentoring programs, can help these populations (Weinberger, 1992; Ong et al., 2010). However, research does not indicate whether formal networks are effective in providing support, whether informal or formal networks tend to be favored by doctoral students or whether departments can encourage students to be more inclusive in their informal networks.

2.4 Advisors and Mentors

One specific formal doctoral student network is the dyadic student-advisor relationship. Every doctoral student has an advisor, a faculty member responsible for providing academic or research advisement. The relationship between the advisor and the student can be the most important relationships formed by a doctoral student during the program. The advisor determines the course of research, which in turn can influence time to graduation as well as potential career prospects. According to Litzler et al.'s (2005) study of graduate students in engineering, having a good relationship with one's advisor is associated with a 61% increase in completing qualifying exams. While a good advisor can enrich a doctoral student's career, a mismatched or inadequate advisor relationship can have adverse effects. For example, poor communication between the advisor and student can slow a student's academic progress (de Welde and Laursen, 2008).

Because of the importance of the advisor relationship, multiple factors should be considered when doctoral students select advisors (London, 2008). Not only the research interests, but also the compatibility between the student and the advisor should be considered due to the interpersonal nature of these relationships. Aspects of the student-advisor relationship that should be considered prior to entering this relationship include the advising style and the personality characteristics of faculty members. Advisors and the relationships with their students vary. The advisor-student relationship may be similar to a friendship, where the student and advisor socialize at parties or over dinner (Gasiewski et al., 2011). Other advisor-student relationships are similar to that of a parent-child, where the advisor shows concern for the personal welfare of the student (Gasiewski et al., 2011).

Aguinis et al. (1996) studied graduate student-advisor relationships by surveying doctoral students with assistantships at a large research institute on their perceptions of power with respect to their advisor. Power is "the ability or potential of an agent (e.g., supervising professor) to alter a target's (e.g., graduate student) behavior, intentions, attitudes, beliefs, emotions, or values" (Aguinis et al., 1996, p. 271). This definition of power in this study is from a well-regarded power taxonomy developed by social psychologists French and Raven. A total of 346 surveys were collected with a response rate of 35.8%. Data were examined using multiple regression analysis with independent variables consisting of power categories and dependent variables consisting of an outcome such as the advisor being asked to chair the dissertation committee.

Results show that students trusted professors who were perceived as experts and did not trust professors who were perceived as coercive. In addition, professors perceived as coercive were less likely to serve on dissertation committees.

Other studies also indicate the importance of advisors to doctoral students. de Welde and Laursen's (2008) interviews of 25 STEM doctoral students revealed that doctoral students needed regular contact with their advisors to feel supported, though there was no universal preference for contact frequency. Students observed that poor communication resulted when advisors traveled often, were working on tenure, were losing interest in the student, or were having other issues that took priority over the student (de Welde and Laursen, 2008). Good communication between advisors and students was not gender-dependent, meaning that men and women both experienced good communication with same-sex or opposite-sex advisors. However, the majority of students who reported having communication issues with their advisors were women.

There is no overall consensus as to the effects of unsatisfactory advisors on doctoral students. de Welde and Laursen (2008) noticed that, of the 25 doctoral students participating in their study, the two students leaving the program were women who cited hostile advisors. However, in Ivie and Guo's (2006) survey of over 1000 female physicists from around the world, eight percent (8%) noted that, as graduate students, they had had poor relationships with their advisors. Although other women who have left the field also had poor relationships with their advisors, Ivie and Guo (2006) observed that it was interesting so many had poor relationships with their advisors yet are still in the field. They attributed these female physicists' persistence in the field to their tenacity and hard work.

The advisor-student relationship may be a mentoring relationship where the student becomes a protégé and is nurtured to become a true scholar in the field (London, 2008). Students may receive mentoring from multiple sources for multiple reasons, such as academic and personal support. However, the common characteristic of mentoring is that it is an extensive activity that entails emotional investment and serving as a role model and advocate for the protégé (Rose, 2005; London, 2008). Mentors often include the protégé in professional socialization at both the departmental and national levels (Rose, 2005; London, 2008). When discussing mentors and mentoring in this paper, the above definitions and descriptions are implicit. The literature is clear that a satisfactory mentor is sincerely devoted to the protégé's development and success.

Because of the investment by mentor and protégé, the mentoring relationship may continue after the protégé graduates. Protégés often continue to contact their mentors for career support and advice (Ivie and Guo, 2006; London, 2008; Ryabov, 2008). Mentors sometimes collaborate with their protégés on research projects when their protégés have started working as professionals (Fox, 2001; Ivie and Guo, 2006; London, 2008). This relationship can be viewed as lifelong professional development for the protégé, even as the relationship becomes that of colleagues. In summary, a mentor provides a comprehensive level of support that extends beyond helping the protégé complete the doctorate.

One's advisor may also serve as a mentor, as was the case with the faculty interviewed in Ryabov's (2008) study. However, the mentor and the advisor are not always the same person. Nuances of mentoring relationships can determine whether one is a suitable mentor. For example, Allen et al.'s (1999) study was on peer mentors, with more senior students serving as mentors. The peer mentors were able to provide information that a faculty member perhaps could not provide, such as test-taking strategies, and were able to serve as role models for successful completion of the first year of an MBA program. de Janasz and Sullivan (2004) argue that due to the number of roles a doctoral student undertakes (student, researcher, educator) and the skills associated with these roles, a doctoral student should seek out multiple mentors to fulfill the various needs.

Because of the demands on faculty to teach, write grants, produce research, and advise multiple students, a faculty member may not be able to devote the time needed to be a mentor (London, 2008). Rose (2005) suggested that the advisor might not even be suitable to mentor because of the power an advisor has over students. The advisor directs the doctoral student's research and determines whether the student is prepared for various degree milestones, such as the dissertation defense. The student may not wish to discuss any difficulties or doubts out of fears of being perceived as incompetent, or worse, of retaliation.

2.4.1 Advisors and Mentors: Demographics Considerations

Similar to other networks, advisor and mentoring relationships can vary according to the demographic population being studied. Noy and Ray (2012) studied how gender and race intersect in doctoral students' perceptions of their advisor. The survey included questions on how they perceived their relationships their advisors. Two types of advisors were studied: the primary advisor, who would have a role similar to a dissertation chair, and a secondary advisor, who may be a member of the committee or someone who provides professional advice. When Noy and Ray compared the responses of students of color to white students, students of color in the humanities and social science perceived lower levels of respect for their ideas from their advisors than white students. Students of color in the biological and physical sciences did not experience this. Female students in the biological and physical sciences perceived their advisors treated their ideas with less respect than male students. However, female students in the biological and physical sciences found their secondary advisors to be more receptive and supportive of them and their work. Women of color found their secondary advisor to be more supportive than their primary advisor.

Women and other underrepresented populations in STEM tend to flourish under mentorships. Research suggests that quality mentoring is a key to success for women and underrepresented populations in both degree completion and persistence in the chosen field (Weinberger, 1992; Borg et al., 2005; Daniels, 2005; Wright-Harp and Cole, 2008). As noted earlier, mentoring often entails career and professional development. If women and other underrepresented populations do not receive quality mentoring, they may not receive critical advice to advance their careers. For example, during a round table discussion on research funding during the second International Union of Pure and Applied Physics (IUPAP) International Conference on Women in Physics, one major topic of discussion was how female physicists often struggle to secure grant money due to a lack of knowledge on navigating the application processes (Daniels, 2005). While the discussion was regarding employed physicists, doctoral students are working towards similar career paths. Mentoring may provide the means to mitigate such issues.

Perceptions of one's relationship with his/her advisor may also hinder the development of a mentoring relationship. Women in STEM tend to see their relationship with their advisors as that of student-faculty, unlike men who see their advisors as mentors or colleagues (Fox, 2001). This suggests that women perceive themselves as having lower status than their advisors, while men see their advisors more as equals or as people who are aiding their development as equals. This may be the reason male doctoral students also tend to publish more research with their advisors than female doctoral students (Fox, 2004). Lastly, due to the personal nature of mentoring, the mentoring relationship cannot be forced (Rose, 2005; London, 2008).

As for the attributes of a mentor, there are small differences according to population. In Rose's (2005) study, international student participants wanted advisors who were involved in their lives and who would provide social support. Women tended to value having a role model more so than men, but both desired camaraderie with their mentors Rose (2005). As Ryabov (2008) noted, being of the same gender is not necessary. The Latina faculty, who represented multiple STEM disciplines, in this study spoke warmly of their male mentors.

Ryabov's (2008) finding is interesting, because other literature suggests that having other women serve as role models is important for women to succeed in STEM fields (Rosser, 1993; Borg et al., 2005). Literally seeing successful women in one's field may be adequate (Ecklund et al., 2012). Based off of a round table discussion of international physics faculty, Borg et al. (2005) note that young women need realistic role models rather than famous scientists to aid in attracting and retaining female physics students. For doctoral students in physics and chemistry, Potvin et al. (2010) found that in comparison to male students, female students were significantly more likely to have a female dissertation advisor and to consider the advisor's gender before selecting an advisor. Potvin et al. suggest that this may indicate that female doctoral students in these fields seek out mentoring from female faculty. These findings suggest that the importance of demographic variables, such as gender, may depend upon field. Perhaps the women studied by Potvin et al. have multiple mentors and desired a female advisor in hopes of receiving mentoring that addresses gender issues in these fields.

2.4.2 Advisors and Mentors: Summary

The literature on advisors and mentors indicates that both relationships are important to the success of students, particularly for women and other underrepresented populations. Advisors hold power over students during the time that they spend at the university completing their degrees, but mentors can influence a student's career beyond the degree conferral. The potential for lifelong influence and support suggests that the mentor's power and prestige within the field are important, although these characteristics were not explicitly named (Rose, 2005). However, Aguinis et al.'s (1996) survey noted that power and prestige, along with personality, are factors considered in advisor selection. Doctoral students may consider these attributes but do not regard them as the most important.

Students who are underrepresented or marginalized particularly benefit from mentoring. The mentor can assist in filling in knowledge gaps, such as how to apply for grants, that will lead to further career success. Results from various studies disagree on whether women benefit more from having female mentors than they do from having male mentors. Although the literature provides hypotheses, what specific benefits women receive from having female mentors and why male mentors cannot provide the same benefits is uncertain. The importance of the mentor's gender for female students may depend upon field. Regardless the mentor's attributes or the demographic attributes of the student, the literature is clear that these relationships are critical not only for degree completion but also for lifelong career development.

2.5 Identity and Belonging

Although graduate school serves as a means of socializing one into a profession, typically doctoral students enter with some experience in their fields that are a part of the socialization. They have typically completed bachelor degrees in their discipline and were able to learn about the values and lifestyle of the profession through faculty interaction and observation in their chosen fields (Sallee, 2011). In addition, doctoral students in STEM fields may enter with research experience from their university experiences or summer internships. The additional experience would likely provide them with insight into these fields as a career.

Through these experiences, students develop ideas regarding which people end up pursuing these fields. Although students may be passionate about the subject matter, negotiating their identities may hinder their desire to continue in STEM fields. Stereotypical beliefs held by faculty and fellow students can also affect their sense of belonging in STEM fields.

2.5.1 Identity and Belonging: Social Identity and Perception of Others

According to West and Zimmerman (1987), gender is a performance or action that people do and is created or sustained through interactions. For instance, gender is sustained when young girls are encouraged to play with dolls and discouraged from playing with toy cars. Deutsch (2007), however, believes gender can be "undone." The idea is to challenge norms, such as the previous examples, and dismantle the idea of gender and the differences from gender. Using the previous example, gender could be undone for children by providing children with gender-neutral toys. Connell (2010) built upon the doing and undoing gender theories to suggest "redoing" gender as a third option. Redoing gender is understanding that gender differences may always exist, but gender can be reimagined to accommodate a wider variety of gender identities. Building upon the previous example, young girls would have a doll but would also have toy cars if she desired.

Both women and men in STEM experience gender through various interactions. Drawing upon West and Zimmerman's (1987) work, Sallee (2011) examined how male mechanical engineering doctoral students performed male gender. Collecting data through interviews and observations, Sallee found that these male doctoral students were encouraged to behave aggressively and have large egos. They tended to discuss women and tell crass jokes when the female doctoral students were not present. They noted that the male faculty also uses crass humor when women are not present; Sallee suggested that this difference indicates a difference in professional socialization, where male students are treated more like colleagues. Despite being socially included because of gender, some of the male doctoral students preferred to socialize with women. Unlike their colleagues within the department, they noted they did not feel competitive when socializing with them and can discuss personal matters with them.

Many female scientists note that men tend to be more aggressive and self-promoting, which aids in their career success (Rolin, 2002). Female scientists also may believe they could not behave in the same manner without receiving negative reactions. Viefers et al.'s (2006) interview case study of 3 female physicists at a Swedish university saw similar results. The female physicists noticed that male physicists come off as more confident, regardless of whether male physicists feel more confident. Simply appearing confident for women in STEM is not necessarily the issue. Women may lack confidence in their work. One woman mentioned that she did not feel confident in her abilities and felt that she was pushed through physics, because she was a woman (Viefers et al., 2006). Doubting one's success and believing that it was not earned is referred to as "impostor syndrome."

Impostor syndrome can partially be generated from others' beliefs. Ecklund et al. (2012) studied biologists and physicists' perceptions on the low percentages of women in physics by administering a survey and conducting interviews. Male and female survey participants, who were graduate students or higher, supported the idea that the lack of mentoring, as well as a preference for biology, were the reasons behind the low female representation in physics. The interviews revealed that participants believed that inherent differences, such as natural ability or women seeking work that helps others, contributed to these differences (Ecklund et al., 2012). When discussing natural abilities, men tended to discuss brain activity and mathematical skills while women focused more on the emotional aspects of work. The participants also included an external reason, such as lack of mentoring or some being discouraged from entering physics. This study indicates that perceptions on low representation are complicated;

while participants acknowledged that structural barriers exist, they also believed there are distinct differences between men and women that make women less suitable for physics. The latter belief could contribute to impostor syndrome, because it suggests that women are inherently less capable of succeeding in physics.

Not only gender but also race affects one's identity and interactions with others. Mere appearance can affect social interactions and feelings of belonging. Ong (2005) studied undergraduate women of color in physics through interviews. They noted that because they did not look like stereotypical scientists, others believed they lacked intellectual competence in science. Students who were lighter-skinned or were able to pass as white felt they belonged in the physics community compared to darker-skinned counterparts who believed their race or ethnicity led to differential treatment by both faculty and peers. Ong noted that all of the participants believed gender was a larger issue than race.

Identity can also affect expectations that the students have for themselves. The Korean female international doctoral students in Green and Kim's (2005) study experienced the model minority myth by feeling pressure to succeed. The model minority myth is a stereotype that Asian and Asian Americans are monolithically successful; this is often attributed to cultural reasons, such as having a strong work ethic or parents having extremely high standards. Museus and Kiang (2009) drew upon literature to point out that Asians and Asian Americans are not a monolith and how this stereotype is problematic. Asia consists of multiple countries with unique languages and cultures. Socioeconomic class, occupation, and generation also demonstrate differences among Asian American experiences. Museus and Kiang (2009) used college completion evidence to demonstrate the differences among Asian Americans, noting that Southeast Asians complete bachelor's degrees at much lower percentages than the national average. Because of this stereotype, Asian and Asian Americans may not receive academic or social support. They also may feel additional pressure to succeed, causing them perform poorly in academics (Cheryan and Bodenhausen, 2000; Suzuki, 2002).

Green and Kim suggested that the experience of undergraduates who preemptively judged the Korean doctoral students as harsh graders is also the result of the model minority myth. These students may have assumed that the doctoral students would use the alleged high standards of Asians. Other international students may also be confronted with students who preemptively judge them. Plakans (1997) conducted a survey and focus group study on undergraduate students who were taught by international student teaching assistants (ITAs). Participants in the study claimed to have some difficulty in understanding the course material explanations provided by the ITAs. However, the honors students in this sample had the fewest number of issues with ITAs. Students who believed they were receiving a grade of a C or lower in the class did not seek help from ITAs, but they did also not seek help from the professor teaching the course or a tutor. The students who had the most complaints about ITAs tended to be traditionally-aged white male undergraduates who expected to receive a grade of a C or lower. They also were raised in rural areas and did have travel experience outside of the U.S. This suggests that U.S. domestic students' experiences with people from other countries play a role in their perceptions of international students.

Research indicates that women and racial minorities may encounter challenges when teaching students that white men may not encounter. Lazos's (2012) literature review contains evidence that women are expected to be pleasant and cheerful. Women of color may be expected to play into certain intersectional stereotypes, such black women as mammy figures (Wilson, 2012). Students may also distrust women and racial minorities more so than white men, believing they are unqualified to teach (Lazos, 2012). In student evaluations, students penalize women much more heavily than men on evaluations. These expectations of students, based on gender or racial stereotypes, result in professors who are female and/or racial minorities receiving lower scores on student evaluations than white male professors.

However, Lazos notes that the evidence is not conclusive and the reasons why female and racial minority faculty receive lower scores is unknown. Female and racial minority faculty may react to what they perceive as unconscious or conscious bias from students. This can result in negative exchanges that support negative stereotypes and unfavorable, emotionally-charged student evaluations.

Using West and Zimmerman's (1987) gender theory and expanding it to include race, the combination of gender and race is shown as performance in this section. Female scientists notice how male scientists display masculinity through aggressive behaviors, and women are perceived not to behave in this fashion. Actions are attributed to race, gender, or the intersection of race and gender. These stereotypes not only undermine who these academics are as people, but they may also have professional implications. If scientists in STEM do not conform to stereotypes, they may not receive acceptance in their fields and choose other career paths. A nurturing nature attributed to women is why some scientists believe women tend to pursue careers in biology rather than physics. This implies that certain attributes are more suitable for certain fields, such as being nurturing is better suited for biology or being aggressive for physics. This also implies that if women are typically nurturing, they should become aggressive and "undo" gender in order to be accepted into physics.

However, research acknowledges that women and racial minorities in academia may face repercussions for undoing gender or race. These repercussions include negative interactions with others (Benckert and Staberg, 2000; Ferreira, 2003). In the context of teaching, not adhering to expected behaviors and actions may result in negative student evaluations. Because of this repercussion, Lazos (2012) advocated for a holistic evaluation of teaching and the evaluators working to ensure that students are not emotionally-charged when critiquing an instructor. Beyond teaching, perhaps, as Connell (2010) proposed, ideas regarding gender and race should accommodate a variety of attributes. Similarly, STEM fields should accommodate a wider variety of social identities. While this is a lofty goal, departments or institutions can aid in facilitating this.

2.5.2 Identity and Belonging: Scientist Identity

A student's identity with the field factors into whether the field is pursued. These identities are often referred to as x-field identity, such as a physics identity, or more generally, a scientist or science identity. In principle, if a student strongly identifies with a profession or field, the student is more likely to persist.

Hazari et al. (2010) studied how high school and college experiences shape students' physics identities by comparing survey responses of male and female undergraduates. Having a physics identity strongly and positively correlated with the following: career interest in physics, intrinsic enjoyment of physics, participating in class, and teaching fellow students. These results applied to both gender groups. Only one variable differed for male and female students: discussion of underrepresentation of women during their physics class. This variable corresponded positively with having a physics identity for female students, while having no effect on male students.

In a more recent study, Hazari et al. (2013) examined the physics identities of undergraduate students via a survey to determine what supported female students in pursuing physics as a career. Two groups were created for each of the following experiences: high school single-sex physics classes, having a female physics teacher, having female scientist guest speakers in physics classes, discussing female underrepresentation in physics, and discussing the research contributions of female scientists in physics classes (Hazari et al., 2013). Members of each group were matched upon the following variables, related to high school experiences: math and science interest, the number of math and science classes taken, and the number of physics classes taken. There were no significant differences among the variables or the combined variables, except for discussions on female underrepresentation. Discussions on female underrepresentation had a significant and positive relationship to physics identity.

Students who begin college with a strong identity in physics or other STEM fields may have advantages in these fields. Eagan et al. (2012) drew upon a large survey data set of first-year students who planned on majoring in STEM fields. Participating in summer research programs or taking multiple science classes as a high school student contributes to a stronger STEM identity. Eagan et al. found that students who entered college with a strong STEM identity continued having a strong STEM identity at the end of their first year. Strong STEM identities are also related to more interactions with faculty during office hours, studying with fellow students, working with faculty on research, and being encouraged by faculty to persist in the field.

Those with weak STEM identities at the beginning of their college careers were more likely to switch majors. Female participants tended to have weaker STEM identities than male participants.

Eagan et al. suggested that having a strong STEM identity is the result of cumulative advantage. Cumulative advantage is a theory that an entity's small advantage will become a much larger advantage. The phrase "the rich get richer and the poor get poorer" illustrates cumulative advantage (and cumulative disadvantage for the poor). This is referred to as the Matthew effect. If students begin college well prepared for STEM classes, they may be more comfortable interacting with faculty and seeking out research experiences. This may lead to being encouraged to continue in the field. If students lack preparation for STEM classes, they may be worried about approaching faculty for help. This may be because they fear they are incapable of succeeding and feel embarrassed. Female students, who have weaker STEM identities, may feel unconfident in their abilities to do science, as discussed in section 2.5.1. Weak STEM identities and feeling unconfident may accumulate dissatisfaction and lead to attrition in STEM fields.

Having a strong science identity is not monolithic. Carlone and Johnson (2007) studied science identity by interviewing upper-level undergraduate women of color in the sciences. From the data, three distinct science identities emerged. The first identity is a *research scientist*, who identifies strongly with scientific work and science. Those with this identity receive praise for research contributions by researchers. The *altruistic scientist* views science as means to others. They have received recognition from family and their personal communities. They do not receive recognition from researchers the way those with the "research scientist" identity do, but they also do not mind. They also believe that being a woman of color was an asset, because women of color do not compete against one another. Last is the *disrupted scientist* who shares the aspirations of those who have a "research scientist" identity, but they have negative experiences. Students with this identity feel alienated from their professors and peers. They fail to receive recognition for research work and are treated poorly in their research labs. They attributed this to race and gender. Carlone and Johnson postulated that the more racially or ethnically different from the current population of scientists, the more likely one was to have a "disrupted scientist" identity.

It is evident that having a strong science identity is critical to remain in STEM fields. Research suggests that developing a science identity starts as early as high school, and it contributes to success and persistence for undergraduate STEM majors (Eagan et al., 2012; Hazari et al., 2010). However, the advantages one has in undergraduate studies, due to high school experiences, do not necessarily guarantee advantages during graduate school.

Although the literature examines cumulative advantage for undergraduates in STEM, doctoral students may experience cumulative advantage. Women of color enrolled in STEM PhD programs often attended minority serving institutes, such as historically black colleges, or single-sex colleges as undergraduates (Ong et al., 2010). They may be less prepared for their doctoral programs, due to fewer research opportunities and offered courses. Undergraduate institutes for all students, regardless of race or gender, offer different opportunities and experiences in research and coursework. These opportunities and experiences could mean that some students are already familiar with the course material and research practices, while others have never been exposed. Even if opportunities are present, students may have different experiences that affect their science identity (Carlone and Johnson, 2007). In summary, while having an early science identity strongly contributes to persistence in STEM fields, other experiences along the way to the bachelor's or PhD may decrease the initial advantages. In turn, this may affect students' science identities and degree completion.

2.5.3 Identity and Belonging: Summary

Doctoral students in the sciences have both social and science identities. Their social identities form at young ages and are sustained through actions, as West and Zimmerman suggest. Scientists notice and describe gender differences among their colleagues as actions and interactions driven by personality traits. Gender and race as actions or interactions are implied to be the reasons why underrepresented populations do not pursue some fields such as physics. The behavior of the dominant group appears to determine which personal characteristics are valued by those in the field.

These social identities affect how people interact with one another; in the context of teaching, students may have prejudices regarding particular identities that affect how they perceive their instructor. Instructors of certain populations may feel as though they need to conform to stereotypes, such as women needing to appear caring, in order to be accepted. While being caring is not a negative attribute, it creates a double standard and adds additional pressure to conform to a stereotype. Also, it is unclear to what extent students expect their instructors to care; as literature on black female academics suggest, students may expect their professors to take on a nurturing role that is inappropriate and coddling. Other populations may feel as though they need to distance themselves from racial stereotypes if the stereotypes are negative. Although Green and Kim did not suggest this, the Korean doctoral students may have tried to fight the negative stereotype of being a harsh grader by grading more leniently than other instructors.

Identity goes beyond demographic variables. One can identify with a career or field. Identifying with a field implies that one feels as though she or he belongs and shares common traits with others in the field. Students who have a science identity feel comfortable in their fields. They participate in social networks related to their discipline, such as seeking out an undergraduate research project. Those who do not have strong science identities tend to not participate in social networks related to their majors. They tend to leave STEM fields, perhaps as a result of not participating in supportive social networks.

Social and field identities do not exist in isolation from one another. Underrepresented science students may feel as though their social identity is at odds with their science identity; they may feel that softer personality aspects, such as compassion for others, are in direct contrast with normative behaviors in the field, such as aggression. Students in these fields may struggle to balance these competing identities. This could lead to attrition if they feel they do not fit the normative behaviors or if these identities prevent them from seeking support.

In order to thrive in STEM fields, underrepresented populations may need to develop strategies in order to feel like they belong. One method is referred to as fragmentation where WOC would emphasize one aspect of their lives, such as interest and ability in their field, and de-emphasize another such as gender or ethnic identity (Ong et al., 2010). Another strategy is to acknowledge differences among populations, as Hazari's research suggests. Perhaps acknowledging differences and struggles help underrepresented populations reconcile their competing identities and realize that the issues they encounter that are not inherent to the field. Being able to understand math is a necessary skill to studying physics; being aggressive and overly self-confident is not. A related strategy is for students of color to redefine the science identity to incorporate their social identities and look to improve work conditions for underrepresented populations (Tran et al., 2011). Redefining the science identity is similar to Connell suggesting that we redo gender, and it may be the next step for underrepresented populations after they are aware of issues surrounding underrepresentation in their fields.

2.6 Departmental Climate and Features

The actions of individuals contribute to creating an overall departmental atmosphere or climate. Friendly interactions contribute to a warm or caring institutional climate, while hostile interactions contribute to a cold departmental climate. The absence of interaction also can be characterized as cold. Institutional climate affects social interactions; people will not choose to participate in a hostile environment.

While individuals do affect the department climate, the institutes or departments themselves can be instrumental in creating an inclusive environment. Departments can shape their climates through policies and community-building activities. In this section, the effects of environments on participants as well as departmental features that support social interactions are discussed.

2.6.1 Effects of Departmental Climate

While the idea that hostile departmental climates exist and are unpleasant may be obvious, the effects of such a climate may not be. Smith-Doerr (2004) observed hostile behaviors in a university biology department where a female doctoral student worked alongside male postdocs. In this situation, the male post-docs used crass humor to cause discomfort for the female doctoral student and essentially chased her out of the lab at that time. Recall the Sallee study on male mechanical engineering doctoral students and gender performance, where the male doctoral students used crass humor. However, in the Sallee study, the male doctoral students used such humor only among themselves and appeared to do so in order to assert masculinity among other men.

Smith-Doerr observed that the male postdocs returned to work and professional behavior once the female doctoral student left. However, the two postdocs continued to display aggressive behaviors towards the same female doctoral student in meetings, constantly questioning her ideas and behaving rudely towards her. The female doctoral student was nervous around the lab's principal investigator (PI), who encouraged her to participate in these meetings, and another male postdoc, even though he was not a participant in the workplace harassment.

Experiencing harassment may depend upon the composition of the department. In a study of biology and chemistry graduate (both master's and PhD) students in two different research labs at the same Midwestern university, Ferreira (2003) collected data via interviews and a survey to examine gender. The survey data included demographic information, the number of hours spent in the lab, and Likert scale questions on self-confidence. The results showed that the biology graduate students felt more socially supported in their research environment than the chemistry students. One major difference between biology and chemistry departments is that biology departments typically have equal gender representation or even a female majority at the undergraduate and graduate student level (NSF, 2011). This suggests that environments that are not male-dominated tend to be more supportive than those that are.

Both female and male graduate students from the chemistry department in the

Ferreira study reported that the department was not friendly towards women. Similar to the findings of Sallee and Smith-Doerr, the men in the chemistry department tended to make crass jokes that made female students uncomfortable. The women in the Ferreira study also felt that the department expected students to be aggressive to succeed. A female chemistry graduate student stated that male students would not discuss science with her, though they would do so amongst one another. She noted that they do not regard her as a peer and only ask her to help locate equipment. Based on her comments and the Smith-Doerr study, this may mean that the male students did not perceive female students as intellectual equals.

Hostile environments are not a universal experience for women in STEM. Although the research indicates that women in STEM work in unwelcoming environments, this depends upon the department. Gardner (2008) noted that female doctoral chemistry students at one university did not indicate any issues of sexism in their department, whereas female doctoral chemistry students at a different university extensively discussed issues related to sexism. Lack of discussion on sexism in the department suggests sexism was not an issue. The difference appeared to be departmental environment, because female doctoral history students at the first university also largely discussed issues related to sexism. The chemistry department where women did not discuss sexism had a female department chair. The chemistry and history departments where women discussed sexism were male-dominated and did not have female department chairs.

Institutional characteristics affect the student population and the experiences they bring, indicating that one must consider nuances when studying multiple institutes (Jacobs, 1999). The Ferreira study demonstrates how fields can vary depending on the members of the institute. Similarly, as Gardner observed, one must consider differences among departments when studying a field. The research also suggests that a female department chair may help develop an environment that is inclusive of women.

What these studies show is that male gender was being performed in the way West and Zimmerman theory describes in section 2.5.1. Gender appears throughout the interactions of graduate students. The research by Sallee, Smith-Doerr, and Ferreira depict how adult men perform gender in academic research environments. Arguably, female gender was being performed in at least the Smith-Doerr work: the female doctoral student who felt intimidated or offended did not confront the male post-docs. Instead, she left the lab. She may have been conforming to expectations that women should be non-confrontational. However, when women are a minority in the department, such action could lead to further ostracism (Gehring et al., 2002). Regardless, the performance of gender by male doctoral students contributed to hostile climates for female doctoral students.

Issues of exclusion, as well as aggressive work environments, may result in women not completing their degrees. Ferreira (2003) found that the attrition rate for both a chemistry department and a biology department, taken over a nine-year period, was higher for female students of both departments than for male students. Female biology graduate students had approximately twice the rate of attrition of male biology graduate students. Female chemistry students in the study had an attrition rate higher than that of both female biology students and male chemistry students; the male chemistry students' attrition rate was similar to that of female biology students. All comparisons of attrition rates were done using chi-square tests and were statistically significant. These attrition rates coupled with the interview data may mean that a cold, harassing environment causes women to leave STEM fields, which is problematic for women remaining in the fields. When female students leave their programs, the already small number of women becomes smaller and may result in further isolation of the remaining female students (Ferreira, 2003).

2.6.2 Departmental Features that Support Inclusion

While individuals contribute to creating an overall hostile and unpleasant work environment, departments can facilitate improvement by creating a genuine community that is inclusive. The goal is not to create an environment where men are excluded or treated poorly, but rather to create an environment which is more welcoming and inclusive of all students (Rosser, 1993; Blickenstaff, 2005; Borg et al., 2005). Men who are not excluded from this environment based on gender may still be unhappy with a hostile and cold environment, such as a few of the male students in the Sallee study. I emphasize this point, because research indicates the work environments where women in STEM can thrive do not hinder men's success and can create a pleasant environment for all workers (Hill et al., 2010; Sallee, 2011).

An inclusive departmental environment for STEM doctoral students may be one that is non-competitive and encourages their students' interest in teaching. Literature indicates that women prefer that their work environments be less competitive (Pierce, 1995; Whitten and Burciaga, 2000; Rolin, 2002; Rosser, 2004; Ferreira, 2003). Developing an environment that promotes teamwork and collaboration may help women participate in social networks. Believing that teaching is appreciated may also be a feature of an ideal department. Moyer et al. (1999) found that 21% of the female doctoral students in their survey study wish that research/publishing were emphasized less and teaching were emphasized more; only female doctoral students were included in the sample. In a study by Fox and Colatrella (2006), tenure-track female professors in STEM consider their roles as educators to be a valuable part of their careers. The combination of these results suggests that women in STEM are interested in teaching.

Another way to interpret the results Moyer et al. found is that it is a work-life balance issue. Teaching takes time, regardless of enthusiasm for teaching. It is an activity that is also constrained by the semester and has immediate obligations, such as being present to teach. Research typically does not have these constraints. Doctoral students may find balancing teaching, research, and coursework responsibilities to be challenging. In Litzler et al.'s (2005) study on gender differences among engineering doctoral students, female doctoral students felt the workload and pacing of the program was more challenging than male doctoral students did. Potvin et al. (2010) found that female doctoral students in physics and chemistry reported spending about 4 hours less on research per week than male students (approximately 46 hours versus 50 hours), and they preferred spending less time doing research than men (approximately 43 hours versus 48 hours). This is not necessarily an indication that women lack interest in research; Potvin et al. also reported that women were more likely than men to indicate they wanted more opportunities to gain research experience.

Having social activities and department or institute-level professional organizations are often suggested to departments that want to improve their climate. The American Association of University Women (AAUW) used multiple databases and sources from the past 25 years to create a report on the status of women in science (Hill et al., 2010). In order to retain students, they suggested having social activities for all members of the department, providing space for students to work and socialize, and sponsor a “Women in Physics” group.

However, simply providing space or hosting a social event where faculty, students, and staff are invited may not be enough. Doctoral students in Deem and Brehony’s (2000) study described social events as a superficial way to create an overall departmental community, because students socialized with students and faculty and staff socialized with faculty and staff. Groups meant for women in STEM or individual STEM fields are anecdotally suggested to provide a space for women to receive social and professional support (Weinberger, 1992; Braselmann, 2003).

To truly become a supportive and inclusive environment for all students, a department may need to go beyond implementing features. Fox et al. (2009) studied 10 institutes ranked according to the proportion of undergraduate science degrees earned by women. Findings included that the programs with higher proportions of female science degree recipients had program directors who could have a nuanced discussion on the low participation rates of women. These program directors were also more critical of the lack of faculty participation and desired to have a broad institutional impact. They also offered a broad range of activities. Fox et al. distinguished the two groups as being “student-centered”, meaning that programs aimed to acclimate students to the current environment, and “institutional-centered” which meant the programs sought to change the institutional environment. This suggests that having identifiable features is important, but the department must have knowledge regarding specific populations and be personally invested in to create an inclusive environment.

2.6.3 Departmental Climate and Features: Summary

As demonstrated by the Smith-Doerr research, the actions of individuals lead to a perception of an overall hostile workplace. Departments that have hostile or cold workplace climates can have deleterious effects on female doctoral students. The female doctoral student in the Smith-Doerr research was uncomfortable and nervous even among non-harassing people such as her advisor. Female doctoral student attrition is also linked to hostile work environments (Ferreira, 2003).

Features mentioned in research indicate that the department should strive to create an environment that is non-competitive and values the members of the department. Valuing the members of the department may include supporting their career interests, such as teaching, or understanding that long work hours are not ideal. Interest in working fewer hours does not mean less interest in research, but perhaps an interest in having a work-life balance. However, executing these characteristics may be challenging for the departments. There is no precise mechanism to create a non-competitive environment. Perhaps policies or coursework designed to promote teamwork would aid in developing these departmental characteristics. Hiring faculty who hold these ideals is another way to cultivate such an environment.

Departments can develop more concrete features to support a community-like atmosphere, such as groups for underrepresented populations and departmental events. Merely offering these opportunities to socialize may not be enough. Homophilous people may socialize with each other, such as students with students, and the event reinforces currently existing ties, not producing new ties. Recall Fox et al.'s findings that science departments that graduated high percentages of female undergraduates tended to desire a greater change in institutional environment, not sustain the current culture and have students adjust. Departments that believe inclusivity is critical may be what is needed to create a welcoming culture. This may be similar to how departments can develop characteristics that promote community. More definitive items, such as departmental events and policies, may only be as effective as the strength of the beliefs of those who implement them.

2.7 Other Factors that Affect Network Participation

Beyond the department, doctoral students have other activities in their lives that affect their social network participation within their departments. Family concerns, such as raising children or spending time with one's spouse, can prevent students from participating in social activities (Deem and Brehony, 2000). In a study on Italian and Dutch doctoral students across multiple disciplines, Ellemers et al. (2004) found that female students spent less time than male students on research. The female students in this study also spent more time on household tasks.

Other studies also show that home responsibilities are challenging. Jacobs and Gersen (2001) pointed out that both dual-income couples and single-parent households will likely struggle in balancing work and family life. Single parents must both earn money and perform household duties. Dual-income couples may be financially less burdened than single parents, but they still tend to lack a person whose primary responsibilities are to care for the home. Doctoral students may be single parents or be in relationships where both partners' time is occupied outside the house. Home life responsibilities and romantic relationships may prevent doctoral students from participating in extracurricular activities or social events. Research discussed in section 2.6.2 indicates STEM doctoral students spend approximately 40-50 hours on research; this does not include any coursework or teaching responsibilities. There may not be enough time to adequately fulfill one's work responsibilities, participate in social activities, and maintain a life outside of being a doctoral student.

2.8 Theoretical Models for Success in Higher Education

The literature presents multiple factors that affect doctoral students' completing their degrees. These factors work together in complicated ways. Their importance often varies according to population. For example, students who are homophilous to others in their field would not likely struggle to fit in the way those who are not homophilous would. In order to better understand how these variables relate to one another and to student success, theoretical models have been developed.

Girves and Wemmerus's (1988) model was designed to create a means of studying progress towards master's and doctoral degrees. The model focuses on degree progress, rather than retention, and uses five points to examine progress: master's level courses are completed; master's level degree is earned; doctoral level courses are completed; student is admitted to doctoral candidacy; doctorate is earned. Degree progress was found to be contingent upon four categories (student characteristics, departmental characteristics, financial support, and student perceptions of faculty).

These four categories influence three intermediate variables: grades, student involvement, and alienation and satisfaction with the department. The student involvement, department characteristics, and student perceptions of faculty combine for the degree progress variable. This model was tested using hierarchal regression on survey data from 324 master's students and 162 doctoral students. Girves and Wemmerus found that their models (master's and doctoral degrees) accounted for 30% of the variability in degree progress.

"The Culturally Engaging Campus Environment" (CECE) was created by Museus (2012) to examine undergraduate success. According to Museus, other models place too much emphasis on the student's role and do not consider racial or cultural reasons for success. Drawing upon literature, the CECE model incorporates external factors, such as finances or family influence, to describe how they affect the individual's experiences, such as a sense of belonging, and degree completion. Features of a culturally engaging campus include:

- A caring and inclusive environment;
- Being able to connect with faculty and students who are of a similar background;
- Ways to keep students involved with their home communities;
- A wide range of support services;
- Faculty who value the cultural and diverse experiences of their students; and
- Opportunities to engage in cross-cultural communication.

Museus believes that students who are a part of a more cultural engaging campus will have a greater sense of belonging and positive social experiences that will make them ultimately more likely to graduate. This model has not been tested yet.

Both models provide a way to understand how these variables contribute to doctoral student degree completion. The Girves and Wemmerus model does include the various aspects of doctoral student life. Knowing specific points where doctoral and master's students may struggle is useful to gain more exact knowledge on student attrition. While some of the variables may be better suited for undergraduates, the CECE model has some validity for doctoral student completion. This model acknowledges that students' backgrounds do make a difference in whether they complete their degrees. Although Museus focused on racial and ethnic minorities, some of these themes are reminiscent of those in the gender literature. Perhaps a combination of these two models would provide a robust model to describe STEM doctoral student degree completion.

2.9 Literature Review Discussion

While physics education research presented in section 2.1 has sought to examine curricular issues, similar research on STEM doctoral students is less prevalent. This may be because doctoral students primarily work on research and spend less time working on coursework than undergraduates. Given the unique environment doctoral students are in, social networks become an important source on the path to earning a doctorate. The research demonstrates that doctoral students in STEM participate in many types of networks. These networks are as follows:

- Coursework learning
- Research, including collaboration partnerships
- Professional organizations
- Mentoring (peers or faculty)
- Advising

- Social support

Many of these networks are informal and voluntary, though they can be valuable for completing the degree. Some of the value in these networks is academic-related, such as helping to navigate courses. The examples discussed in section 2.3 demonstrate the ways in which networks are beneficial for students and include sharing academic and professional knowledge, cultural adaptation for international students, and providing encouragement and support. Although the emphasis in Chapter 2 has been on STEM doctoral students and the socialization that occurs within graduate school, all students in the doctoral student network enter with previously learned behaviors and beliefs. Men and women have developed gender-specific behaviors that start from childhood and continue into adulthood. International students join a culture that is unlike theirs. These behaviors and beliefs can hinder graduate student network formation.

Beyond the informal relationships that doctoral students cultivate, they are also required to create formal relationships in their programs. The primary formal role of faculty in a doctoral student's life is that of an advisor who supervises the student's research and prepares the student for the dissertation defense. In section 2.4, the significance of advisors and mentors for a doctoral student is discussed. The advisor has a large role in guiding the student's research. Doctoral students, regardless of gender or nationality, value their advisors' input and support. An advisor can help or hinder the research process and thus, graduation date, by their level of communication, their availability, and their investment in the advisor-advisee relationship.

Informally, mentors may be present in students' lives by providing advice and support throughout the protégé's student's program, and, possibly, career. Unlike advisors, doctoral programs do not necessarily require or officially offer mentors. This role is more extensive than the advisor's role. The mentor role includes being involved in the student's professional life and having emotional investment. For populations such as women and underrepresented minorities in STEM, the mentor can be a critical component in later career success. Mentors often provide valuable guidance early on in areas such as how to navigate grant applications.

The development and quality of many of these relationships depend upon the doctoral student's identity, as seen in section 2.5. Doctoral students in STEM have a social identity, which includes aspects such as gender and race. They may also have a science or discipline-based identity. Both identities can help or hinder participating in social networks. Social identities may mean underrepresented populations do not feel as though they belong in predominantly white or male disciplines. Interactions with others may reinforce feelings of not belonging or otherness. Underrepresented populations may also be subjected to stereotypes based on race or gender that they must negotiate.

Discipline-based identities indicate the students see the discipline as part of themselves. This suggests they will find that they belong among others in the particular discipline. Students who feel that they belong in their STEM disciplines tend to participate in social networks that support their progress and success. Underrepresented populations may need to learn how to balance their social identities with their discipline-based identities. There are several tactics to employ, including keeping identities separate or reimagining the fields to accommodate the conflicting identities.

These smaller interactions among individuals produce a departmental social climate or atmosphere. Fellow doctoral students, post-docs, and faculty all play roles in these networks and contribute to the social environment. Students may feel more or less comfortable interacting with students, depending upon characteristics within a lab or department. Social identities, such as gender, can play a role in how one experiences these environments. As seen in 2.6, students and postdocs contribute to the workplace environment and can create either a hostile one, or a supportive one. Although power has previously been discussed in terms of advisors and mentors, fellow students and postdocs can also have power over one another in that they can affect one's social experiences and participation in receiving knowledge regarding the profession, which can affect a student's eventual career path. Departments can help create a welcoming and inclusive atmosphere by being truly invested in the welfare of all members of their departments.

Circumstances independent of the department may affect whether doctoral students actively participate in these social networks. As mentioned in section 2.7, they may have responsibilities outside of the university, such as children or household duties. Students may have significant others with whom the wish to spend time. Because of the amount of time spent at the university for academic or work-related reasons, students in these situations may opt out of frequently participating in non-required social networks.

Models help relate these variables to one another and understand how they may affect degree completion. Section 2.8 discusses two models that incorporate variables related to degree completion. These variables include experiences prior to enrolling the program, as well as institutional features. Each model has its strengths. The Girves and Wemmerus model has been tested and specifically studies doctoral students. However, the CECE model by Museus acknowledges that universities must not treat students monolithically and must consider how to include racial and ethnic minorities.

Though the literature provides useful insight into the networks of doctoral students and recognizes demographic differences, the literature also raises many questions. The actors in the network are important, because they affect the information and support received by the student. The research up to this point does not suggest what doctoral students do if their mentorship or advising needs are not being met. Although some literature suggests that attrition is likely to happen, other literature suggests that a considerable percentage of doctoral students are capable of succeeding in less than ideal environments. However, the literature does not suggest what these students are doing differently to succeed. For instance, if advisors do not fulfill mentoring roles, do these students seek out other mentors?

Section 2.4 shows that advisors and mentors are important, but as other research suggests, doctoral student-faculty interaction is less frequent than that of student-student interaction. Doctoral students may rely on fellow students for most types of support and only approach faculty when the situation is dire. For example, faculty may be better equipped to handle severe situations, such as harassment, than a fellow student would. Faculty may know the policies better or may be less fearful of repercussions when advocating for a student. Understanding the kinds of relationships doctoral students foster with faculty and fellow students for support may also reveal gender differences. Male students may have more camaraderie with faculty than female students have. Due to the closer relationship, male faculty may contact faculty for multiple reasons. Female students may only contact faculty when they are in difficult situations. In other words, what are the motivations for doctoral students to contact various members of their networks (students, faculty, advisors, and mentors)?

Peer networks are considered important for doctoral students to receive personal and academic support. The research does not discuss whether doctoral students who do not participate in peer networks receive similar support elsewhere. It does not indicate whether the mentor or advisor is adequate to satisfy the student's needs if the student lacks peer support. Lacking peer support may affect different populations differently; perhaps some populations are not bothered by a lack of peer support in their departments. Concern regarding peer support may also vary depending on the network type.

Peer support can be found through more formal structures. The literature suggests that graduate student organizations such as groups that support women in STEM can fill in gaps of support, but the literature does not indicate if students use these groups. The literature does not indicate whether the groups often provide the type of support suggested. If students are not receiving the support they need through their programs or student organizations, they may have these needs met through means such as their spouses or friends at a different university. Furthermore, certain populations of students may be more likely to seek out resources to support themselves in degree completion. Perhaps international female science students do not participate in organizations for women in STEM, but they have friends outside of their department who are able to help them navigate their graduate programs. More research would help clarify these matters and help universities support specific populations.

In section 2.5.1, it is suggested that gendered behavior is learned during childhood and continues to into adulthood through similar behaviors; research also indicates that, similar to gender, race is at least partially constructed as action. In section 2.6.1, the issues surrounding gender performance are discussed. While the ramifications of gender and race stereotypes as actions are demonstrated, the research does not address how these ramifications contribute to differences in representation. Other fields, such as medicine, that have been historically male-dominated have reached gender parity (NSF, 2011). There is no reason to believe the men in other fields would be less likely to learn stereotypical male behavior than men in STEM. While the research shows women are harassed in different STEM fields and suggests these experiences may lead to attrition, biology has reached equal gender representation in doctoral student representation. This suggests that organizational barriers within other departments may result in low female participation, and differences in social experiences may exist among STEM fields. Perhaps these fields are more supportive of having both social and science identities.

The differences among fields may exist within the field, due to research specialty. Perhaps some subfields are more female-friendly than others. For example, working in particle physics may offer a different social climate than does biophysics; this would be analogous to how biology and chemistry departments are different. Female students who complete their doctorates may be in STEM fields or subfields where there is a critical mass of women. These fields may have other features that dissuade sexual harassment and other unwelcoming behaviors. Women may also be included in some networks and not included in others. Learning more about these variables that may contribute to differences in female network participation may aid in understanding why female participation is low in some STEM fields..

Even if the department is supportive of students, other factors may hinder progress and social participation. The household and family responsibilities mentioned in section 2.7 may affect social network participation. However, the literature does not reveal whether doctoral students who have these responsibilities still participate in social networks or departmental events. It also does not indicate whether they still have close friends in the department and whether they are satisfied with their departmental social networks. The research also suggests women often have more household responsibilities and work less on research than men; this may contribute to gender representation differences. Again, the research does not indicate whether faculty understand and accommodate these students or if they regard these students to be less serious than students who lack these responsibilities.

All of these aspects can be related in degree completion models that include many of the attributes needed for STEM doctoral students to complete their degrees. However, the Girves and Wemmerus model does not account for peer interaction. The model does not distinguish faculty interaction in different settings, such as research versus the classroom. It also does not account for gender, race, or other demographic variables. The CECE model is more comprehensive regarding students' races and ethnicities, but it does not include gender or other demographic variables. It was also created for undergraduate degree completion. Undergraduates primarily work on coursework, while doctoral students primarily work on research. The CECE model does discuss different types of interactions, but it has not been tested to see whether the model works and for whom it is applicable. The model also describes types of networks that support students but does not provide details of these networks, such as the size or frequency of interaction needed to be supportive of students.

One limitation of the literature was a relative lack of studies examining STEM as separate entities. Even within the presented literature, field differences appear as shown in chemistry and biology. These differences may contribute to the national graduation trends of individual fields, which vary considerably. Focusing on a single STEM field may make issues more pronounced for certain fields. A second limitation of the literature is the publication date of the research and whether the findings are still valid or outdated. Some of the research is almost twenty years old; current doctoral students may have different experiences.

Rather than examine the experiences of individuals or study large national trends, investigating the experiences at the departmental level may bridge the gap between these two bodies of research. A comprehensive social network analysis is an ideal way to provide an aerial view, as Kadushian stated, of the connections formed by individual entities. This aerial view may reveal that individuals of certain demographics are connected in the network but are not connected to individuals of a different demographic. The national studies show graduation trends and other outcomes, while smaller studies describe the experiences of individuals. The study in this dissertation provides an aerial view of the social network trends within a department to examine the middle ground between the experience of individuals and the assertions made by some of the large national studies.

2.10 Research Questions

This study seeks to examine gender difference in the social networks of physics doctoral students within the physics department. Physics doctoral students are an ideal population for this study, because there are notable gender differences compared to other STEM fields. The boundary of the network is at the department level, because the department is typically the center of students' doctoral lives. The department can be considered the gatekeeper to the doctorate; the department chooses which students to admit and which students can graduate. The students complete the majority of their coursework and perform any teaching duties within the department. They primarily select members of the department as their advisors. The members and structure of the department can influence what happens between entering and exiting the department.

Based on the literature, my study sought to answer the following questions:

1. In what types of networks do doctoral students in physics participate for professional and personal reasons within their physics department?
    (a) How are these networks formed and sustained?
    (b) What are the characteristics of the doctoral student networks for research, social, academic, professional, teaching, and/or support? Does this vary by network type?
    (c) If doctoral students do not participate in networks within their own physics department, do they participate in other networks and if so, where, how, and why?

2. What is discussed in these doctoral student networks?

   (a) What conversation topics occur in this network? What types of information and support are sought and received by doctoral students?

   (b) Who is providing the information and support the students seek?

   (c) Do the doctoral students find the information and support they seek and if not, why not?

3. Does doctoral student participation within the various networks have any relationship to progress in the program and confidence in PhD completion, and if so, what kind of relationship?

4. Do the responses to any of these questions vary by gender, race/ethnicity, student type (U.S. domestic or international), year in program, type of undergraduate institute, relationship status, subfield, or research type?

5. Do other factors hinder or help doctoral students in physics participate in social networks? And if so, which factors and social networks?

Question #1 seeks to describe the network. Professional reasons includes academic coursework, career, research, and teaching reasons. Personal reasons include friendships and romantic relationships. The subquestions delve into the details of the network, including whether the relationships are strong, how connected graduate students are, the role of identity in network participation, and the demographic similarities among members. I ask the last subquestion of question #1 because graduate students may seek support from outside of the department. They may work in interdisciplinary fields, conduct research at national labs, find other forms of support through online means, and so on.

Question #2 looks at what is being asked as well as whether their queries are satisfied. Students may participate in networks but not receive the advice or support they need. Some students may receive unsought but useful advice. Question #3 looks at whether network connections possibly influence degree completion. Perhaps a student who works alone is able to finish degree requirements with more ease than one who has many connections and is encumbered with responsibilities independent of research. Question #4 compares students using categorical variables to see if there are any difference in the experiences. While this study focuses on gender, other variables may be linked to differences. Question #5 considers other reasons why students may not participate. Perhaps a shy student may be less inclined to participate in social support networks but willing to be in a research network.

2.10.1 Hypotheses

For the research questions in section 2.10, I constructed the following hypotheses:

1. Doctoral students who have more ties in research, coursework, and personal support networks are more likely to complete their PhDs.

2. If they do not find adequate support within the department, they will either look outside of their departments or be more likely to consider leaving the program before degree completion.

3. Doctoral students seek a variety of information, primarily any information linked to degree completion or careers.

4. Those who have strong physics identities will have more ties in research, coursework, and personal support networks.

5. The more homophilous the students are to one another, the stronger the ties will be.

6. The more homophilous the students are to faculty and staff, the stronger the ties will be.

7. Departmental events will not aid in helping students make new connections to students or faculty.

8. First-year students will have stronger ties to one another. As the students become more involved in research, they will have stronger ties to fellow students in their research group or subfield.

9. Degree centrality will vary according to the type of network. Different students will be more central depending on the type of network.

10. Gender and other variables will affect the responses to all of the research questions.

Hypotheses #1, 2, 3, and 4 were developed from the literature in sections 2.3, 2.3.2, and 2.5.2. Hypotheses #5 and 6 drew upon the general social network literature on homophily in section 2.2.1. Hypothesis #7 is based upon the literature in section 2.6.2 my casual observations at multiple departmental events, such as colloquia or the fall barbecue. Hypothesis #8 is partially based upon the existence of homophily, partially based upon the primary work changing from coursework to research. Hypothesis #9 anticipates certain students may be more sought-after depending upon the situation. A doctoral student approaching graduation may be asked to give advice on careers to more junior students. Hypothesis #10 has appeared in all sections of this literature review.

Chapter 3

Methodology

Because of the advantages and disadvantages of each data collection method discussed in section 2.2.2, using a mixed methods approach is the ideal way to collect social network data. This study uses both a roster survey method and interviews for data collection method to capture the bulk of the doctoral student experience; observations, while useful for other social network projects or objectives, would be challenging to complete for a representative sample of a departments various interactions in a time-efficient manner.

Being mixed-methods, this study consists of both a survey of the entire doctoral student population in a physics department and selected participants for interviews. Section 3.2 delves into the survey portion of the study, while section 3.3 discusses the interview portion Section 3.4 outlines the data analysis for both the survey and interview data. The final section includes limitations and information on the researcher.

Privacy and anonymity is of the utmost importance as these are students who are participating in a study regarding their program. Raw data collected will be password protected, stored in a lock box on flash drives when possible, and only accessible to me, Peter Garik (Boston University School of Education), Bruce Fraser (Boston University School of Education), and Deborah Belle (Boston University Psychology Department). Participants in the interviews were given pseudonyms.

I was funded by the Gates Millennium Scholars program, a scholarship program through the Bill and Melinda Gates Foundation, during this time. The Gates Millennium Scholars program has no involvement whatsoever in my research, beyond agreeing to fund my education at Boston University.

3.1 Departmental Information Data Collection

Part of this study examines faculty members as alters in the doctoral student networks. Various aspects of the faculty members may help or hinder the students. For example, professors who have professional responsibilities outside of teaching and research may not have the time to dedicate to their doctoral students. Additionally, the recognition and visibility of faculty, such as having an internationally recognized professor serve as an advisor, may provide more resources and ties to doctoral students. As discussed in section 2.2.1, the prestige of one's network connections can have implications. For instance, having a highly prestigious advisor may contribute to opportunities during and after graduate school.

Prestige in this dissertation is not simply defined as having many connections; besides practical matters in evaluating the number of ties a faculty member has, prestige conceptually has other parameters. An award recipient or leader in a major laboratory may be considered prestigious. Similar to the prestige as defined by connections, opportunities may arise for the students of such a faculty member.

In order to measure prestige more holistically, data on multiple parameters were collected from the last five years. I selected the last 5 years, so junior faculty would not be penalized as much for having shorter careers. Additionally, the model does not reward senior faculty members who were active in the early stages of their careers but were less active in later stages. Only faculty who were considered part of a research specialty, as indicated on the physics department website, or have noted contributions in the annual reports (e.g., receiving grant money or are otherwise active in research and teaching) are considered; this is because there are affiliate faculty who may not be active in the department and may not have much contact with students.

To quantity prestige, the following information per professor was collected:

1. Research dollars and number of grants
2. Research centers directed
3. Departmental appointments at the university

4. Departmental appointments at other institutes
5. Number of articles published
6. Times served as Chair of the Dissertation Committee
7. Awards won at the university
8. Awards won outside of the university
9. Officer positions in professional national organization (e.g., APS/AIP) committees, boards, and so on
10. Journal editorial roles
11. h-index

In cases where multiple professors received a single grant, the total amount was divided evenly among the professors.

The h-index is a way of measuring both the productivity and the impact of researcher. Productivity is the number of papers, N, that were published, while impact is measured by the number of times the work, N_C has been cited in research. In order to find a researcher's h-index, one needs a list of individual articles by that researcher and the number of times each article is cited. The articles are then listed in descending order by the number of times cited. The h-index is equal to the N of papers in the list that have at least N_C citations. For example, suppose a researcher has 5 papers published. If one paper has 25 citations and the other four have one citation, the h-index is 1. If all five papers have been cited at least 5 times, the h-index is 5.

H-indices were found using Reuters' "Web of Science" website, which uses the above method to find h-indices. Because some professors have the same first and last names as other professors, care was taken to ensure that the correct papers were used to calculate each professor's h-index. This was done by filtering by university affiliation. For faculty members who were not part of the university for the entire 5-year period, I also included previous affiliations during the 5 years. Because the Web of Science website provides a list of each paper included in the h-index calculation, I also manually checked each list to ensure that the papers were attributed to the correct professor.

All other data were obtained via departmental reports from the past 5 years or the professors' websites.

3.2 Survey

3.2.1 Population and Network Boundary

In order to capture the doctoral student network in its entirety, the sample consists of one physics department's entire doctoral student population. The university is located in the New England area and is referred to as "Jonas University." The doctoral physics program is considered a "Top 50" program. The program has typical requirements, such as qualifying exams and required coursework as described in literature (Nicholson et al., 2005). Jonas University has a similar percentage of female faculty in the physics departments to other departments (Ivie and Ray, 2005).

As mentioned in sections 2.9 and 2.10, the network's boundary is at the level of the department for two reasons. One reason is to provide an intermediary perspective on doctoral students; research has been conducted on the networks of individual doctoral students and large national trends of doctoral students. The second reason is much of the doctoral student experience is associated with the department, from admission to completing coursework to gaining approval for degree conferral.

Choosing a boundary at the departmental level is also practical for survey completion. Using a roster method limits generalizability, but it provides a level of detail and consistency that has not appeared in research. The analysis and conclusions are less tentative, because there is less variation among the students; they were admitted into the program by the same faculty, are members of the same academic and social environments, have access to the same professors, take the same courses, and have the opportunity to be a part of the same networks. In other words, fewer variations within in the sample are present when studying doctoral students in one departmental level than a sample of doctoral students in multiple departments.

Using multiple departments would introduce challenges to aggregating the data. For example, if the study were conducted using multiple departments, women may appear to have smaller networks than men. Several reasons for this result may be possible. Women in physics may have smaller networks than men in physics. All students, regardless of gender, in department A may have smaller networks than those in departments B and C. Such a result may be due to sample biasing where the majority of students in the sample are from department A. Departments vary in size, research specialties, extracurricular programming offered, social activities, and other areas.

Examining the entire department rather aggregate network data may indicate whether doctoral students tend to cluster, whether particular demographic groups tend to cluster, and whether connections are reciprocal (reciprocity occurs in the data when two participants name each other). Thus, focusing on one department using the roster method eliminates much of the variation that would arise if multiple universities were used. However, this limits generalizability as the focus is one department. Although the issue of generalizability is not completely eliminated, careful selection of the department ameliorated this issue. As mentioned earlier, Jonas University has a typical representation of female faculty and doctoral students. Their course requirements and program structure are typical as well. While these departmental attributes are not exhaustive of similarities, similar departmental attributes suggest that Jonas University's physics department is not an anomaly among physics departments.

The participants were working on their degrees during the 2012-2013 academic year, which was from September 2012 through August 2013. This timeframe was selected because it is the most recent complete year. Social interactions should be easier for participants to recall that interactions from earlier years. Because first-year students are a part of this study, it is important they have had adequate time to develop ties to other students. During the 2012-2013 academic year, there were 110 doctoral students and 45 faculty members.

3.2.2 Survey Questions

The survey questions are based upon the Ibarra study of men and women working in an advertising firm; this paper was discussed in section 2.3.2. Ibarra (1992) asked the following of her participants:

1. "With whom do you discuss what is going on in the organization?"

2. Who are: "important sources of professional advice, whom you approach if you have a work-related problem or when you want advice on a decision you have to make"

3. "that you know you can count on, whom you view as allies, who are dependable in times of crisis,"

4. "that you have personally talked to over the past couple of years when you wanted to affect the outcome of an important decision"

5. "who are very good friends of yours, people whom you see socially outside of work?"

The Ibarra survey questions were rewritten to be relevant to a physics doctoral student population. My survey questions delved into research, academic, social, and teaching areas. They are as follows:

1. With whom do you discuss what is going on in the Jonas University physics department?

2. Who are important sources of professional advice or career-related advice in the Jonas University physics department?

3. Whom do you approach for research-related reasons in the Jonas University physics department?

4. If you took classes during the 2012-2013 academic year, whom would you approach for course-related reasons in the Jonas University physics department?

5. If you were a teaching fellow or in another teaching position, whom would you approach for teaching-related reasons in the Jonas University physics department?

6. Whom would you approach for procedural advice (e.g., required courses, paperwork to file for graduation) in the Jonas University physics department?

7. Whom do you know you can count on, who are dependable in times of crisis in the Jonas University physics department?

8. Who are very good friends of yours within the Jonas University physics department, people whom you make plans to see socially or outside of a professional setting? E.g., go to the movies, play sports, see on the weekends for recreational purposes, etc.

9. Who are very good friends of yours, people whom you see socially at events organized by the department or a professor? E.g., attend departmental colloquia/seminars and other department events, have lunch during the work day, professor's lab party, etc.

3.2.3 Survey Design and Qualtrics

The survey was created using Qualtrics software, a web-based software for survey creation. Qualtrics offers many ways to design survey questions and is available for free at Boston University.

For questions related to doctoral students, I used a roster method where all doctoral students in the physics department were listed on the survey. The participants select which doctoral students they have contacted at least once during the 2012-2013 academic year. A roster method was selected due to issues with recall. According to a literature review by Brewer (2000), participants are likely to forget a substantial number of ties. No method exists to estimate the number of ties forgotten. Participants tend to do slightly better when given a specific prompt or context, such as asking about people at work (Brewer, 2000).

By providing a roster, participants did not have to recall names. For questions related to faculty and staff, a recall method was used. This was used to ensure survey fatigue did not occur. and the survey questions were not too repetitive. Students were also likely to be in contact with a smaller number of faculty and staff and thus, would more easily remember their names.

After agreeing to the informed consent, participants were initially asked to select doctoral students with whom they have contacted at least once during the 2012-2013 school year from a roster of all doctoral students with the physics department. This generated a personalized roster that participants used for subsequent questions. This was done in order to keep the list manageable to review for each question. Qualtrics populates each of the questions in section 3.2.2 with the names the participant selected from this first question. Immediately following each of the questions is a question on frequency of contact. On the screen, the names selected for that question appear alongside 6 boxes describing options for frequency of contact. The categories for frequency of contact are as follows: daily; 2-3 times a week; weekly; 2-3 times a month; monthly; less than once a month. The participant drags and drops the name to the appropriate box. A text box for further comments or clarification was included. This format is used for subsequent questions in relation to the doctoral students.

Not all of the survey questions are relevant to every doctoral student; students further along in the program may have already completed coursework or not be working in teaching positions. Because of this, the survey uses conditional logic which means that questions appeared depending on how previous questions were answered. For instance, if the participant had taken courses in the 2012-2013 time frame, questions related to courses would be asked. Otherwise, the next question would be about teaching. After questions regarding peer networks were asked, the same questions were then asked in relation to faculty and staff. Participants provided the names of relevant faculty and staff.

Participants might not socialize with other students in the context of some of these questions. If no one from their available choices was a source for a particular topic, participants were asked select "None from the list of graduate students." For faculty and staff questions, participants were instructed to type "None" into the first text box. These specific responses were to ensure that participants are not merely skipping questions but genuinely did not have a relevant person to name for the provided question.

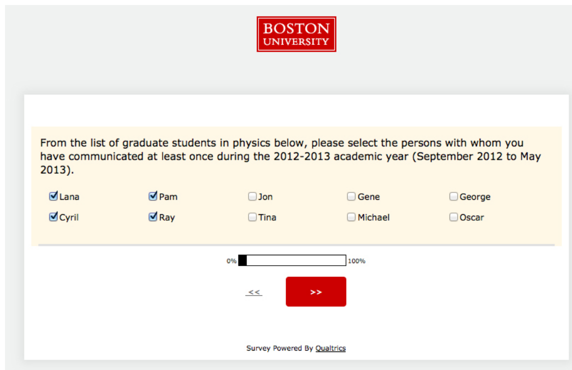

Figure 3·1: Personal roster creation. Participants select which doctoral students of the physics department with whom they have communicated in the past year

As an example, suppose there is a total of 10 doctoral students in a department, and the participant selects four: Lana, Cyril, Pam, and Ray for one's personal roster. Figure 3·1 depicts this. For question # 1, "With whom do you discuss what is going on in the university physics department?", the participant has the option of selecting all four but chooses only Lana, Ray, and Pam. If the participant does not seek out others for the displayed reason, the participant can select "None from the list of graduate students" and Qualtrics' conditional logic will skip the following question on the frequency of contact. Figure 3·2 depicts this screen.

The next question asks the participant to drag and drop those names into the box that best describes frequency of contact. Figure 3·3 displays this screen. Once questions regarding doctoral students are completed, the questions on faculty appear. If the participant discusses research with a faculty member, the participant provides the name of the faculty member when the question appears.

After being asked questions regarding ties within the department, participants were asked if there are any other relevant people who were important sources for academic, research, procedural, social, teaching, or support roles. This is asked not only

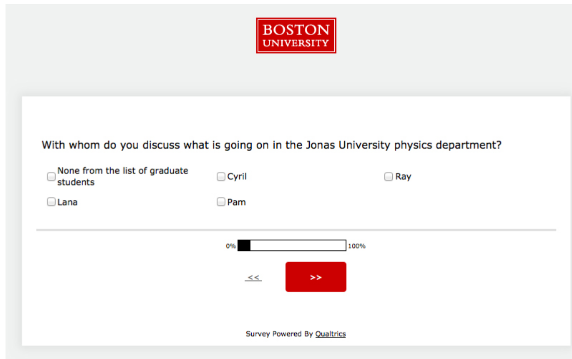

Figure 3·2: Example of answering the first question. The participant's personal roster is displayed for all questions. The participant then selects which students she or he communicates for each purpose.

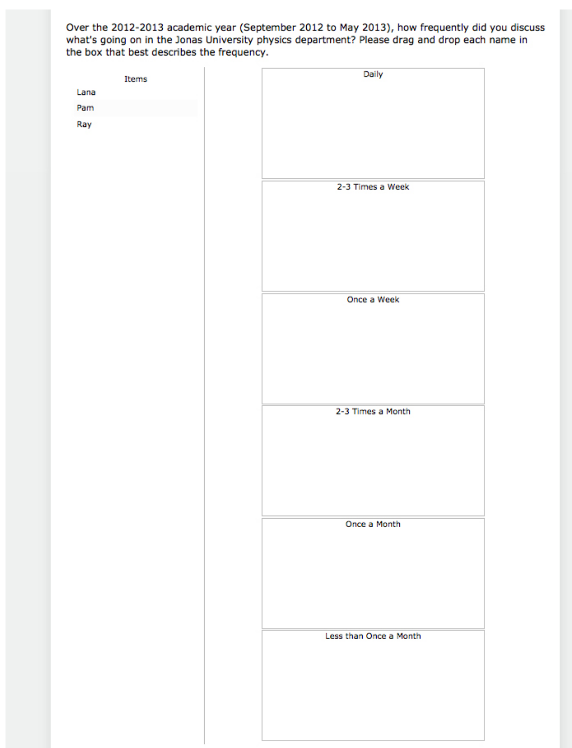

Figure 3·3: After selecting the students with whom the participants communicates for the purpose, the next screen asks the participant to drag and drop the names into the box that best describes the frequency of contact.

because the participants are a part of other settings, such as the university or town, but also the research itself may be interdisciplinary. Conducting interdisciplinary research may mean that the participant relies on other faculty. Although the network boundary was set at the department level for literature-based reasons, I wanted to capture the physics doctoral student social network experience; I anticipated that departmental ties would be the primary foundation of the various social networks, but I also considered that may not be true for all students. For example, a student who frequently works at a national lab in a different state may have more ties to those who work at the national lab than at the university; the department may not be the most suitable place for the student's needs being met. I also am interested in the ties that students form if the department does not meet their needs.

At the end of the survey, demographic and student information questions are also asked. They include the following pieces of information:

1. Age
2. Race/ethnicity
3. Gender
4. Relationship status
5. Student type (International or U.S. domestic)
6. Undergraduate institute
7. Prior graduate degrees
8. GPA
9. Semester and year entering program
10. Graduation semester and year or anticipated graduation semester and year
11. Subfield and research type (experimental or theoretical)
12. Advisor

13. Committee members

14. Mentor

15. Persistence (whether they considered leaving the program)

16. Perceptions of progress compared to other students

17. Completion of departmental requirements

The data from these questions not only provided descriptive information on the population but also were used for analysis.

The survey was tested via a pilot study in a similarly sized department. The four pilot study participants varied in terms of student type, gender, race/ethnicity, and year in program. The survey took 20-30 minutes for the pilot study participants to complete. A few questions were refined for clarity based upon feedback from those participants.

3.2.4 Survey Recruitment and Participation

Before gaining IRB approval, I sought permission from the department chair to conduct this study and to send an initial recruitment email. I expected that an email from the chair would increase the likelihood of the recruitment email being read. In the recruitment email, I briefly explained the study and provided a link to the survey. Because doctoral student colleagues within the physics department had expressed concerns regarding privacy, the email also contained detailed information on the IRB and participant privacy protection. I provided my contact information, as well as my advisor's, in this email in case participants wanted more information.

I also asked the department chair for a roster of doctoral students from this period. Because the departmental website lists the names of the students, my initial roster was created using the "Way Back Machine" (http://archive.org/web/), a publicly-accessible website that digitally archives the internet. However, the physics department website is frequently updated to reflect the current student population. The Way Back Machine's archives are sporadic, so one may miss a student depending upon the availability of archived versions. For this population, the archived versions I used spanned two academic years. For clarity, consider this example: two archived versions of a departmental website exist. One version is from April 2012, and the other version is from February 2013. Each version is a part of a different academic year. A student may be listed on the April 2012 website but not on the February 2013. Because of the amount of time between archived versions, two scenarios could have occurred. This student may have been a student during the fall 2012 semester but not the spring 2013 semester. However, this student may have also finished during May 2012 and thus, would not be eligible for my study.

The department chair allowed me to conduct my study and provided a roster of names. Our rosters differed by two names. My roster had included a student who had graduated, and the departmental roster left out a student who left the program for the 2013-2014 academy year. This was determined through corresponding with the departmental administrator. The final survey roster included 112 PhD students. However, after sending the first survey reminder email, I learned that two students who were listed had graduated prior to September 2012; they were not included in the data.

Due to privacy protection laws, I had to create my own email roster. The current departmental website was the source for current student email addresses. Contact information for doctoral students who left the program was found using other publicly available means such as the archived versions of the departmental website, LinkedIn, and Facebook. I also searched for students using the Google search engine. These Google searches aided me in finding email addresses from dissertations and from websites for their postdoctoral labs. I was able to locate up-to-date contact information for all students.

After obtaining IRB approval in late August, the department chair sent the recruitment email along with a personal message encouraging students to participate. I had initially offered $10 for completing the survey, which the pilot study participants found satisfactory. Although I had conducted a pilot study in a similar department, the survey took the first ten participants approximately an hour to complete. With

IRB approval, I increased the amount offered to $15. Money was sent via Paypal or mailed to the participant. Each participant also received either an email thank you note or a handwritten thank you note inside a handmade card.

Two weeks after the initial email, I sent another recruitment email to students who had not taken the survey. This email mentioned the increase in monetary compensation. These and subsequent emails were addressed and tailored to individual students. I mentioned common friends, read parts of their dissertations, or any other similar information to establish rapport with individuals. If the only available means of contact were LinkedIn or Facebook, I sent a message via those sites' messaging systems. After I had sent a second email to each student who had not taken the survey, I learned from my physics doctoral student colleagues that some students were still concerned about privacy protection. They also wanted to know the purpose of this study and more about me. I sent a clarification email a week after the second email. This third email provided more details regarding how I would protect privacy, the purpose of the study and my overall research goals, and the link to my LinkedIn page. My final email was sent the week of 13 October 2013. Copies of these recruitment emails appear in section 6.1.

The survey closed on 7 November 2013. Seventy-three (73) surveys were started. Fifty-five or 50% of the doctoral students completed the survey. Eighteen surveys were not completed and were not included in the data. Three students explicitly chose not to take the survey by not agreeing to the informed consent or sending an email to me.

3.3 Interviews

The purpose of the interviews was to gain further understanding of the social network data collected via the survey. While survey data do delve into some detail, interviews provide rich detail of the what, how, and why of the doctoral students' experiences. For example, knowing what specifically transpires during communication is important. Students may discuss work-related issues during social outings or talk about the latest baseball game. Research discussions may be unhelpful or unsupportive.

Interviews are also an opportune time to discuss reasons why (or why not) topics are discussed, as well any advantages or disadvantages students feel in participating by the departmental networks.

3.3.1 Sample and Recruitment

At the end of the survey, participants selected whether they would like to be contacted for an interview. Thirty-one (31) participants selected this option. Although this is a convenience sample, these participants represent various fields, time in the program, and student types. I also wanted to be sensitive when recruiting for interviews. The doctoral students had privacy concerns regarding the survey, which involved providing the names of the people with whom they discussed various topics. While the survey data have some context, such as alter nodes in one's research network, the information is rather neutral and not easily identifiable. Given the more intimate and specific nature of interviews, I did not wish to cause any unnecessary discomfort.

However, only 5 women had selected this option on the survey. Through my physics doctoral student contacts, I discovered that their doctoral student colleagues within the department were unsure why I was conducting interviews; I was never told which students were unaware of my purpose. My contacts suggested I send an email to clarify the purpose behind interviewing students. I specifically sent these emails to the seven additional female survey participants. One additional female participant agreed to an interview. Interview recruitment email examples can be found in section 6.1

Participants who had indicated they would like to be interviewed were sent an interview recruitment email. If they did not respond within two weeks, I sent a second email. I sent final interview recruitment emails three weeks after the second email.

When a participant agreed to an interview, they selected the date and time. To ensure comfort, I asked interview participants to select location. Ensuring comfort was important; after sending the scheduling email, several interview participants emailed me with concerns that faculty or fellow students would overhear their conversations with me. I reminded them that they could select any location of their choosing, as long as it was easily accessible. Participants selected academic buildings or coffee shops. When participants were not conveniently located to the area, interviews were conducted via Skype or phone.

3.3.2 Interview Protocol

After reviewing the interview informed consent, the interview began. The interviews were semi-structured using the following questions, which are intended to flesh out the survey data. Although the list is lengthy, I did not ask all of these questions; most participants provided this information on their own, without inquiry from me; the detailed nature of the questions were to ensure I did not forget to ask about important pieces of information. For organizational purposes, except for the first interview question, the survey question to which I am referring is listed first followed by the interview questions as subitems in the list:

1. Would you describe how you came to know each person you selected on the survey?
2. With whom do you discuss what is going on in the physics department at the university?
   (a) What kind of information do you find out about the department? Are these items of particular interest to you? What else would you like to know?
3. Who are important sources of professional advice or career-related advice in the university physics department?
   (a) What kinds of career-related advice do you seek?
   (b) How did you decide to ask these people/this person for career and professional advice?
   (c) Do you find the advice given is adequate? What types of information would you like to receive but do not?

4. Whom would you approach for research-related reasons in the university physics department?

    (a) What types of research information do you seek?

    (b) Do you feel your questions and concerns are addressed? What types of information would you like to receive but do not?

5. Whom would you approach for course-related reasons in the university physics department?

    (a) Why did you decide to talk these people/this person about courses?

    (b) What kinds of information do these sources provide?

    (c) Do you feel your questions and concerns are addressed? What types of information would you like to receive but do not?

6. Advisor

    (a) How did you select your advisor? What characteristics were you looking for?

    (b) What are your interactions like with your advisor? Is she or he helpful? What kind of help does she or he provide?

    (c) Before you began working with your advisor, what did you expect and hope for in your relationship with your advisor? Have your expectations and hopes been met?

7. Mentor

    (a) *If a mentor is named* How did you select your mentor? What job does this person have (professor, students, etc.)?

    (b) Describe what types of conversations you have with your mentor.

    (a) *If a mentor is not named* Are there any reasons why you do not have a mentor?

8. Committee members (if applicable)

    (a) How did you select the members of your committee?

    (b) What are your interactions like with your committee? Are they helpful? What kind of help do they provide?

    (c) Before you began working with your committee, what role did you imagine your committee would play in your research? Have they lived up to your expectations?

9. If you are a TF or in another teaching position, whom would you approach for teaching-related reasons in the university physics department? (if applicable)

    (a) What kinds of information do these sources provide?

    (b) Do you feel your questions and concerns are addressed?

    (c) What types of information would you like to receive but do not?

10. Whom would you approach for procedural advice (e.g., required courses, paperwork to file for graduation) in the university physics department?

    (a) Do you feel your questions and concerns are addressed? What types of information would you like to receive but do not?

11. Whom do you know you can count on, who are dependable in times of crisis within the university physics department?

    (a) Have you had to call upon these sources and if so, what type of situation? What happened?

    (b) What kind of support did they provide?

    (c) Looking back, do you wish they had handled things differently?

12. Who are very good friends of yours within the physics department, people whom you make plans to see socially or outside of a professional setting ? E.g., go to the movies, play sports, see on the weekends for recreational purposes, etc.

(a) When you see these friends, what do you do with them? Who makes the plans?

(b) What do you discuss?

(c) Do you find these relationships fulfilling?

13. Who are very good friends of yours, people whom you see socially at events organized by the department or professor? E.g., attend departmental colloquia/seminars and other department events, have lunch during the work day, professor's lab party, etc.

    (a) At what types of professional settings do you socialize with them?

    (b) What do you discuss?

    (c) Do you find these relationships fulfilling?

14. Socializing with faculty and staff in non-professional settings

    (a) When you see the named faculty members, what do you with them?

    (b) How did you and this faculty member/these faculty members start doing this activity?

    (c) What do you discuss?

15. Socializing with faculty in professional settings

    (a) At what types of professional settings do you socialize with them?

    (b) When you see the named faculty members, what do you with them?

    (c) What do you discuss?

16. Are there other people outside the physics department at the university you contact? Please list their names and select the nature of the relation.

    (a) Are these relationships any different from the ones you have formed within the physics department?

(b) How important are these relationships compared to the ones within the physics department at the university?

17. Are there any issues or challenges that prevent you from discussing any of these topics with the people you named?

18. Are there any other details or pieces of information you would like to share about your social experiences in the physics department?

I recorded each interview using a digital voice recorder with the consent of the interview participant. These recordings were later transcribed by me using Express Scribe software to play the recordings; Express Scribe is a free software that allows for customized shortcut keyboard commands to play and stop the audio recording when using a word processor. The software can also change the speed of the audio recording and remove ambient noise for clearer recordings. If the participant declined to allow me to record, I then took detailed notes on what was discussed. At the end of the interview, the participant received $10 in cash. For Skype and phone interviews, I sent the money via Paypal or mail.

The pilot study interview questions took 15-30 minutes. Those questions were refined and elaborated upon to obtain more detail. The interviews with this set of questions to take 20-60 minutes, depending on the participant's network and speed at which she or he spoke. Most interviews were 30-40 minutes. Participants could decline to answer questions or stop the interview should they have felt uncomfortable.

Interviews took place from the beginning of October to the middle of December 2013. Out of 38 contacted participants, twenty-eight completed interviews. Twenty-four participants allowed me to digitally record the interviews.

3.4 Analysis Methodology

In order to answer the research questions in section 2.10, data were collected via surveys, annual reports, internet searches, and interviews. Surveys and annual reports provided quantitative data, while interviews provided qualitative data. Prior to analysis, the survey data were further stripped of identifying information in order to maintain the privacy of the survey participants. This is discussed in section 3.4.1. In section 3.4.2, I describe the development of a model that draws upon annual reports and internet searches in order to rank faculty in order to determine relative prestige within the department. In section 3.4.4, the statistics determined from the data are discussed.

3.4.1 Anonymizing Survey Results

After closing the survey and removing incomplete surveys from the data, pseudonyms were assigned to every person in the data set to preserve anonymity. This includes the physics doctoral students, postdoctoral fellows, faculty, staff, and personal acquaintances of the participants. I created a list of first names for men and one for women. For last names, I used a list of the 1000 most common last names from the 2000 U.S. Census. These lists were then loaded into Mathematica 9.0.1 in order use the "RandomChoice" function. This function selects a name from the list pseudorandomly. If the function selected a first or last name similar to the actual name of the person, such as selecting Ann when the participant's real name is Annie, I ran the function again. This was done in order to further protect the privacy of the participants. Additionally, I only used last names that would be considered white and non-Hispanic for privacy reasons and to prevent possible confusion to any readers.

I collected data on undergraduate institutes, which also was anonymized. Undergraduate institutes were categorized as liberal arts colleges, public universities, private universities, or international universities. These are the labels the institutes themselves selected. These data were found on the websites of the universities. These categories include liberal arts college, public research university, private research university, and international university. Year in program data were aggregated for the sixth year and higher, because few students in individual years are still working on their degrees.

Due to low numbers, race/ethnic identities were placed into categories. Because race/ethnic identity is complex and has multiple ways of being examined, race/ethnicity was examined in two ways. The first method entailed examining race/ethnicity as specifically as possible while still maintaining some anonymity. The categories created are as follows: White, Asian (South and East Asian), and Other Non-White (Hispanic, Latino, Black, and Middle Eastern). The last category was created due to low counts for the respected ethnicities. The second method looked at a race/ethnicity as a binary: White and Non-White. The "Non-White" category included South Asians, East Asians, Hispanic, Latino, Black, and Middle Eastern identifying survey participants. These categories did not consider citizenship or the country in which the survey participant was raised. For example, a Latino student raised in the U.S. and a Latino student raised in the Dominican Republic would be considered Other Non-White

3.4.2 Prestige Ranking

The purpose of developing the prestige ranking equation was to determine relative prestige of faculty members in the physics department. The use of the word "prestige" in this dissertation does not merely refer to the number of network ties; it considers multiple variables to determine an individual's prestige. Data collection for this prestige model is described in section 3.1.

Before creating a ranking equation, several university ranking list methodologies were examined. I used university ranking lists, rather than faculty, because the only methodologies I could find for ranking faculty only considered citations and publications. For the purposes of this study, a more thorough means of ranking is needed. The variables included in university rankings tend to look at variables beyond research, making these methodologies a suitable starting point.

I considered the following ranking list methodologies: the National Research Council's (NRC) *Assessment of Research Doctorate Programs*, Academic Ranking of World Universities (also known as the Shanghai Rankings), Times Higher Education's *World University Rankings*, and U.S. News World and Report's *Best Graduate Schools* rankings. The Times Higher Education formula was selected, because it was the most comprehensive of the afore-mentioned lists and had field-specific weights for each category. The weights of each category varied according to the field. The Times Higher Education list for 2013-2014 used the following for their ranking of the physical sciences (Baty, 2013):

- Teaching
- Research
- Citations
- Industry income
- International outlook

Teaching, research, and citations each were worth 30% of the total score (Baty, 2013). Industry income was worth 2.5%, and international outlook was worth 7.5%.

For faculty ranking in this study, I decided not to include industry income or international outlook. Industry income was not included because some subfields may be more likely to have industry income than others. For the Times Higher Education rankings, international outlook was a means of examining diversity. Because I am ranking individual faculty members, this variable was irrelevant.

The following variables, with their abbreviation in parentheses, were initially considered:

- Teaching
  - Number of PhD recipients advised (T_{PhD})
  - Number of faculty appointments ($T_{FacAppt}$)
  - Number of published textbooks ($T_{PubText}$)
- Research
  - Number of papers published ($R_{PubPapers}$)
  - Amount of grant money ($R_{GrantMoney}$)
- Publication Citations

  - H-index (H)

- Awards/honors (A)

  - Number of awards or honors received

- Leadership Positions

  - Number of director, dean, and provost positions ($L_{Director}$)
  - Number of chair positions (L_{Chair})
  - Number of external committee head positions (L_{ExComm})
  - Number of journal editor positions: regular and guest ($L_{Journal}$)

These variables provide a comprehensive look at a professor's career by considering professional reputation, productivity, and recognition.

Each category is worth 20%. David Campbell, a member of my dissertation committee, helped determine the weight of each variable as a starting point. He was selected because he held multiple administrative positions at several institutes and is familiar with these rankings. The initial equation is as follows:

$$P = 0.1T_{PhD} + 0.05T_{FacAppt} + 0.05T_{PubText} + 0.15R_{PubPapers} + 0.05R_{GrantMoney} + 0.2H + 0.2A + 0.07L_D + 0.04L_C + 0.02L_{ExComm} + 0.07L_{JE} \quad (3.1)$$

where P is the prestige of the faculty member. Faculty members were then ranked according to P. The mean and standard deviation were determined. Faculty members who received a P score higher than one standard deviation were considered to be "higher prestige." Faculty who received a P score more than one standard deviation below the mean were considered to be "lower prestige." Those whose P score was within one standard deviation of the mean were considered "typical prestige." The outliers were categorized accordingly.

Equation 3.1 was revealed to favor high energy experimentalists working at CERN, due to the large amounts of grant money received. Scaling the grant money did not ameliorate this effect, nor did changing the weight to 5%. Furthermore the standard deviation was larger than the mean. These data were analyzed by finding the averages by research type (experimental or theoretical/computational) and subfield. For instance, I considered high energy experimentalists as separate group from condensed matter experimentalists and high energy theorists.

Even when dividing the faculty by subfield and research type, the standard deviations remained larger than the mean for all categories. After finding the rankings of faculty members in their subfield and research type, I then looked at individuals to see if any outliers remained. The highest ranked individual for one group had a P score that was double that of the second ranked person. This is known as the "King effect" where one entity's value is significantly higher than others in the sample. There were also faculty who were not active in the above areas during this period. These outliers were not considered when performing mean and standard deviation calculations. However, they were categorized. Even when excluding outliers, the standard deviations remained larger than the mean. Because of this reason, grant money was not considered. The equation also already has ways of examining productivity (number of papers published, PhD recipients advised) and quality of work (h-indices, awards).

The final equation is as follows:

$$P = 0.1T_{PhD} + 0.05T_{FacAppt} + 0.05T_{PubText} + 0.2R_{PubPapers} + \\ 0.2H + 0.2A + 0.07L_D + 0.04L_C + 0.02L_{ExComm} + 0.07L_{JE} \quad (3.2)$$

This equation was used to find P scores for faculty within their research type and subfield. Nine faculty members were in the higher prestige category, twenty-six in the typical prestige category, and ten in the lower prestige category.

Although care was taken to ensure that the rankings were fair, I note that there is some subjectivity and user discretion to any ranking system. The individual weights assigned to variables is one example of subjectivity; someone else may believe the weight for one variable should be significantly higher or lower. This equation does not consider the nuances of each variable; there is a hierarchy among the academic journals, for example. Being an editor of a journal may carry more value if the journal is highly regarded.

However, there is merit in this ranking system. The faculty ranking equation in this study does not privilege particular subfields or research type; faculty members were ranked against their peers. The overall category weights and categories themselves were based upon what members within the physical sciences community valued; while these values were found for institutional performance, individuals are what drive the institutional performance. Perhaps the nuances of each variable may not be significant. An editor of a less regarded but still respectable journal may receive ample respect and acknowledgement from the research community.

Survey participants also named people who are not physics department faculty or students. While these people are included in the analysis, they are not ranked. These include staff (administrative and technical) and post-docs, who each received their own categories of "Staff" and "Post-docs." Research scientists (non-teaching) and faculty from outside the department (either within or outside of the university) were categorized as "Other Scientist."

3.4.3 Network Graphs and Calculations

Gephi, an open source software initially developed by students at University of Technology of Compiègne and further developed through Google's "Summer of Code" institute, was used to generate sociogram graphs. Node and tie data are loaded into Gephi to create the graphs. There are many visualization options for data. Nodes and ties can be colored randomly or through user selection; for various demographic considerations, Colors were selected to signify demographic groups. Sociograms can be laid out manually (the user moves the nodes) and through built-in algorithms.

The "Force Atlas" algorithm, which is designed to group nodes into clusters of connected nodes, was used. The algorithm attempts to depict communities. Nodes were then manually moved to provide spacing between one another and to ensure that connections were clear. For example, node A occasionally would intersect the tie between node B and node C. It would appear as though node A was a bridge between the two nodes when it was not.

There are also graphical options for ties. In this study, the thickness or weight of the line connecting to nodes indicates how strong the tie is; stronger ties have thicker lines. Arrowheads indicate direction of the tie. Ties are also color coded. If ties are not reciprocated, the tie color is a lighter shade. Reciprocated ties are a darker shade; for example, darker red would indicate a reciprocated tie while lighter red or pink indicate an unreciprocated tie. For example, suppose Regina selected Florence but Florence did not select Regina. The line connecting Regina to Florence would be light red. If the tie is reciprocal, the line connecting the two would be dark red.

A multiplex graph was also created to see how nodes are connected overall. Multiplexity is when nodes are connected for multiple purposes, such as being friends and classmates. Graphically, multiplicity is depicted as one sociogram where ties from all purposes connect the nodes. Numerically, this becomes a total for the number of times named. For example, suppose Archer was named by Malory for departmental information and research. Cheryl named Archer for departmental information. The number of in-ties for Archer would be 3.

Some basic network calculations can also be found using Gephi. For this study, Gephi was used to calculate betweenness centrality, degree centrality, and network density. Gephi uses typical network equations to find these attributes. Tie direction was also found using Gephi. Weighted ties are calculated by multiplying the weight of the edge by the node value; in this case, the node value is 1 (which indicates a relationship) and the frequency of contact on scale of 1 (least frequent) to 6 (most frequent). Section 2.2.1 describes these concepts in more detail and provides the equations to find these quantities.

3.4.4 Analysis Techniques

Qualitative data were analyzed thematically. Transcribed interviews were initially coded individually, without consideration for the research questions. This was done in order to assure that the true meaning of the interviews were found. Quoted passages from every interview were then grouped according to code. Codes were further refined when I reviewed the quoted passages from multiple interviews. Lastly, the codes with quoted passages were grouped by research question.

The survey data were analyzed statistically primarily using SPSS 22. Descriptive statistics, such as frequencies, were used to describe the responses to each survey question. R Studio, an open source software that runs the statistical programming language R, was used for Fisher's exact tests and odds ratios. In the following sections, I describe the specific statistical techniques used, separated by the main research questions.

"In what types of networks do doctoral students participate for professional and social reasons within their physics department?"

Qualitative data provided answers to how social networks form for the various purposes, for both peer and student-faculty/staff networks. Interview participants discussed how they maintain their ties to fellow students. Additionally, the interview data provided information on what hinders network formation.

Averages for each network purpose were taken for the number of student ties, number of faculty and staff ties, direction of ties (whether they were reciprocal), contact frequency, degree centrality, betweenness centrality, and network density. ANOVAs were used to compare the number of student ties to the number of faculty, per prestige ranking, and staff ties, per network network purpose. T-tests were also used to determine if in-ties varied between non- survey participants and participants. ANOVAs were taken to compare each network purpose for each network attribute. For example, the mean betweenness centrality was compared for all network purposes. Levene's test for equality of variance was run to ensure comparison groups have similar variances. For ANOVAs, if the varianced was not equal, Welch's test was used to determine if the difference among the means were statistically significant. Post-hoc Tukey tests were run for ANOVAs that had equal variance and statistical significance; post-hoc Games-Howell tests were run for ANOVAs that did not have equal variance but were statistically significant.

Reciprocity was found for each network purpose. The data used for reciprocity only included survey participants. This was calculated as percentage. For example, suppose there are 100 ties among survey participants. If 60 of these ties are reciprocal, then reciprocity would be 60%.

"What is discussed in these doctoral student networks?"

Frequencies of interview data codes were taken to see which individuals fromxs which roles (student, staff, faculty) are contacted for what reasons.

"Does doctoral student participation within the various networks have any relationship to progress in the program and confidence in PhD completion, and if so, what kind of relationship?"

The survey includes several questions that delve into participant confidence and perceived progress in completing the PhD. These questions include:

- During your time at Jonas University, how seriously did you consider leaving the physics PhD program?
- During your time at Jonas University, how seriously did you consider leaving the physics PhD program with a master's?
- Compared to other students in the physics PhD program at Jonas University, how would you best describe your progress?

The responses regarding leaving the program and perceived progress are all categorical data with few data points per category. Because of this, Fisher's exact tests were used to find the relationship between network attributes and these outcomes variables; network attribute data were also collapsed into categories. The categories for ties are as follows: 0 for having no ties, 1 for having one to five ties, 2 for having six to ten ties, and 3 for having eleven or more ties. For weighted ties, the categories are as follows: 0 for having no ties, 1 for one to fifteen, 2 for sixteen to thirty, and 3 for over thirty-one to sixty, and 4 for over sixty.

The survey also asked participants whether they had a person they considered to be a mentor. Although some participants noted multiple mentors, the mentoring variable was collapsed as whether one had a mentor or did not. Fisher's exact tests were used to see if having at least one mentor had any relationship with the responses to these questions.

Participants were also asked to provide the semester and year entering the physics PhD program and their projected or actual end semester and year; actual end semester and year are for those who completed the program with a doctorate. From that information, I found the estimated or actual amount of time to graduation. Because doctoral students in physics tend to be full-time students who work throughout the calendar year, I counted each semester as one third of the year. Summer was considered to be one third, as it is approximately the same length of a semester. To clarify, suppose a student's first semester was Fall 2010. The student estimated she would graduate during Spring 2015. Her time in the program would be estimated as 4.67 years. If the participant listed a month and not a semester, I rounded to the nearest completed semester. For instance, if a student estimated his graduation date will be January 2015, I would consider the graduation semester and year to be fall 2014. The time in program variable was used as a dependent variable for linear multiple regression. Independent variables were all network attribute variables.

"Do the responses to any of these questions vary by gender, race/ethnicity, student type (U.S. domestic or international), year in program, undergraduate institute type, relationship status, subfield, or research type (experimental or theoretical)?"

The above analyses were also done with consideration for the following demographic categories: gender, race/ethnicity, student type (U.S. domestic or international), year in program, undergraduate institute type, relationship status, subfield, or research type (experimental or theoretical). T-tests, chi-squares or Fisher's exact tests, and ANOVAs were used; the statistical analysis technique depended on the number of categories and the amount of data.

Gender was selected by survey participants; no participants identified as transgender or genderqueer. Survey participants selected whether they were a U.S. domestic or international student, their research type, and relationship status. Survey participants provided the following in free-response boxes: race/ethnicity; entering semester, projected or actual end semester; undergraduate institute type; and subfield. Race categories are described in section 3.4.1 Survey participants provided their subfields. These subfields include biophysics, condensed matter physics, and high energy physics. Some survey participants identified a different field, such as statistical physics. Those participants were aggregated into the subfield of their advisor. For instance, a participant who identified his/her field as statistical physics would be assigned to condensed matter physics if that were the advisor's primary field.

Homophily was calculated using point biserial correlation coefficients, as done in the Ibarra (1992) study; this type of correlation coefficient was selected because it considers the number of possible selections per group. For example, suppose there are seven men and three women in a department. If a male participant selects 2 women and 1 man, one could interpret the participant's network as 33% homophilous. However, this would not be accurate as there were more male participants to select. Point biserial correlation coefficients correct for this.

The equation to calculate homophily Ψ using this correlation coefficient is as follows:

$$\Psi = \sqrt{\left(\frac{a}{a+c} - \frac{b}{b+d}\right)\left(\frac{a}{a+b} - \frac{c}{c+d}\right)} \tag{3.3}$$

where a is the number of ties of the same demographic; b is the number of ties of a different demographic; c is the number of people of the same demographic that could have been selected but were not; and d is the number of people of a different demographic that could have been selected but were not. The same demographic would be a man selecting other men; a different demographic would be a man selecting other women. The range of values is -1 to 1, where -1 is completely heterophilous (an entire network of nodes who are the opposite demographics) and 1 is completely homophilous. If Ψ is equal to 0, the person's network has a balanced network.

3.5 Limitations

The primary limitation of this study is that it is a case study of one physics doctoral program. Conducting this study at a different university may yield different results.

For example, a smaller department may have more densely connected networks. However, Jonas University is not an anomaly, as discussed in section 3.2.1.

The second limitation is that only half of the doctoral students participated in the survey and twenty-eight agreed to be interviewed. Those who did not participate in the survey may have felt particularly vulnerable. Through other student participants, I learned that a few of the doctoral students were concerned about their privacy and how the data would be used. Similarly, those who did not agree to be interviewed may have been concerned about their privacy. These concerns included faculty or fellow students overhearing the interview.

Specific concerns were never articulated to me, so I am unsure what the exact nature of the privacy concerns were. However, I addressed these concerns as best I could. I was careful to explain how I planned on protecting their privacy and the purpose of this study in any email communication. Ways in which I protected their privacy include storing the data on password-protected flash drives and using pseudonyms when analyzing survey and interview data. I explained that while I asked for detailed information, I would aggregate the data such that identifying information, such as race, would not be easily determined. As mentioned earlier, I allowed interview participants to select the location of our interview. Prospective participants were also encouraged to contact me regarding any concerns they may have had. Lastly, I asked that the participants who mentioned their peers' concerns inform their peers of all this.

The third limitation is that several demographic categories consist of aggregate variables. For instance, international students are examined without regard to their national origin. There may be differences between Chinese and Indian international student participants. These categories were aggregated due to the low representation of participants in disaggregated categories. Despite the possibility of differences, there are commonalities in among the variables in the collapsed categories. Continuing with the example of Chinese and Indian international students, these students are likely to be less familiar with the U.S. and are more familiar with a different school system.

Lastly, intersectionality cannot be statistically examined in this data set. As discussed in chapter 2, demographic categories interact. Intersected variables, such as race and gender, cannot be analyzed due to low representation. For example, there are too few women to create separate categories for black women and white women However, this is an issue even at the national level where there are few physics doctoral students who are underrepresented in multiple ways such as black women.

3.6 About the Researcher

My own social network is very much a part of this research. I have numerous professional and personal connections to the physics department in this study. These connections were formed from employment, research, service, and personal reasons. Although the strength of each connection varies, I consider most of them quite strong.

3.6.1 Employment

From summer 2010 through the present time, I have worked for professors within the physics department. During summer 2010, I worked as a program manager for a K-8 science teacher immersion program. I met and communicated with 3 professors during this time. From May 2011 through August 2013 (approximately 2 years), I was the program manager for an NSF-funded Graduate STEM Fellows in K-12 Education (GK-12) program. A physics professor from the previous summer was the principal investigator (PI) for this program.

During my time as the GK-12 program manager, I worked with physics doctoral students. Nine doctoral students from this program were eligible for this study. This work entailed high levels of involvement with these doctoral students, from organizing their training activities to giving teaching feedback to acting as a mentor for their teaching endeavors. Due to their different teaching experiences, I met with some of the doctoral students more frequently and provided more support. I also met with the PI frequently to discuss the status of the students and the program.

Concurrent with GK-12 was my work with the Learning Assistant (LA) program. The LA program designed to provide pedagogical training to undergraduate teaching assistants. I was the teaching assistant for the physics LAs from Fall 2011 through

Spring 2013. The same three professors from Summer 2010 are active within the program. In addition to directly working with professors in the physics department, I learned about the graduate students and other professors through the LAs discussions and writings. However, they often did not provide names so I am not sure whom the LAs discussed.

In addition to these larger projects, I worked in two other areas that involved physics graduate students. I taught a high school science teaching pre-practicum in which science majors enroll to determine whether teaching is a suitable career for them. I also work for my former GK-12 PI. He is currently the Director of STEM Education Initiatives at the university. I currently am his graduate assistant for this work, which involves working closely with him.

Part of the work entails receiving information about and interacting with other members of the physics department. I provide guidance and support for a small teaching research project that involves two doctoral students. Both were eligible for my study. My role as the graduate assistant also involves interviewing faculty for videos on innovative STEM teaching practices; we plan on interviewing the two professors with whom I worked summer 2010, as well as a staff person from the physics department. I am currently creating department-level preliminary reports on graduate student teacher training for the STEM departments; this includes the physics department.

3.6.2 Research

David Campbell, who is on my committee, is a member of the physics department. During Fall 2010, I had noticed his name and affiliation with the university on a report from APS on graduate students in physics. Because I was searching for a research topic and direction, I wrote to him. I have been in contact with him since January 2011. I often refer to him as my mentor. He has provided me with ample professional guidance and has been an invaluable asset in helping me make connections for my research.

3.6.3 Service

During the summer of 2013, the physics department developed and implemented a comprehensive teaching fellow (TF) mentor program for incoming physics doctoral students. The program included a training weekend, observing new TFs, student assessments, and meetings with the mentors and protègès. Because I have been a mentor since January 2011 and have received extensive mentor training, I worked with this program. I provided feedback on the training modules designed by the mentors, as well as guidance and support for the mentors. Two of the mentors were a part of the GK-12 program, and the other two are working on the teaching research project. Two of the professors for whom I had worked during Summer 2010 were involved in supporting and guiding the four senior doctoral student mentors who led and implemented the features of this program.

After suggesting a career panel for the undergraduate physics club, I have been in sporadic contact with another physics professor. I primarily send any undergraduate physics opportunities to him to disperse to the undergraduates. He is also married to one of my friend's aunts.

Since November 2013, I have assisted one physics professor with the Northeast LA Regional Workshop; he is a professor from my work during Summer 2010. This consists of website creation, creating publicity materials, and frequent meetings to discuss recruitment and other tasks related to the workshops.

3.6.4 Personal

Many of my friends and acquaintances are or were doctoral students in the physics department. In addition to the students I have already named, I also socialize with two physics doctoral students and one alumnus of the program. The socializing with the alumnus and the current students varies from being close friends to seeing them at student-organized gatherings to seeing them at departmental events such as colloquia. I was also dating one of the physics doctoral students' close friends during much of this study.

3.6.5 Miscellaneous

While I was the GK-12 program manager, I would bring in homemade baked goods to share with them. I would leave them in the physics main office's kitchen, because the majority of the GK-12 participants were in physics. The location was central to the other GK-12 participants. The baked good were also shared with the main office workers as well as any students who stopped in the kitchen. Many of the staff met me when I was leaving items, or they knew me from the notes I would leave. I still occasionally leave baked goods.

During the 2013 academic year, I joined a biophysics journal club started by one of the TF mentors. Two other TF mentors and a friend all participate regularly, as well as another physics doctoral student. This journal club started after I had closed the survey.

3.6.6 Discussion on the Researcher

In many ways, these connections have provided me with advantages in conducting this research. Having friends and acquaintances in the department may have positively affected the response rate to the survey, because my friends have discussed my survey with their friends and acquaintances in the department. My friends were also able to share any concerns that their friends had regarding my research, which I could address in general emails. Some of the respondents may recognize my name from leaving baked goods; one of the participants I interviewed requested a recipe from me earlier in the year. The staff has responsive and accommodating to my requests for help. My familiarity with the department also helped in correcting misspelled faculty names or when students provided nicknames for faculty; this was important to ensure that the nodes in the network were accurate.

Although the connections to the department have many positive effects, they also have the potential for negative effects. I may not intend to do so, but I potentially have unconscious biases. Survey data could be biased towards those I know or the friends of those I know. I knew 13 of the 110 doctoral students in my sample prior to the commencement of this study. However, not all of the 13 students I knew prior participated in the study. The majority of participants in the study were not friends or acquaintances of mine, and their connections to my friends and acquaintances varied. Beyond a potential sampling bias, I see no other concerns regarding my affiliation with the department in analyzing the survey data. The survey data are more straightforward for analysis; participants provided the names of the faculty, staff, and students in their networks.

Of more concern is the interview data. There are opportunities for biases to affect the data. As their supervisor, coworker, friend, or instructor, I have formulated opinions on some of the doctoral students based on my experiences with them. Similarly, I have opinions towards the faculty. These biases could have affected how comfortable participants were in divulging their experiences to me. An example would be if a student knew I favored a particular professor that the student did not like. The participant may be concerned that I would reveal this information to the faculty member or simply feel uncomfortable saying something unfavorable about this person.

There were also opportunities to either miss vital data or to accidentally draw upon personal, private conversations. Some of my friends and acquaintances have discussed faculty and fellow students with me. Because we have shared experiences and conversations, they may not feel it is necessary to explain an event or situation in as much detail as they would to a stranger. This could produce data that is ambiguous to those who are not privy to the personal conversation. For example, someone may refer to a time of crisis in a succinct statement that is clear to me, because I was there and could recall what happened. However, this would not be clear to a reader who does not know the participant. The reader would need detailed information to understand why such a time was considered a crisis and what its affect was on the participant. Referencing conversations or events outside of the interviews would be problematic. Friends and acquaintances may not want some details of those conversations or events included in the research.

I dealt with the potential unconscious biases and respect to personal relationships in the following ways. When interviewing students I already knew, I asked that they discussed all topics as though I did not know anything about these topics; I wanted to ensure that I had a complete interview without ambiguities. I was careful to ask neutral questions that did not assert my opinion on the people mentioned by the interviewee. If the participants were aware of my connections to the afore-mentioned faculty, I emphasized that I was respectful of privacy and interested in knowing the person's opinion. Only the data that I received from interviews is in the analysis. None of my personal experiences or casual observations are included in the data analysis, although they did aid in creating hypotheses. I analyzed the interview data only when the pseudonyms were incorporated in the transcript. I then sorted all of the interview data by research question and theme. Without the entire interview to provide context, it became more difficult to determine the real names of the people mentioned.

While there is potential for unconscious biases to affect the data and interpretation, I have consciously worked to ensure these biases are minimized. The survey data are representative of the department. During interviews, I was conscientious of my role as a researcher and reminded the participants of this. Additionally, by removing identifying information during the analysis, I created further distance between the interview participants and myself.

Chapter 4

Data and Analysis

Data are presented by research question. Both qualitative and quantitative data are presented in this chapter.

In chapter 5, I discuss the results presented in this chapter. Specifically, chapter 5 looks at prominent themes and how the qualitative and quantitative results work in conjunction for understanding the social networks of the physics doctoral students.

4.1 Sample Description

4.1.1 Survey Sample

Fifty-five (55) of 110 possible participants completed the survey. Because no question was required to complete the survey, some questions have fewer than 55 responses. Unless otherwise noted, all demographic data are within 2 standard deviations of the mean.

The mean age of the survey participants is 27 ± 3 years, with one participant not providing his or her age. Forty-three participants are male, while twelve are female. Thirty-two participants are White, sixteen are Asian (East and South Asian), and seven are Other Non-White. For the binary race category, twenty-three are Non-White. Nineteen participants are in dating relationships, seven are engaged, twelve are married or in domestic partnerships, and seventeen are single. Twenty-nine are international students, while twenty-six are U.S. domestic students. Undergraduate institute breakdown is as follows: ten participants attended a liberal arts college (U.S. or international), twenty-three attended an international university, nine attended a private university, and thirteen attended a public university. Twelve participants

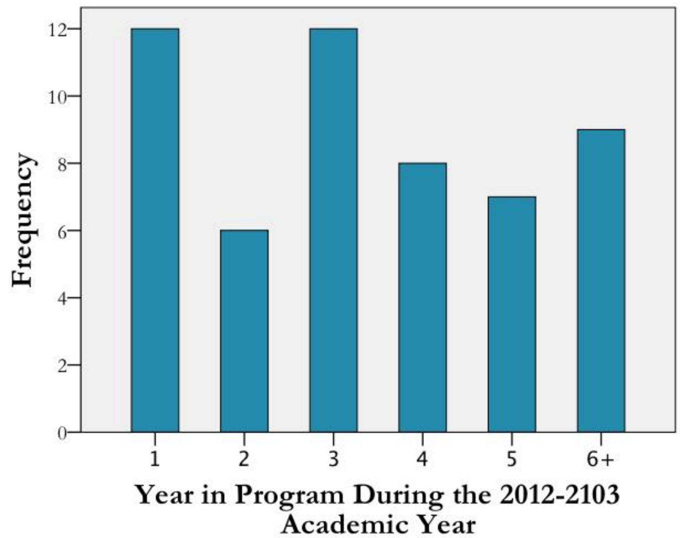

Figure 4·1: The number of participants by year in the program.

earned master's degrees prior to starting the doctoral program at Jonas University. Figure 4·1 depicts the distribution of the participants' year in the program during the 2012-2013 academic year. There are six to twelve participants per year category.

The mean GPA of the participants is 3.7 ± 0.3, with four participants who did not provide their GPAs. The mean time to completion, both actual (participants who graduated) and estimated (degree still in progress) is 6 ± 1 years. Three participants did not provide information on time to degree. Of the three, two have left the program. Seven participants have taken or anticipate taking 7+ years to complete their degrees. Twenty-five participants are conducting experimental research, while thirty are conducting theoretical or computational research. Figure 4·2 displays the distribution of subfields. Thirty-three of survey participants are in condensed matter physics (CM), fourteen participants are in in biophysics (BIO), and eight are in high energy physics (HE).

Thirty-seven participants identified having at least one mentor; eighteen participants did not identify a mentor. Of the thirty-seven participants who have mentors, each individual has 2 ± 1 mentors. Although most participants had a single mentor, two participants named seven mentors.

Table 4.1 summarizes various benchmarks the participants have completed. The

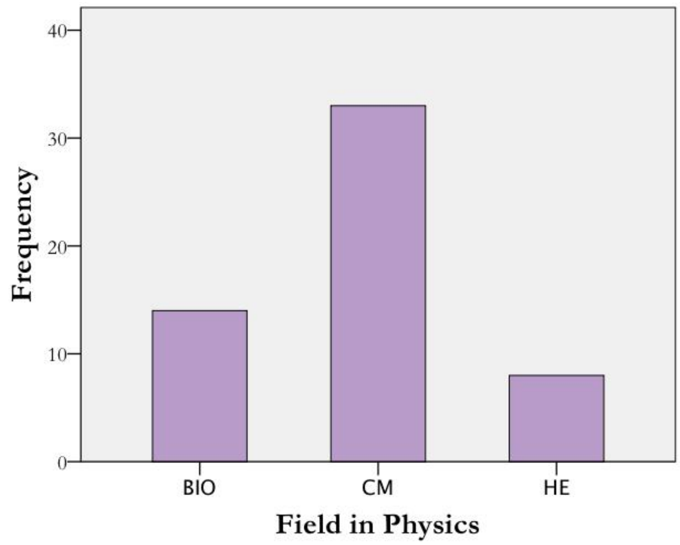

Figure 4·2: Distribution of survey participants by subfield. BIO is biophysics, CM is condensed matter physics , and HE is high energy physics.

departmental seminar is a research talk given prior to the dissertation defense. Because the sample consists of students in different stages of the doctoral program, some students may not be at a point where they have completed these benchmarks. The "Did Not or Have Not Passed" category is consists of three categories: attempted and did not pass, have not attempted, and attempted but have not received results. These categories were aggregated to protect the participants' identities.

The first question on the survey asked participants to select the students with whom they had a conversation during the 2012-2013 academic year. Figure 4·3 displays this sociogram. Nodes that are grey represent students who did not take the survey; nodes that are black represent students who completed the survey. Unless otherwise noted, the node color coding remains the same. Two-thousand sixty-six (2066) ties are represented.

Only one survey participant did not select any other students. Twenty-one participants, including the participant who did not select any other students, selected themselves as someone with whom they had a conversation. Because subsequent questions on the survey pertain to matters such as advice or discussion partners, these answers were not included in the data that were analyzed. Selecting oneself did

Table 4.1: *Summary of departmental benchmarks completed*

	Yes	No	Passed	Did Not or Have Not Passed
Written Qualifying Exam	-	-	47	8
Completed Coursework	32	25	-	-
Oral Qualifying Exam	-	-	28	27
Given Departmental Seminar	11	43	-	-
Dissertation Defense	-	-	3	52

The "Did/Have Not Pass" category consists of those who attempted to complete the requirement and did not pass, those who do not know their results, and those who have not attempted to complete the requirement. The departmental seminar is a research talk given prior to the dissertation defense.

not appear to be an error on behalf of the participant; the participants who selected themselves in the first question also selected themselves conscientiously for certain purposes. For example, one participant selected himself or herself for career advice but did not select himself or herself for research advice.

For the first question, which asked participants which peers they had contacted at least once during the 2012-2013 academic year, survey participants received 22 ± 9 in-ties. This is the total number of times they were named by other participants. Non-participants have an average of 16 ± 8 in-ties. An independent t-test was run on these data; the probability is less than 0.05, indicating the difference between the two groups is statistically significant. Figure 4·3 is the sociogram of these data for the first question. There no distinct groups in these data or obviously areas with a higher density of ties.

Because this is a closed network, some information on the non-participants was available. Seven first-year, ten second-year, eight third-year, seven fourth-year, two fifth-year, and seventeen sixth or higher year students did not take the survey. The year in program data are not available for five non-participants. Five women and fifty men did not take the survey. Thirty-two White, twenty-one Asians, and two Other

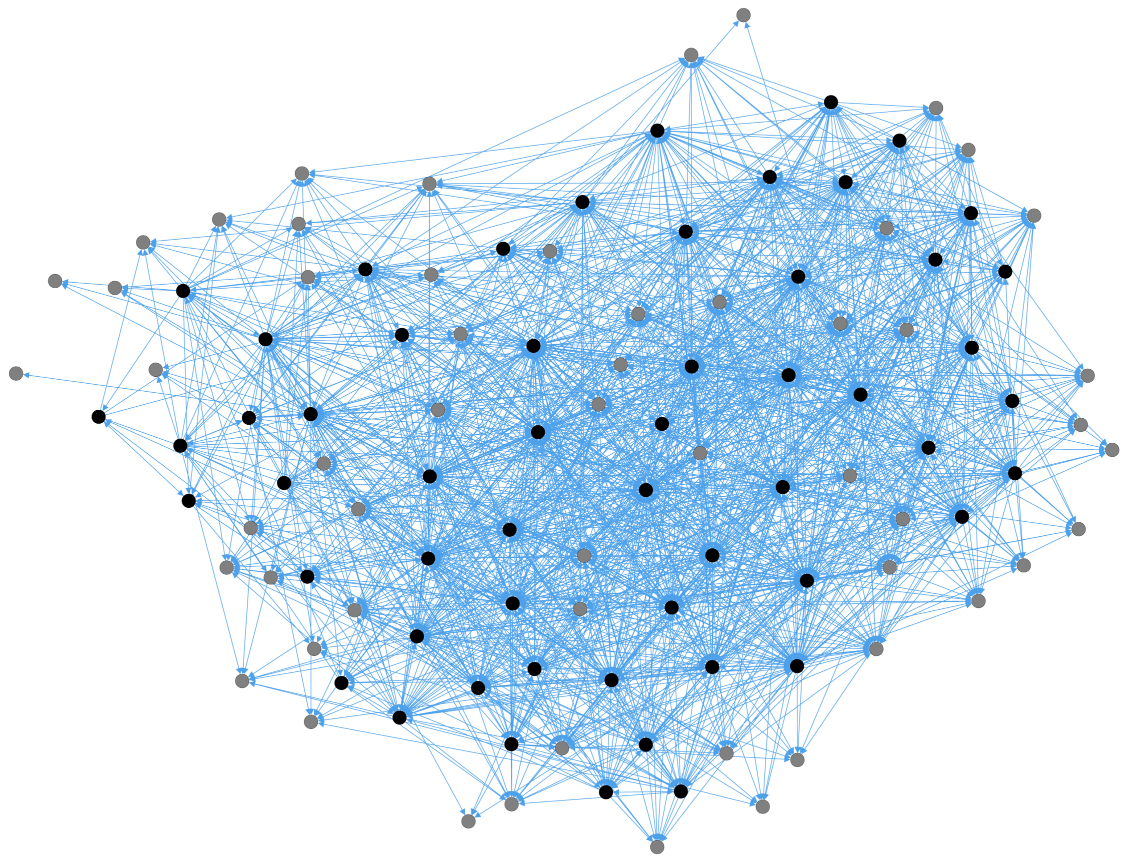

Figure 4·3: Sociogram depicting the connections among students who had at least one conversation during the 2012-2013 academic year. Black nodes represent students who took the survey; grey nodes represent the students who did not.

Non-White students are non-participants; twenty-three non-participants are categorized as Non-White for the binary race category. Twenty-seven non-participants are international students, while nineteen are U.S. domestic; nine are unknown. Undergraduate institutes are as follows: one non-participant attended a liberal art college; twenty-three attended an international university; eleven attended a private university; and thirteen attended a public university.

Twenty-seven students conducting experimental research and nineteen students conducting theoretical/computational research did not take the survey. The research type for nine students is unknown. For subfields, five students in BIO, thirty-four students in CM, and twelve students in HE are non-participants. Four non-participants' subfields are unknown.

4.1.2 Interview Sample

Twenty-eight survey participants agreed to be interviewed. Five interview participants are female, and twenty-three are male. Twenty participants are White, six are Asian, and two Other Non-White. Nine participants are international students, and nineteen are U.S. domestic students. Seven participants are single, twelve are in dating relationships, four are engaged, and five are married or in domestic partnerships.

Four were in their first-year during the 2012-2013 academic year, two were in their second-year, seven were in their third-year, five were in their fourth-year, five were in their fifth-year, and five were in their sixth or higher year. Nine interview participants are in BIO, sixteen in CM, and three in HE. Thirteen work in experimental research, while fifteen are in theoretical research.

4.2 "In what types of networks do doctoral students participate for professional and social reasons within their physics department?"

The survey asked questions regarding the following types of networks: general departmental information, coursework, teaching, research, career, crisis, socializing within the department, and socializing outside of the department. Doctoral students participate in these networks with fellow doctoral students, faculty, research scientists, postdocs, and staff.

Sections 4.2.1 and 4.2.2 describe how these networks are formed and sustained, as well as quantitative characteristics of the overall networks. The data were analyzed in aggregate form in section 4.2.3. In section 4.2.4, the data were compared by purpose. Additionally, networks formed with people unaffiliated with the physics department are also discussed in section 4.2.5.

4.2.1 "How are these networks formed and sustained?"

Networks with Peers

Although peer networks for physics doctoral students form through a variety of means, there are distinct trends in network formation. The first question asked of every interview participant was how they knew the students and faculty they selected on the survey.

Twenty-six of the twenty-eight participants interviewed mentioned that the students they selected on the survey were students from their entering cohort. Simply being in the same entering cohort was not the motivation for establishing these relationships; other reasons helped the participants connect with their cohort. Below are four quotes from participants that illustrate the ways in which the participants formed networks within their entering cohort:

> [Getting to know people] started early, with all the first years coming in, trying to find things around the department, trying to find an apartment. How do you deal with getting to school? Umm, I think it starts there and with the people you develop a better relationship with, you start talking with them more.- *Bailey Hudson*

> Most of them are from my incoming class. And the way we do it in our class, at least in our department, you tend to take your classes all together, so you tend to work on problem sets together. Long hours, most of us are friends.- *Jacques Booth*

> In the first year, you're practically all in the same classes. And we would- we would do the problem set mostly on our own and we'd collaborate on the parts we're mostly confused about. So that's kind of how that relationship was fostered.- *Albert Burgess*

> I would say most of the people are in my year, so I took classes with them. Most of my interactions with them were in the class, but there was also homework so we worked together. Also, I think proximity played a big

> role. The tiny little basement hallway used to be the first years' [office] and everyone was here. We didn't really see anyone else really, because we were in the basement. A lot of our friendships were forged in that small hallway.- *Glenn Blevins*

As indicated by the quotes, the student networks formed through utility. This was either from navigating a new environment or working on coursework together. The structure of the program also contributed to connecting to one's cohort; much of the coursework in physics doctoral programs is for entering students.

The need to work together on coursework is not as straightforward as placing the students in the same class and creating assignments. Lysander Barber suggested that assignments are difficult not only to teach advanced physics but also to ensure peer collaboration occurs. This difficulty likely leads to the long hours spent together that Jacques Booth stated were a contributing factor to social network formation.

Lack of of difficulty can mean students work independently. Cooper Shields' experience in one elective course suggests this: "It was pretty individualized, that course. I don't think I had much work. We had to write a little paper. I don't think I worked with anyone for any of those things... There were like group discussions. There wasn't like any interaction with other students in terms of- beyond saying hello." The course structure plays a role in whether students work together on coursework, as Cooper's comment suggests. While the difficulty of assignments can lead to working together, more specific structure or design of the course can contribute to forming other connections. Albert Burgess recalled a course where group problems were assigned: "We had to do group problems once a week. Those people I tended to collaborated with, because you had a problem due once a week... I thought it was good. I branched out and met some students I probably wouldn't have spent as much time with."

Another prominent theme is how the geographic layout contributed to peer network formation. The department is spread across several buildings; the greatest distance between two buildings is approximately a half-mile. After the first year, the physics doctoral students are placed into different offices. Their new offices are in proximity to their advisor, who is typically in proximity to others in the subfield.

Seventeen participants noted that their location plays a role in their peer networks, either in forming or sustaining their networks. Below are five quotes from participants on the effects of the physical space on their social networks:

> I was surprised with how easy it was to make friends when I first came here, because I had a really hard time doing that when I was an undergrad. I think the department has a really good policy of- they put all the first year grad students together so you get to know people well.- *Malcolm Rollins*

> The nice thing I felt, too, was even that the basement was dingy and miserable- I like that the department makes an effort to keep the first years together. I remember that we'd be working on a quantum set and either Cooper or Lysander [*students in his cohort*] would run by and ask "Hey, are you working on #3? How did you do this?" In general, foster communication among the first years. Even if they weren't in the same office, they were in the same area.- *Bailey Hudson*

> [*When asked about meeting more senior students*] Basically, from getting lunch together. You're already there with the lunch on the third floor, so I- we can't now. [*The space no longer exists.*] Back in that time, we had lunch in the open area. Yeah, just a very natural gathering.- *Natalie Wilson*

> [*When asked about sustaining friendships*] Part of the problem is we're spread in three different buildings. I never go to Building C, that's like a black hole to me.- *Max Thompson*

> I started coming [to this building during my second year], and I stopped meeting new people. I don't think I have close friends in the physics department that I really hang out with outside of school. I guess because I work in a different building, I don't really see them. - *Walter Jenkins*

Although necessity is indicated to be the impetus behind these peer networks, being in the same location also helps to organically create and cultivate these peer relationships. As Max and Walter indicated, these peer relationships are more challenging to maintain if students are physically separated.

Hypothesis #8 in section 2.10.1 predicted that students in their first year would have stronger ties to one another, but more senior students would have stronger ties to those in their research group or subfield. This is somewhat unsupported by these data; first year students do have strong ties to one another and students meet others through their research group, but the ties to the cohort are stronger than those to the research group.

Thirteen participants mentioned that they met some of the students they selected through their research group. Three of these participants are not primarily based at Jonas University and work on their research elsewhere. Relationships established through research did not appear to be strong. Participants did not emphasize the importance of their research connections in the same manner they emphasized their cohort connections. For example, Cooper Shields stated:

> The students mostly are all people I knew from my first year. Let's say the majority of people I choose are from my first year I had classes with, stuff like that. The other ones I met throughout the years, either teaching with them or similar research interests.

Hypothesis #7 predicted that departmental events would not help student establish new network connections. This hypothesis is mostly supported by these data. Seven participants mentioned that they knew some of the students they selected through departmental events, such as colloquia and social events organized by the department or through the physics graduate student organization; however, they emphasized the importance of their cohort connections. Eleven participants, including four who said they knew some of the students they selected through events, mentioned that the people they tend talk with at departmental events are people they already knew through other means; these events tend to be a time to talk about research and general life matters with fellow students they already know, both ones they see frequently and ones they see less frequently.

These events may not provide any opportunities to meet students one does not know, due the student participants. Ronan Willis noted that certain students attend and the lack of intergroup mingling: “In the colloquium, we always have this common set of people we sort of meet, the colloquium set of people. We don’t really go out and say hi to different people and stuff.” Two other participants observed that individual doctoral students either tend to attend the majority of departmental events or never attend.

Three participants noted that they are making a conscious effort to meet new people. Although departmental events appear to sustain already existing network ties, doctoral students are not opposed to forming new connections. Brenden Briggs remarked, “Most people are open to chatting. Most people are quiet in this department, but that’s the nature of people who are attracted to physics graduate programs. But most people understand that people aren’t being cold to you, they just can’t think of anything to say or aren’t thinking about it.”

Besides events organized by the department, some students have taken initiative in cultivating their relationships with one another. Six participants mentioned meeting up with other students for lunch. They either make specific plans or happen to run into others. Six participants said that they met and kept in touch with fellow students through social events, such as parties or movie nights, hosted by other students. These events were organized by a few individuals who were in different stages of the doctoral program. Although the students who organized these events were in different stages of the doctorate, the participants indicated that they organized or attended these events during their first or second year in the program.

Other ways in which the interview participants note they maintain their friendships within the department is through a variety of casual activities away from the university; these activities are informally organized. The activities include: athletic activities, such as rock climbing and Frisbee; outdoor activities, such as hiking or riding on bike paths; going to bars; and art and music events within the area.

Networks with Faculty and Staff

While two participants mentioned speaking with faculty prior to arrival at the university, the student-faculty network ties are formed on campus. Fifteen of the participants mentioned that they met the faculty they named on the survey through taking courses. Although the interview participants mentioned making small talk with faculty at departmental events, any other socializing with faculty is facilitated by the faculty member. For example, three participants mentioned that one faculty member tends to take students enrolled in his course out for beer at the end of the semester.

The coursework ties to faculty have some effect on advisor selection. Seven participants met their advisors because they had enrolled in that professor's course. Knowing one's advisor through coursework is not the only factor in advisor selection; the majority of interview participants indicate that multiple factors went into selecting one's advisor. The research subfield does factor in; eleven participants picked their advisors because of the subfield. Eleven participants noted going through a process of interviewing professors or being interviewed by professors before selecting their advisor. However, five participants felt as though they did not have a choice or much of a choice when selecting their advisors due to their circumstances within the program.

Another factor in the selection criteria is funding, with eleven participants mentioning funding. Five participants indicated that past experiences with advisors or research, from other institutes or at Jonas University, influenced their choices. Four participants indicated personal compatibility played a role in advisor selection. Three participants received advice on how to select an advisor. Below are four quotes that demonstrate the various factors and how they are considered when physics doctoral students chose their advisors:

> I was initially interested in working with Kelvin Warren, but he had no funding or very little funding. And then I knew another grad student who was in Pennington's group, so I went to talk to Brody. He does similar things to Kelvin Warren. I read some papers from the various groups, and I found, even though I wasn't interested in [the topic], per se, the model

> aspect that happened to be used to study [the topic]. But the tools, the techniques used to solve the model were interesting and I liked that. I asked if he'd take me, and he did.- *Tyrone Burns*

> I sort of realized the research I've been doing... was more similar to [other] work [I had done]. It was basically doing data analysis [but with a different type of data]. Also, it was partially finding the right advisor. You need a good combination of a research project that you want to work on and an advisor whose personality works with yours.- *Racquel Christensen*

> I looked at all the professors' websites and figured out which ones I wanted to talk to. Which ones were doing research that interested me. I talked to maybe half a dozen. They all said they weren't looking for people right now, except for one which was Spencer- Spencer Sutton. He had a project that was already funded. Well, the rest had projects but they weren't funded. Umm, and- it looked interesting, it looked a little bit different from what other people were doing.- *Kerr Steele*

> There were some theoretical groups that had openings at the time I was looking for a group. But I also admittedly wasn't a strong candidate. I had some trouble [in the PhD program]. Rufus needed someone immediately, and it was sort of a risk that I might not... continue in the program. It was kind of a good fit at the time. But I wasn't- I didn't have my choice of group, so to speak... It did work out. I do find my research and the work interesting... I didn't really come to the university, expecting to work with this group. There was a time I was working with another group. I used to work with Enrico Matthews, actually... He asked me to find another group. That's the polite way to say it.- *Terrence Winters*

Other students had also switched advisors during their time as physics doctoral students at Jonas University. Twelve participants stated that have switched advisors at least once; the maximum any student has switched advisors is twice, for a total of three different advisors. Three of these twelve participants said that their original advisor had told them to leave the group or to find a new advisor.

The other participants appear to have left voluntarily. One participant felt that her original advisor micromanaged. Natalie Wilson explained: “The pressure comes from management skills. Like, it was more like I don’t want people to check my work every 2 hours. I cannot work with that. I cannot take that. Literally, every 2 hours. That’s a little too much for me.” For nine participants, their own perception on the lack of progress in research was the reason they switched advisors. Two of the participants indicated that their advisors did not appear to believe there were any issues; the other seven participants simply stated there was a lack of progress and did not indicate whose perception it was. None of these participants indicated whether there were any attempts to rectify the lack of progress.

Switching advisors is a neutral and/or amicable process in terms of relations between students and faculty. Kerr Steele, who switched advisors twice, stated:

> In both cases, they were- um, maybe a little bit surprised, but- also supportive. They said I shouldn’t feel bad about leaving, which I did in both cases. [They said] I shouldn’t feel like I’m abandoning anybody, but it’s something that happens all the time. Which is nice to hear. Both cases, they were very supportive.

Although the advisors may be supportive when their students switch to a new advisor, only one participant still talks with his former advisor on a regular basis. Overall, students who have switched advisors are satisfied with their current advisors.

While there are specific requirements, committee members are selected in a variety of ways. Committee members are needed for an oral exam, which allows the physics doctoral students to advance in candidacy, and for the dissertation. Nine participants noted that they selected their committees members based up their familiarity with the faculty. Both research skills and personality compatibility were considered when making selections. Five participants stated that their advisors helped the selection process. Below are three examples of the different advice from advisors:

> When I had to form a committee for my oral exam, I asked Regis. You know, "Do you have any advice on who I should get?" And then he asked "Who do you know?" I listed off some people, and he went, "I don't want you to work with them." I don't know why he said that. [He then said] "Why don't you work with this person? This person seems good." Regis and I worked it out together, and I asked them and they said yes.- *Archie Calderon*

> Another aspect of [my advisor's] leadership I really kind of dig is his firm grasp of the politics of the department. So if I went to him and I said, "I want Professor so and so on my committee", he's perfectly honest in saying, "You shouldn't pick that guy, because one of my other students had him on a committee and he was sort of nit-picking at the thesis defense. He didn't add anything to the research." Things like that. He's brutally honest about the, I don't know, the social aspects and the interactions the professors have with one another. If I ask him if this professor can be on my committee, he'll be like "No, we don't get along." At the end of the day, Rufus helped me pick out my committee members.- *Terrence Winters*

> Part of it was you have to pick one person- well, there are rules. You have to pick one person who is in your field, one person who is outside, one person who is experimentalist. So I picked people, for the group who is supposed to be in my field, I picked people who sort of knew what I was doing. Part of it was I either personally knew them or Nathaniel [my advisor] knew them. We knew personality-wise, they wouldn't be- they wouldn't cause trouble. *Laughs.* [*When asked what is trouble*] I don't know, like asking tough questions, giving people a hard time.- *Douglas Cannon*

While the advice from the advisors does consider the potential research benefits, the advice is primarily given to avoid extraneous issues.

Seven of the participants discussed their relationships with their mentors. These relationships developed organically, by being around the person who would become their mentor. Jacques Booth described his relationship with his advisor as that of a mentor for this reason: "I think it's sort of hard to work with someone day in and day out, who has been in your position, and not have them become a mentor." One participant who named a committee member as a mentor described the relationship initially forming due to necessity. He perceived being abandoned by the advisor after a poor performance on a departmental benchmark. Tyrone Burn described the situation:

> [My advisor] sort of tried to- pawn me off on, uh, the other members of my committee. I wasn't sure if he didn't want- didn't have the time for me or didn't want to deal with it or he thought other perspectives would be better. But, I mean, you know. That was sort of his doing... [Regis] also mentored me. He would try his best to give me good advice, even if it was too general to be of use. He also tried.

For others, the professor presented himself or herself as a mentor in a more general manner. Greg Hardin was noted as a mentor by four students. The mentoring relationship is less definitive in its purpose and provides social support.

> He sort of actively presented himself as a mentor. You know, he just- he's very caring, and you know Very positive towards any effort you put into things. He wants to see you do your best, and- I think- he seems like he's very interested in being a mentor.- *Kerr Steele*

> [Describing who he would seek out for mentoring] I would ask Greg because he's like- he gives a very nurturing- imminence or aura.- *Gavin Braun*

Staff also play a nurturing role. Seventeen participants named one staff person, Aileen Brewer, who aids in their paperwork needs. All of the students have commented not only is Aileen helpful in completing the tasks but also is interested in their well-being. They chat about socially when they meet to handle paperwork or solve other administrative issues.

4.2.2 "What are the characteristics of the doctoral student networks for research, social, academic, professional, teaching, and/or support? Does this vary by network type?"

The survey asked about network ties for 9 different types of networks related to the physics doctoral student experiences. These purposes are: departmental information (e.g., office gossip); procedural reasons; academic coursework; research; career and professional advice; crisis support; inside department socializing; and outside department socializing. There was also one question asking the participants to identify who is in their research or lab group.

Because not all doctoral student members in the Jonas University physics department took the survey, some of the analysis is undirected. This means that for some data, I can consider node A and node B connected, but that I do not whether consider the relationship is reciprocated or in one direction (e.g., node A selected node B but not vice-versa). When possible, tie direction is considered. All betweenness centralities and densities are normalized on a scale of 0 to 1. One is when all nodes are connected. When none of the nodes are not connected, the density would be 0.

Unless otherwise noted in the particular section, the following details on sociograms and network statistics are applied to each network type. Thicker lines indicate more frequent contact. The length of the line representing the tie is not symbolic of any network attribute.

Node color is indicative of the role or prestige group for the members of the department. Black nodes in this section represent the survey participants, while grey nodes represent the non-participants. Staff are depicted as blue nodes and are listed in a category referred to as "Staff." Postdocs are depicted as purple nodes and are referred to as "Postdocs." Olive green nodes denote faculty from other departments and research scientists employed by the department; they are listed as "Other Scientist." Faculty were categorized by a prestige model described in section 3.4.2. Lower prestige faculty members are bronze, typical prestige are silver, and higher prestige are gold.

I did not indicate whether staff, other scientist, and postdoc participation was absent for each network purpose. This is because people in those roles may have limited opportunities to interact with the students. As an example of limited opportunities to interact, staff may be relegated to a specific lab and not meet the general doctoral student population.

"W. In-ties" and "W. Out-ties" stands for weighted in-ties and weighted out-ties, respectively. Weighted ties were calculated by averaging the frequency of contact values. Unless otherwise indicated, all t-tests were conducted assuming equal variance between the comparison groups and have 108 degrees of freedom (d.f.). For each network category, the mean for each network attribute, such as in-ties, was calculated individually for those who took the survey and those who did not. The mean network attributes were found for the combined group.

In addition to characterizing the networks, this question also seeks to answer hypothesis #9: degree centrality will vary accordingly to network type, and different students will be more central depending on the network's purpose.

Departmental Information Network Characteristics

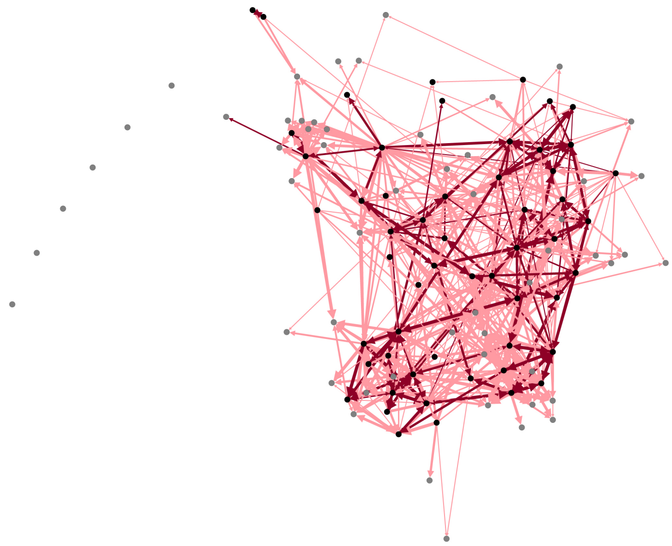

Figure 4·4: Sociogram depicting with whom students talk about departmental matters. Darker red lines indicate a reciprocated relationship. Table 4.2 describes the statistics of these connections.

The data for this network are from the following survey question: "With whom do you discuss what's going on in the department?" Two survey participants wrote in the comments section that they interpreted this question to mean both research and departmental gossip. Six-hundred twenty-nine (629) ties exist among peers for the departmental information network. Six doctoral students did not have any connections in this network; they are also six non-participants who did not take the survey. The undirected density is 0.086, meaning that 8.6% of the possible connections are made.

Reciprocity was examined for only those who participated in the survey. Three-hundred eighty-seven (387) of the ties are to survey participants. Fifty-two percent (52.2%) or 202 of the ties are reciprocal. Figure 4·4 displays the sociogram for this network The darker red lines represent reciprocal ties, while pink lines represents ties in one direction. There is one large group and one smaller group towards the left of the sociogram. The sociogram and density suggest that students socialize in a relatively large group that is not well-connected among the members in the group.

Table 4.2: Network attributes for the departmental information network

	Participants	Non-Participants	t(d.f)	Combined
Not in network	0	6	-	6
In-ties	7 ± 5	4 ± 4	3.36(102) **	5 ± 4
W. In-ties	23 ± 15	15 ± 13	2.93(108)***	19 ± 15
Max. In-ties	17	19	-	19
Mode In-ties	11	2	-	2
Out-ties	11± 8	-	-	-
W. Out-ties	60 ± 38	-	-	-
Max. Out-ties	30	-	-	-
Mode Out-ties	11	-	-	-
Deg. Centrality	18 ± 11	4 ± 4	9.24(66)***	11± 11
Btwn. Centrality	0.02 ± 0.02	0.002 ± 0.004	5.64(58)***	0.01 ± 0.02

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.2 provides the details of the following results for participants and non-participants for the departmental information network. For the t-tests, equal variance could only be assumed for weighted in-ties. Survey participants have larger mean values for in-ties, weighted in-ties, degree centrality, and betweenness centrality than non-participants. However, the maximum in-ties received by survey participants is 17 while the maximum in-ties received by non-survey participants is 19. The t-tests show statistically significant differences (p≤0.01) between participants and non-participants for the following: in-ties, weighted in-ties, degree centrality, and betweenness centrality.

Participants also provided information regarding with which faculty, non-physics faculty scientists, postdocs, and staff they discussed the department. Figure 4·5 displays the sociogram for the student- faculty/staff/postdoc department information network. There is one large group of connected notes. Two small groups are not connected to the main group. This suggests that there are particular groups of socialization. Seven survey participants did not name any faculty, research scientists, postdocs, or staff. Three (30%) lower prestige faculty members, 9 (35%) typical prestige faculty members, and 1 (10%) higher prestige faculty member were not named by any of the survey participants.

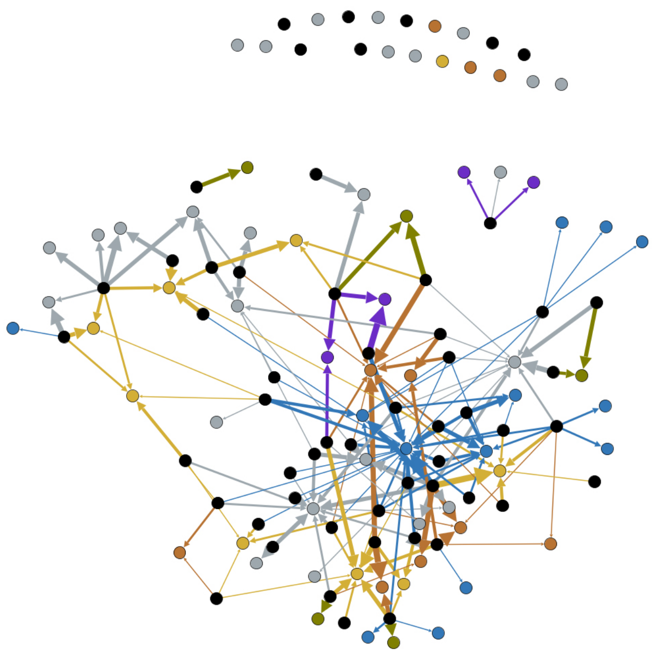

Figure 4·5: Sociogram depicting the connections between students and faculty, staff, or postdocs for departmental information. Table 4.3 contains the statistical information on this network

Table 4.3 displays these data for faculty and staff by prestige ranking. The student participants named 3 ± 2 ties Higher prestige faculty and staff were named most frequently with in-tie means of 4 ± 2 and 4 ± 6, respectively. Higher prestige faculty also have the highest weighted-in degree, 10 ± 8; this indicates that not only are the majority of ties faculty but also these ties are contacted the most.

ANOVAs were used to determine if the difference of the averages for the network attributes for the staff, postdocs, other scientist, lower prestige, typical prestige, and higher prestiges groups were statistically significant. The network attributes examined were in-ties, weighted-in ties, and betweenness centrality. These averages have no statistically significant differences.

Table 4.3: Network attributes for the student-faculty/staff network regarding departmental information

	Students	Staff	postdocs	Other Scientist	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	7	-	-	-	3	9	1	
In-ties	-	4 ± 6	2 ± 1	1 ± 2	3 ± 3	2 ± 3	4 ± 3	0.861(5, 61)
W. In-ties.	-	8 ± 15	5 ± 4	6 ± 2	7 ± 8	5 ± 7	10 ± 8	0.522(5, 61)
Max. In-ties	-	24	2	2	11	12	10	-
Mode In-ties	-	1	2	1	2	0	3	-
Out-ties	3 ± 2	-	-	-	-	-	-	-
W. Out-ties	8 ± 8	-	-	-	-	-	-	-
Max. Out-ties	10	-	-	-	-	-	-	-
Mode Out-ties	2	-	-	-	-	-	-	-
Btwn. Centrality	0.02 ± 0.02	0.02 ± 0.07	0.001 ± 0.001	0.0002 ± 0.0004	0.01 ± 0.03	0.009 ± 0.02	0.02 ± 0.02	0.538(5, 61)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Procedural Advice Network Characteristics

The data for the procedural-related network comes from the following survey question: "whom would you approach for procedural advice (e.g., required courses, paperwork to file for graduation) the university physics department?" One-hundred ninety-seven (197) ties exist among doctoral students for procedural advice network. Twenty-six doctoral students did not have any connections in this network; five of these twenty-six doctoral students are survey participants. The undirected density for the student procedural advice network is 0.024. This means that 2.4% of the possible connections are made.

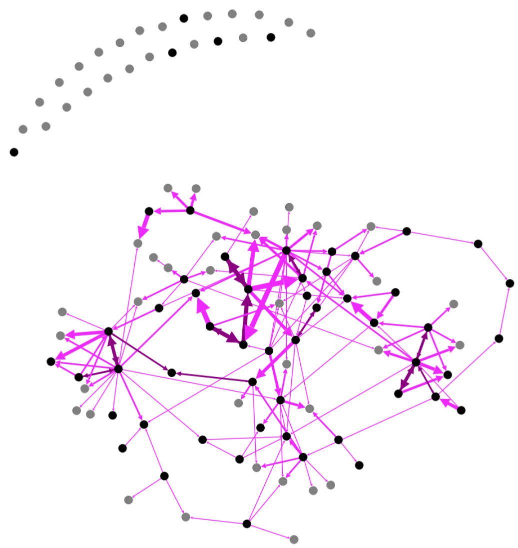

Figure 4·6: Sociogram depicting which students are consulted for procedural advice. Darker magenta lines indicate a reciprocated relationship. Table 4.4 describes the statistics of these connections.

Of the 154 ties to survey participants, sixteen percent (15.6%) or 24 ties that are reciprocal. Figure 4·6 depicts all of the ties in the procedural advice peer network. The darker magenta represents reciprocal ties, while lighter magenta represents ties in one direction. There are two somewhat medium densely connected groups towards the left, and two loosely connected groups. Both participants and non-participants, form chains that act as bridges that connect these groups.

Table 4.4 provides the details of the following results for participants and non-

Table 4.4: Network attributes for the procedural advice network

	Participants	Non-Participants	t(d.f)	Combined
Not in network	5	21	-	26
In-ties	2 ± 2	1 ± 1	2.13(98)*	1 ± 1
W. In-ties	4 ± 4	2 ± 3	2.57(96) *	3 ± 3
Max. In-ties	7	5	-	7
Mode In-ties	0	0	-	0
Out-ties	4 ± 3	-	-	-
W. Out-ties	6 ± 7	-	-	-
Max. Out-ties	16	-	-	-
Mode Out-ties	0	-	-	-
Deg. Centrality	5 ± 4	1 ± 1	6.30(64)***	3 ± 3
Btwn. Centrality	0.005 ± 0.008	0 ± 0	4.08(54)***	0.002 ± 0.006

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

participants. Equal variance could not be assumed for the following: in-ties, weighted in-ties, degree centrality, or betweenness centrality. Survey participants had a larger means than non-participants for all network attributes. Participants have a larger maximum of in-ties (7) larger than the maximum for non-participants (5). Both participants and non-participants have an in-tie mode of 0. The t-tests reveal that the mean differences between participants and non-participants is significant for $p \leq 0.05$ for in-ties and weighted in-ties. The mean differences are significant for $p \leq 0.001$ for betweenness and degree centralities.

The doctoral student named staff, postdocs, and faculty as sources for procedural advice. Four survey participants did not name any faculty. Figure 4·7 displays the sociogram for the student-faculty/postdoc procedural information network. The density for this sociogram is 0.021. The students primarily are connected to one staff member.

Seven (70%) lower prestige, seventeen (65%) typical prestige, and 2 (18%) higher prestige faculty members faculty member were not named by any of the survey participants. One "Other Scientist" was named by a participant. Due to there being only one person in this category, no averages were calculated for him or her. The

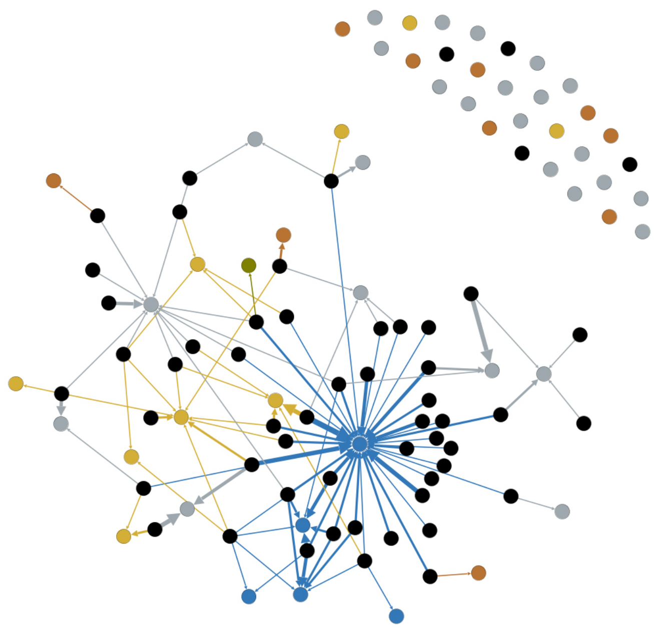

Figure 4·7: Sociogram depicting the connections between students and faculty, staff, or postdocs for procedural advice. Table 4.5 contains the statistical information on this network

student participants named 2 ± 1 ties. Staff were named most frequently for in-tie and weighted in-ties, 10 ± 15 and 19 ± 28 respectively. Staff also have the highest maximum number of in-ties, with 36 ties directed towards one staff person.

ANOVAs were used to determine if the variance among the means for these four groups. Equal variance could not be assumed for in-ties, weighted in-ties, and betweenness centrality. Welch's test was run for each network attribute that was found to not have equal variance. There is no statistically significant difference among the groups for each network attribute.

Table 4.5: Network attributes for the student-faculty/staff network regarding procedural advice

	Students	Staff	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	4	-	7	17	2	
In-ties	-	10 ± 15	0 ± 1	1 ± 3	3 ± 3	3.24(3, 12)
W. In-ties	-	19 ± 28	1 ± 1	2 ± 3	3 ± 4	3.19(3, 12)
Max. In-ties	-	36	1	12	9	
Mode In-ties	-	6	0	0	0	
Out-ties	2 ± 1	-	-	-	-	
W. Out-ties	3 ± 2	-	-	-	-	
Max. Out-ties	6	-	-	-	-	
Mode Out-ties	1	-	-	-	-	
Btwn. Centrality	0.01 ± 0.01	0.01 ± 0.01	0 ± 0	0.01 ± 0.02	0.01 ± 0.02	!

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
! = No variance for at least one group, so test could not be run

Academic Coursework Network Characteristics

The data for the academic coursework network are from the following survey question: "if you took classes during the 2012-2013 academic year, whom would you approach for course-related reasons in the university physics department?" Thirty-three participants took at least one course during the academic year. One doctoral student who took at least one course during the academic year did not have any connections in this network. Two-hundred twenty-six (226) ties exist in this network.

Data were analyzed for the participants who did take courses. Participants who did not take courses were also named by course-taking participants; data were analyzed for those participants as well. The directed density of the network is 0.11, meaning that 11% of the possible ties in this network were made.

Figure 4·8 depicts all of the ties in this network. Black nodes are survey participants who took at least one course during the 2012-2013 academic year. Brown nodes are survey participants who did not take a course during the 2012-2013 academic year. Grey nodes are non-participants. The darker blue represents reciprocal ties. Two somewhat connected groups appear. One is towards the top left side of

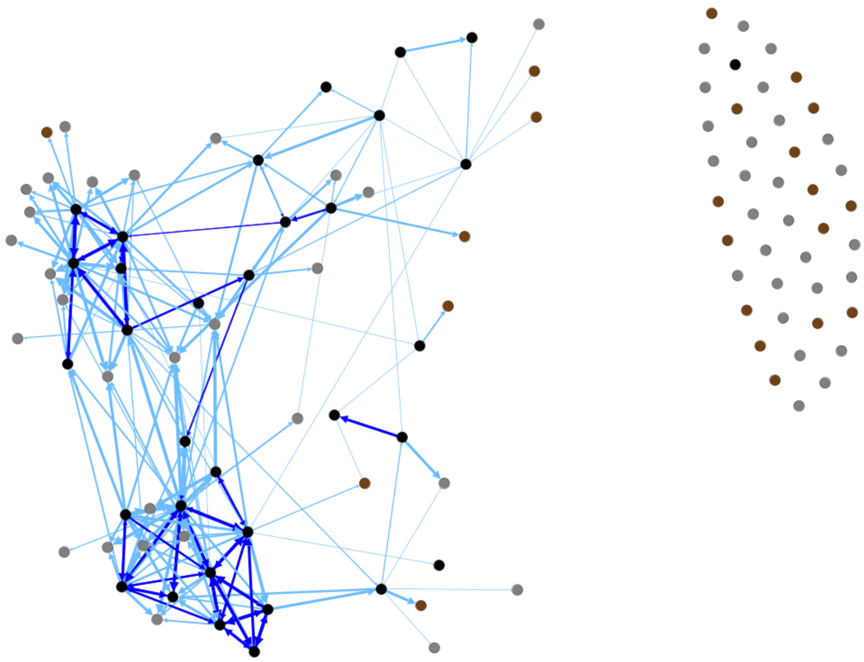

Figure 4·8: Sociogram depicting with whom students discuss their courses. Darker blue lines indicate a reciprocated relationship, and lighter blue are non-reciprocated ties. Table 4.6 describes the statistics of these connections.

the sociogram, the other is underneath the first. Reciprocity was examined for only those who participated in the survey and took at least one course during the academic year. Among these thirty-three participants, there were 126 total ties. Among those, sixty-four or 50.8% of the ties were reciprocal.

Table 4.6 summarizes the network attributes for those who took courses and those who did not; non-participants who were not selected by course-takers are not included in these data for out-ties and for betweenness centrality. Although twenty-two participants did not take a course, seven were still selected as a discussion partner for courses. As expected, the averages of non-course takers for all network attributes is lower than that of course-takers. The number of in-ties (4±2) is smaller than the number of out-ties (7±6) for course-taking participants.

Survey participants named faculty and staff in their coursework networks. The data only include faculty that the students named, because other factors, such as whether a faculty member taught a doctoral-level course, may affect whom students named. Twenty-one faculty members and one staff member were named by the course-takers. Figure 4·9 depicts the faculty and staff contacted by the survey participants for course-related matters. Fifty-eight edges are represented. The undirected density of this sociogram is 0.039. The sociogram clearly depicts a low density plot, indicating faculty are not active in this network.

Table 4.6: Network attributes for the coursework purposes.

	Took Courses	Did Not Take Courses
Not in network	1	15
In-ties	4 ± 2	0 ± 1
W. In-ties.	14 ± 12	1 ± 2
Max. In-ties	9	2
Mode In-ties	2	0
Out-ties	7 ± 6	-
W. Out-ties	39 ± 12	-
Max. Out-ties	21	-
Mode Out-ties	16	-
Deg. Centrality	11 ± 7	-
Btwn. Centrality	0.02 ± 0.02	0.0002 ± 0.0008

The mean for each network attribute was calculated for those who took at least one course during the 2012-2013 academic year and those who did not.

Table 4.7 displays these data. Fourteen participants had no faculty or staff connections whom they contacted for course-related purposes. Faculty and staff have more betweenness centrality than students; this is due to the number of course-takers who are not connected to faculty. When considering only students are connected to faculty, the mean betweenness centrality for students is 0.04 ± 0.05.

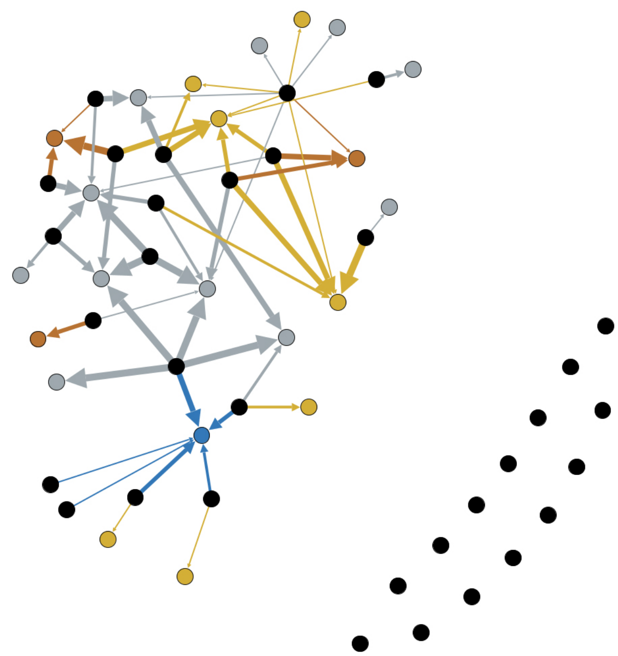

Figure 4·9: Sociogram depicting the connections between students and faculty, staff, or postdocs for course-related reasons. Only students who took at least one course are depicted in plot.

Table 4.7: Network attributes for the coursework purposes of faculty/staff and doctoral students.

	Course-takers	Faculty/Staff
In-ties	-	3 ± 2
W. In-ties.	-	7 ± 7
Max. In-ties	-	6
Mode In-ties	-	1
Out-ties	1 ± 2	-
W. Out-ties	4 ± 6	-
Max. Out-ties	5	-
Mode Out-ties	0	-
Btwn. Centrality	0.01 ± 0.04	0.03 ± 0.05

The mean for each network attribute was calculated for students who took courses and the faculty and staff they named.

Teaching Network Characteristics

The data for teaching network are from the following survey question: "if you were a teaching fellow or in another teaching position, whom would you approach for teaching-related reasons in the university physics department?" Twenty-eight participants taught in some capacity. Four doctoral students who taught during the academic year did not have any connections in this network. The undirected density of the network is 0.067, meaning that 6.7% of the possible peer connections were made. Data used to determine network attributes included both participants who taught and those who were selected by the participants who taught.

However, ties in this network may not always be for positive reasons. One survey participant wrote in the comments that his contact with one of the doctoral students was not by choice, stating the situation "...forced my hand on this one." The network tie is still in the data.

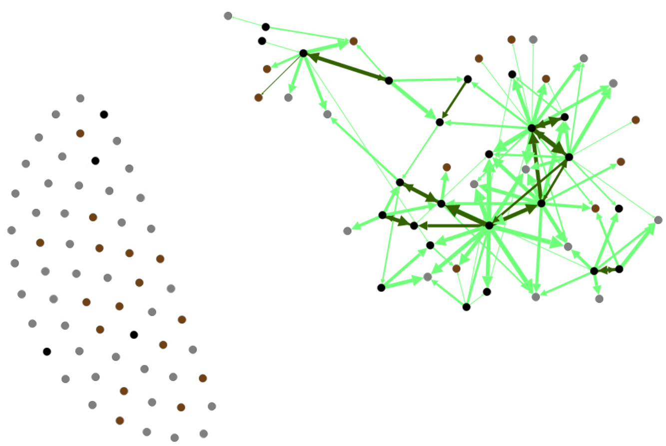

Figure 4·10: Sociogram depicting with whom students discuss teaching. Darker green lines indicate a reciprocated relationship, and neon green are non-reciprocated ties. Table 4.8 describes the statistics of these connections.

Figure 4·10 is the teaching network of fellow doctoral students. The darker green represents reciprocal ties, while the neon green represent unreciprocated ties. Black nodes are participants who taught during the 2012-2013 academic year. Brown nodes are participants who did not teach. Grey nodes are non-participants. The group in the top left of this plot is more densely connected than the group in the lower half of the figure; these participants may be more interested in teaching or teach courses where communication among peers is important. One-hundred four (104) ties are represented. The majority of doctoral students (59) did not participate in this network.

Table 4.8 summarizes the network attributes in the peer network for those who taught and those who did not. Although 27 participants did not teach, thirteen non-teaching participants were still selected as a discussion partner for teaching. As expected, the averages of those who are not teaching for all network attributes is lower than that of teaching fellows. Reciprocity was examined for only those who participated in the survey and taught during 2012-2013. Fifty-four ties belong to doctoral students who meet that criteria. Among those, twenty-four or 44.4% of the ties were reciprocal.

Table 4.8: Network attributes for teaching purposes

	Taught	Did Not Teach
Not in network	4	14
In-ties	2 ± 2	1 ± 1
W. In-ties.	19 ± 21	2 ± 3
Max. In-ties	5	3
Mode In-ties	0	0
Out-ties	4 ± 4	-
W. Out-ties	13 ± 18	-
Max. Out-ties	18	-
Mode Out-ties	0	-
Deg. Centrality	11 ± 7	-
Btwn. Centrality	0.01 ± 0.02	0.0007 ± 0.003

The mean for each network attribute was calculated individually for those who taught during the 2012-2013 academic year and those who did not.

Nineteen faculty and staff were named by survey participants for the teaching network. The data only include faculty that the students named, because other factors, such as whether a faculty member is involved with a course that has teaching fellows, may affect whom students named. Figure 4·11 depicts the faculty and staff

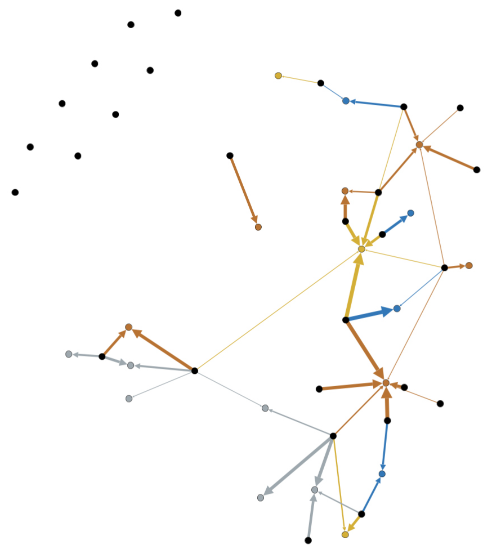

Figure 4·11: Sociogram depicting the connections between students and faculty, staff, or postdocs for teaching-related reasons. Only students who taught are depicted in plot.

contacted by the survey participants for course-related matters. Nine participants had no faculty or staff connections with whom they discussed teaching. Fifty-one edges are represented. The students do not share many common faculty nodes; this may be because their faculty contact is the professor of the course.

Table 4.9 displays these data for the named faculty, staff, and the students who taught. Faculty and staff have more betweenness centrality than students; this is due to the number of teaching fellows who are not connected to faculty. Teaching fellow participants who are not connected have zero betweenness centrality, decreasing the betweenness centrality for students. When considering only students are connected to faculty, the mean betweenness centrality for students is 0.04 ± 0.05.

Research Group Network Characteristics

Participants were asked to choose which other doctoral students are in their research group or lab. Figure 4·12 displays the different research groups in the Jonas University physics department. One-hundred eighty-one (181) ties are displayed in this sociogram. Survey participants received seventy-nine (79) in-ties. Forty-four (44) or

Table 4.9: Network attributes of faculty/staff and doctoral students for teaching purposes

	Teaching Fellows/Assistants	Faculty/Staff
In-ties	-	2 ± 2
W. In-ties. Centrality	-	7 ± 6
Max. In-ties	-	7
Mode In-ties	-	2
Out-ties	2 ± 2	-
W. Out-ties Centrality	5 ± 5	-
Max. Out-ties	5	-
Mode Out-ties	2	-
Btwn. Centrality	0.03 ± 0.05	0.05 ± 0.08

The mean for each network attribute was calculated individually for those who taught during the 2012-2013 academic year and the faculty and staff they named.

55.6% of the connections are reciprocal. Seven participants do not have any research group connections. One participant noted in the comments that he worked in different groups and listed members of both groups. This did not affect the data in terms of producing an unusual sociogram, such as an outlier group. These data for that participant are included.

There are two large (10 or more members) and ten small (9 or fewer members) research groups. Table 4.10 provides the network attributes for participants and non-participants. Betweenness centrality was not calculated for this network; because these are research groups, every node cannot be expected to be connected to one another.

A non-participant had the maximum number of in-ties, 8. The average number of in-ties for non-participants is greater (2 ± 2) than for participants (1 ± 2). T-tests were performed on in-ties and the undirected degree centrality to compare participants and non-participants. Neither network attribute has equal variance. Only degree centrality had statistical significance; this is expected, because participants have ties that are both directed and undirected to them.

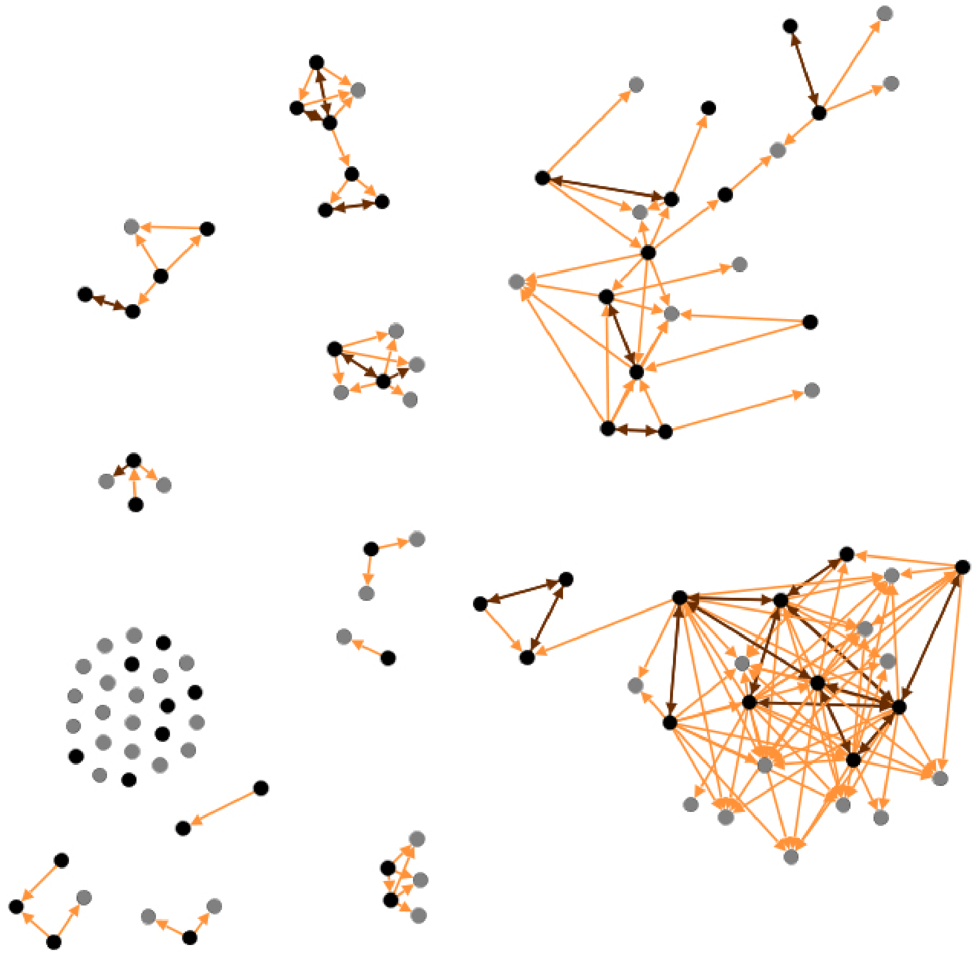

Figure 4·12: Sociogram depicting how students defined their research groups. Darker orange lines indicate reciprocal ties, while light orange indicates uni-directional ties. Several groups exists but are not connected; this was expected, because participants were asked about doctoral student members in their research group or lab.

Research Network Characteristics

The data for research network are from the following survey question: "whom do you approach for research-related reasons in the university physics department?" Two-hundred thirty-eight (238) ties exist among doctoral students for the research discussion network. Sixteen doctoral students did not have any connections in this network; three of these 16 are survey participants. As indicated by the comments,

Table 4.10: Network attributes for research groups

	Participants	Non-Participants	t(d.f)	Combined
Not in network	7	17	-	24
In-ties	1 ± 2	2 ± 2	1.17(96)	2 ± 2
Max. In-ties	5	8	-	8
Mode In-ties	1	0	-	1
Out-ties	3 ± 4	-	-	-
Deg. Centrality	5 ± 5	2 ± 2	3.90(74)***	3 ± 4

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

research reasons vary and include collaborations, work-related discussion, and equipment/computer help. The undirected density is 0.036, meaning 3.6% of the possible connections among students were made.

Figure 4·13: Sociogram depicting with whom students talk about research. Darker brown lines indicate a reciprocated relationship. Table 4.11 describes the statistics of these connections.

Of the 130 ties are connected to survey participants, thirty-three percent (33.1%) or 46 ties are reciprocated. Figure 4·13 depicts all of the ties in the research peer network. The darker brown represents reciprocal ties, while lighter brown represents ties in one direction. There are three somewhat large and densely connected groups towards the left, and two small groups on the right; this suggests separation by research subfield. Several nodes, both participants and non-participants, act as bridges to connect the groups.

Table 4.11: Network attributes for the research network

	Participants	Non-Participants	t(d.f.)	Combined
Not in network	3	13	-	16
In-ties	3 ± 2	2 ± 2	1.98(108)*	2 ± 2
W. In-ties	7 ± 5	6 ± 6	0.812(108)	6 ± 6
Max. In-ties	9	8	-	9
Mode In-ties	2	1	-	2
Out-ties	4± 4	-	-	-
W. Out-ties	12 ± 12	-	-	-
Max. Out-ties	25	-	-	-
Mode Out-ties	3	-	-	-
Deg. Centrality	7 ± 5	2 ± 2	7.23(67)***	4± 4
Btwn. Centrality	0.03 ± 0.05	0.002 ± 0.008	3.578(57)***	0.01 ± 0.04

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.11 provides the details of the following results for participants and non-participants. Equal variance could not be assumed for degree or betweenness centrality. Survey participants had larger means than non-participants for the following network attributes: number of in-ties, weighted in-ties degree centrality, and betweenness centrality. Degree centrality and betweenness centrality have statistically significant differences between participants and non-participants ($p \leq 0.001$). The number of in-ties has a statistically significant difference between participants and non-participants ($p \leq 0.05$).

Fifty-three participants named at least one advisor; one participant named two advisors, and two participant named none. Six participants have an advisor with lower prestige, twenty-four with a typical prestige advisor, twenty-one have with higher prestige, and three with an advisor outside of the department. Forty participants had no committee members, while fifteen have committees. For those who did have a committee, they named faculty members of different rankings. Their advisors were included as part of the committee. Higher prestige faculty were named 19 times, typical prestige faculty were named 34 times, lower prestige faculty were named 18 times, and research scientists were named 11 times. Committees consist of 4 ± 1 members, with the majority (10) committees consisting of 4 members.

The doctoral student discussed research with postdocs, research scientists, and faculty. Fifty-five students, six postdocs, fourteen faculty members from other departments (in Jonas University or elsewhere), ten lower prestige faculty, twenty-six typical prestige faculty, and nine higher prestige faculty are represented in these data. Three survey participants did not name any faculty. Figure 4·14 displays the sociogram for the student- faculty/postdoc research information network. There are two large groups, one medium, and five small groups. This suggests that students contact the faculty only within their subfield and/or research type.

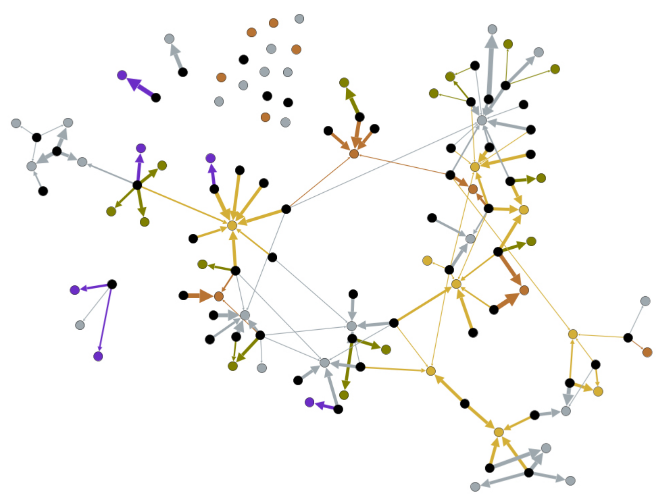

Figure 4·14: Sociogram depicting the connections between students and faculty, staff, or postdocs for research-related reasons. Table 4.12 contains the statistical information on this network

Five (50%) lower prestige faculty members and seven (27%) typical prestige faculty members faculty member were not named by any of the survey participants. All higher prestige faculty were named at least once by the survey participants. The student participants named 2 ± 1 ties; this mean consists of both student participants who named faculty, staff, and postdocs, and those who did not. Higher prestige faculty were named most frequently, with an in-tie mean of 4 ± 2. Higher (11 ± 8) and lower (11 ± 3) prestige faculty have the highest average of weighted-in ties.

The Levene statistic indicates that the groups do not have equal variance. Welch's test revealed that none of the network attributes have statistically significant differences among the various faculty and staff groups.

Table 4.12: Network attributes for the student-faculty/staff network regarding research-related reasons

	Students	postdocs	Other Scientist	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	3	-	-	5	7	0	-
In-ties	-	1 ± 0	1 ± 0	1 ± 2	2 ± 3	4 ± 2	!
W. In-ties.	-	4 ± 1	3 ± 1	11 ± 3	6 ± 7	11 ± 8	2.78(4, 22)
Max. In-ties	-	1	2	5	11	8	-
Mode In-ties	-	1	1	0	1	4	-
Out-ties	2 ± 1	-	-	-	-	-	-
W. Out-ties	7 ± 4	-	-	-	-	-	-
Max. Out-ties	19	-	-	-	-	-	-
Mode Out-ties	4	-	-	-	-	-	-
Btwn. Centrality	0.02 ± 0.04	0 ± 0	0.0002 ± 0.0005	0.03 ± 0.03	0.03 ± 0.05	0.07 ± 0.07	!

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
! = No variance for at least one group, so test could not be run

Career and Professional Advice Network Characteristics

The data for the career and professional advice network are from the survey question: "who are important sources of professional advice or career-related advice in the university physics department?" One-hundred ninety-seven (197) ties exist among doctoral students for the career and profession advice network. Twenty-six doctoral students did not have any connections in this network; six of these 26 are survey participants. The undirected density is 0.030, meaning 3% of the connections among peers were made.

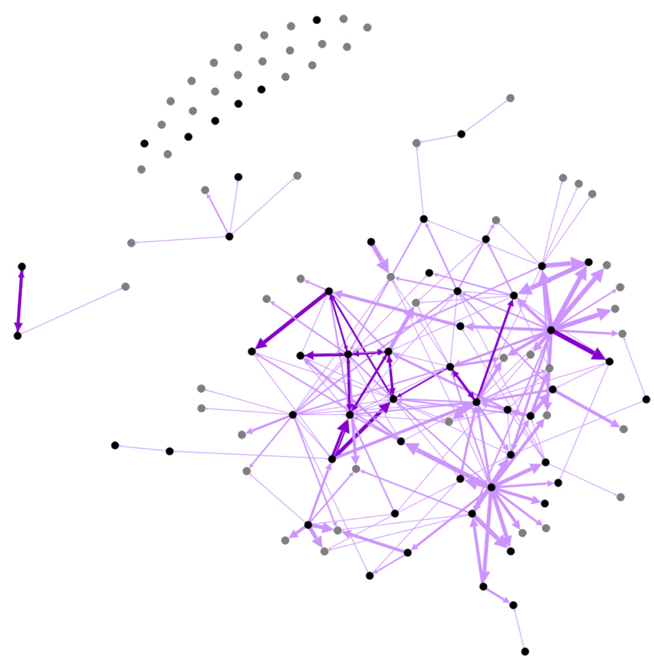

Figure 4·15: Sociogram depicting which students are consulted for career or professional advice. Darker purple lines indicate a reciprocated relationship. Table 4.13 describes the statistics of these connections.

Of the 144 ties are connected to survey participants, twenty-one percent (20.8%) or thirty ties that are reciprocal. Figure 4·15 depicts all of the ties in the research peer network. The darker purple represents reciprocal ties, while lighter purple represents ties in one direction. There is one somewhat large and densely connected group towards the right, and two groups that are not connected to the main group. Several nodes, both participants and non-participants, act as bridges to connect the nodes on the periphery of the main group.

Table 4.13: Network attributes for the career network

	Participants	Non-Participants	t(d.f)	Combined
Not in network	6	20	-	26
In-ties	2 ± 3	1 ± 1	2.65(72)	2 ± 3
W. In-ties.	6 ± 7	3 ± 3	3.00(81)**	4 ± 5
Max. In-ties	13	5	-	13
Mode In-ties	0	1	-	1
Out-ties	4± 4	-	-	-
W. Out-ties	8 ± 13	-	-	-
Max. Out-ties	18	-	-	-
Mode Out-ties	0	-	-	-
Deg. Centrality	6 ± 6	1 ± 1	6.23(60)***	4± 5
Btwn. Centrality	0.02 ± 0.02	0.001 ± 0.004	4.61(57)***	0.01 ± 0.02

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.13 provides the details of the following results for participants and non-participants. Equal variance could not be assumed for in-ties, weighted in-ties, degree centrality, and betweenness centrality. Survey participants have larger means than non-participants for all network attributes. Participants have a larger maximum of in-ties (13) than the maximum for non-participants (5). However, non-participants have an in-tie mode of 1, while participants have an in-tie mode of 0. T-tests show that the mean difference between groups for weighted-in ties is statistically significant for $p \leq 0.01$. Betweenness and degree centralities have statistically significant differences between groups for $p \leq 0.001$.

The doctoral student named staff, postdocs, and faculty as sources for career and professional advice. Seven survey participants did not name any faculty. Figure 4·16 displays the sociogram for the student- faculty/postdoc career and professional advice network. There is one main group and two smaller groups branching off the main group in the lower right.

Three (30%) lower prestige, nine (35%) typical prestige, and one (11%) higher

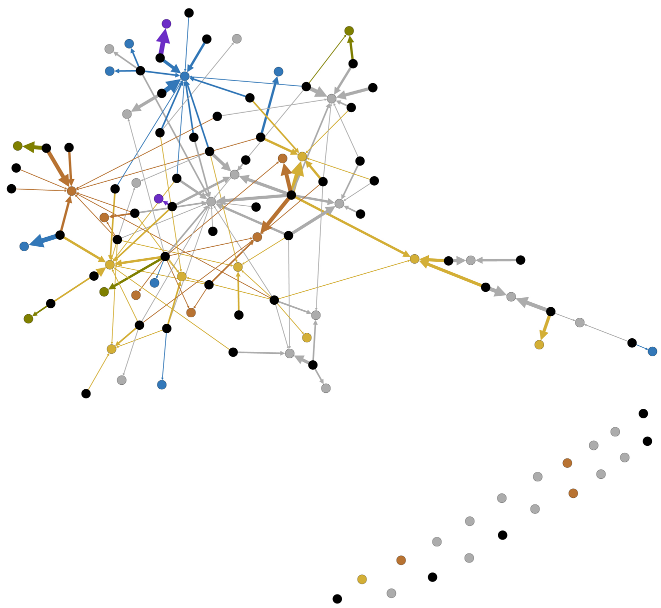

Figure 4·16: Sociogram depicting the connections between students and faculty, staff, or postdocs for career or professional-related reasons. Table 4.14 contains the statistical information on this network

prestige faculty members faculty member were not named by any of the survey participants. The student participants have 2 ± 1 faculty, postdoc, or staff in-ties. Higher prestige faculty were named most frequently, with 4 ± 3 in-ties. Higher prestige faculty have the highest average for weighted in-ties. ANOVAs were used to determine if the variance among the means for these five non-student groups is statistically significant; postdocs were not included because of the low count. None of the ANOVAs are statistically significant.

Table 4.14: Network attributes regarding the faculty, research scientists, postdocs, and staff that the student contact for career/professional advice.

	Students	Staff	postdocs	Other Scientist	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	7	-	-	-	3	9	1	-
In-ties	-	2 ± 4	1 ± 0	1 ± 1	2 ± 3	2 ± 3	4 ± 3	0.885(4, 52)
W. In-ties.	-	5 ± 9	4 ± 3	4 ± 1	4 ± 6	4 ± 7	8 ± 7	0.581(4, 52)
Max. In-ties	-	12	1	2	10	14	11	-
Mode In-ties	-	1	1	1	0	0	1	-
Out-ties	2 ± 1	-	-	-	-	-	-	-
W. Out-ties	7 ± 4	-	-	-	-	-	-	-
Max. Out-ties	6	-	-	-	-	-	-	-
Mode Out-ties	1	-	-	-	-	-	-	-
Btwn. Centrality	0.03 ± 0.04	0.01 ± 0.04	0 ± 0	0.0001 ± 0.0001	0.01 ± 0.03	0.01 ± 0.04	0.04 ± 0.05	0.951(4, 52)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Crisis Support Network Characteristics

The data for the crisis support network are from the following survey question: "whom do you know you can count on, who are dependable in times of crisis in the university physics department?" Two-hundred forty-nine (249) ties exist among doctoral students for crisis support advice. Twenty-one doctoral students did not have any connections in this network; they are all non-participants. The undirected density is 0.035, meaning that 3.5% of the nodes are connected.

Several participants provided comments to this question. Three participants stated that they were unclear what a crisis entailed. One participant noted that many of the crises experienced were short-lived. Two participants were unsure if they had a crisis. One participant has not had a crisis but selected the students who would be reliable during a crisis.

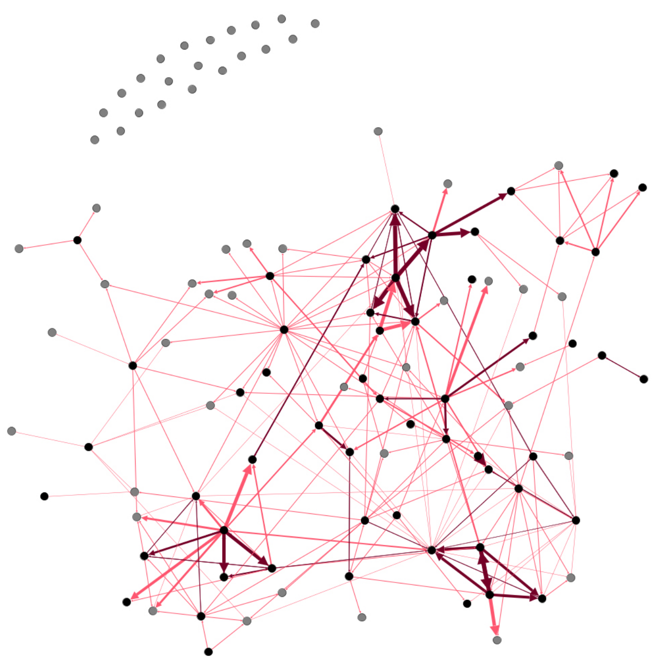

Figure 4·17: Sociogram depicting which students are consulted or potentially consulted in times of crisis. Darker coral lines indicate a reciprocated relationship. Table 4.15 describes the statistics of these connections.

Of the 176 ties are connected to survey participants, forty-seven percent (46.6%)

or 82 ties are reciprocal. Figure 4·17 depicts all of the ties in the crisis support peer network. The darker coral represents reciprocal ties, while lighter coral represents unreciprocated ties. The question regarding frequency of contact asked specifically about the amount of contact during a time of crisis, so not all ties were given a weight by participants. A total of fifty ties had no weight. I considered these contacts hypothetical, meaning that they were potentially reliable in times of crisis. I assigned a weight of 0.5 to those ties. There are four somewhat large groups in the center of the network. Two smaller groups branch off of the larger main group, with other nodes (participant and non-participant) bridging the various group. There are distinct groups of nodes, but they are not densely connected.

Table 4.15: Network attributes for the crisis network

	Participants	Non-Participants	t(d.f)	Combined
Not in network	9	21	-	21
In-ties	3 ± 3	1 ± 1	4.31(83)***	2 ± 2
W. In-ties	5 ± 5	2 ± 2	4.93(69)***	3 ± 4
Max. In-ties	11	5	-	11
Mode In-ties	0	0	-	0
Out-ties	5 ± 4	-	-	-
W. Out-ties	6 ± 7	-	-	-
Max. Out-ties	21	-	-	-
Mode Out-ties	0	-	-	-
Deg. Centrality	7 ± 5	1 ± 1	4.59(60)***	5 ± 5
Btwn. Centrality	0.02 ± 0.03	0.002 ± 0.008	8.28(62)***	0.01 ± 0.03

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.15 provides the details of the following results for participants and non-participants. All selected participants, regardless of whether they were hypothetical contacts, were included in the statistics. Survey participants have larger means than non-participants for all network attributes. Participants also have a larger maximum of in-ties (11) larger than the maximum for non-participants (5). However, both non-participants and participants have an in-tie mode of 0. Equal variance could not be assumed for the network attributes. T-tests show that the mean difference between participants and non-participants for in-ties, weighted-in ties, betweenness centrality, and degree centrality is statistically significant for $p \leq 0.001$.

The doctoral student named staff, research scientists, postdocs, and faculty as sources for crisis support. Ten survey participants did not name any faculty. One participant named several faculty and staff but did not indicate time spent on crises, so I categorized those ties as hypothetical. Figure 4·18 displays the sociogram for the student- faculty/postdoc crisis support network. There are no clear groups, but many student rely on the same staff member for crisis support.

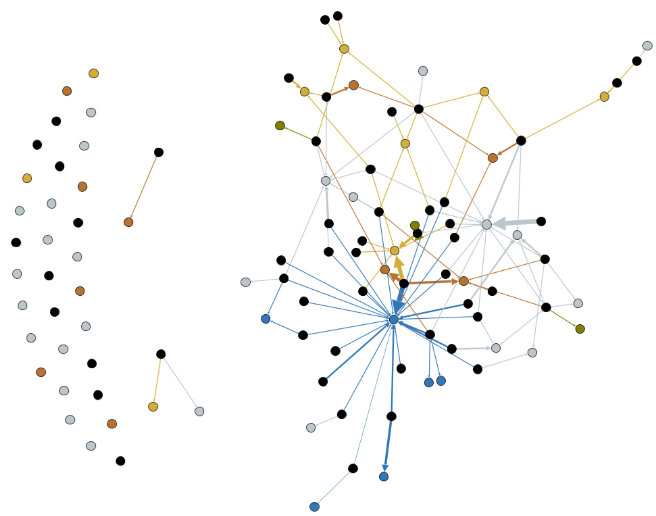

Figure 4·18: Sociogram depicting the connections between students and faculty, research scientists, staff, or postdocs for crisis support. Table 4.16 contains the statistical information on this network

Five staff members, three Other Scientists, and one postdoc were named. Due to low numbers, the data for those categorized as Other Scientists and the postdoc were not analyzed statistically. Five (50%) lower prestige, fourteen (54%) typical prestige, and two (22%) higher prestige faculty members were not named by any of the survey participants. The student participants named 2 ± 2 ties. Staff had the highest average in-ties (6 ± 10) and weighted-in ties (8 ± 14).

Because equal variance could not be assumed, Welch's test was used to determine if the differences among the means for these four non-student groups were statistically significant; postdocs and Other Scientists were not included because of the low count. None of the results from Welch's test are statistically significant.

Inside Department Socializing Network Characteristics

The data for the inside department socializing network are from the following survey question: "who are very good friends of yours, people whom you see socially at events organized by the department or a professor? E.g., attend departmental colloquia/seminars and other department events, have lunch during the work day, professors lab party, etc." One participant commented that he answered the question by including only people with whom he actually socializes, not people he literally sees at events. Six-hundred seventeen (617) ties exist among doctoral students for work-related socializing. Nine doctoral students did not have any connections in this network; two are survey participants. The undirected density is 0.083.

Of the 386 ties are connected to survey participants, fifty-nine percent (59.1%) or 228 ties are reciprocated. Figure 4·19 depicts all of the ties in the in-department socializing peer network. The darker pink represents reciprocal ties, while lighter pink represents ties in one direction. There are two large denser groups, although the nodes in each group also have many ties to the other group.

Table 4.17 provides the details of the following results for participants and non-participants. Survey participants had larger means than non-participants for all network attributes. Participants also have a larger maximum of in-ties (20) larger than the maximum for non-participants (15), as well as a higher in-tie mode (7 for participants, 1 for non-participants). Equal variance between participants and non-participants cannot be assumed for weighted in-ties, degree centrality, and betweenness centrality. T-tests show that the mean differences between participants and non-participants for in-ties and weighted-in ties are statistically significant ($p \leq 0.01$). Betweenness centrality, and degree centrality are significant ($p \leq 0.001$).

The survey question pertaining to faculty and staff in the survey participants' departmental socializing network is as follows: "which faculty or staff members of the

Table 4.16: Network attributes of the faculty, research scientists, postdocs, and staff that the students contact for crisis support

	Students	Staff	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	10	-	5	14	2	-
In-ties	-	6 ± 10	1 ± 2	1 ± 3	3 ± 2	2.02(4, 43)
W-In ties	-	8 ± 14	2 ± 3	2 ± 4	4 ± 4	1.63(4, 43)
Max. In-ties	-	24	5	12	7	-
Mode In-ties	-	1	0	0	3	-
Out-ties	2 ± 2	-	-	-	-	-
W-Out ties	3 ± 3	-	-	-	-	-
Max. Out-ties	8	-	-	-	-	-
Mode Out-ties	2	-	-	-	-	-
Btwn. Centrality	0.01 ± 0.01	0.04 ± 0.01	0.004 ± 0.007	0.01 ± 0.03	0.02 ± 0.01	1.58(4, 43)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

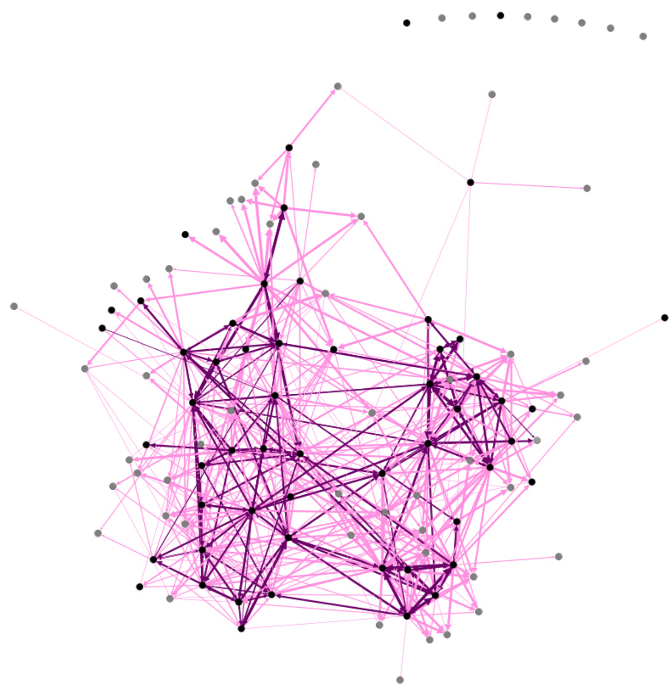

Figure 4·19: Sociogram depicting the social network of in-department socializing. Darker pink lines indicate a reciprocated relationship. Table 4.17 describes the statistics of these connections.

Table 4.17: Network attributes for the in-department socializing

	Participants	Non-Participants	t(d.f)	Combined
Not in network	2	7	-	9
In-ties	7 ± 5	4 ± 4	3.32(108)**	6 ± 4
W. In-ties.	23 ± 16	13 ± 12	3.23(103)**	18 ± 15
Max. In-ties	20	15	-	20
Mode In-ties	7	1	-	1
Out-ties	11 ± 9	-	-	-
W. Out-ties	35 ± 32	-	-	-
Max. Out-ties	35	-	-	-
Mode Out-ties	5	-	-	-
Deg. Centrality	18 ± 13	4 ± 5	7.78(63)***	11 ± 13
Btwn. Centrality	0.02 ± 0.03	0.002 ± 0.005	5.39(59)***	0.01 ± 0.02

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Jonas physics department do you see socially at events organized by the department or a professor? E.g. Attend departmental colloquia/seminars and other department events, have lunch during the work day, professor's lab party, etc.?" Seven staff members, five Other Scientists, and one postdoc were named. Due to the low numbers, the data for the postdoc were not analyzed statistically. Figure 4·20 displays the sociogram for the student- faculty/postdoc research information network. There are no clear groups, except for one student-faculty dyad that is not connected the larger network

Five (50%) lower prestige, 9 (35%) typical prestige, and 1 (11%) higher prestige faculty members were not named by any of the survey participants. Twenty survey participants did not name any faculty, staff, or postdocs. One student who did not name anyone, however, noted in the comments that he does see most faculty during in department events. This participant was counted as having no faculty or staff connections because of the wording of the question. The student participants named 3 ± 3 ties. Higher prestige faculty members had the highest average in-ties (7 ± 3) and weighted-in ties (20 ± 6). Lower prestige faculty had the highest maximum number of in-ties at 15.

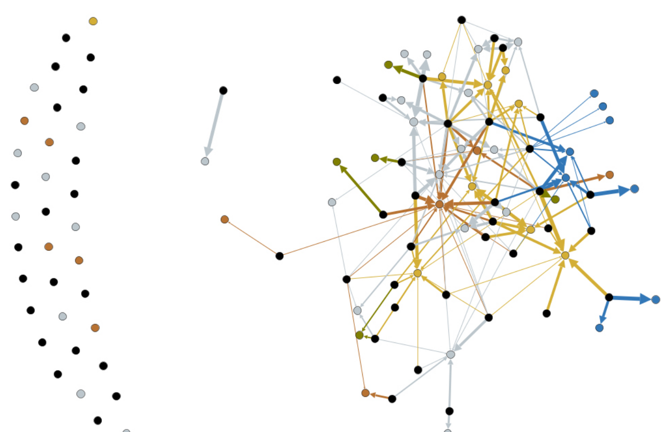

Figure 4·20: Sociogram depicting the connections between students and faculty, research scientists, staff, or postdocs when socializing within the department. Table 4.18 contains the statistical information on this network

ANOVAs were used to determine if the differences among the means for these five non-student groups were statistically significant for in-ties and degree centrality. Levene's test shows that betweenness centrality does not have equal variance among the groups. Welch's test indicates that betweenness centrality has statistical significance for $p \leq 0.05$. The post-hoc Games-Howell test does not show any statistically significant differences between the various pairings.

Table 4.18: Network attributes regarding the faculty, research scientists, postdocs, and staff with whom students socialize within the department.

	Students	Staff	Other Scientist	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	20	-	-	5	9	1	-
In-ties	-	2 ± 3	1 ± 0	2 ± 5	3 ± 3	7 ± 3	1.69(4, 52)
W. In-ties.	-	7 ± 8	4 ± 1	6 ± 12	7 ± 7	20 ± 6	2.21(4, 52)
Max. In-ties	-	7	1	15	12	11	-
Mode In-ties	-	1	1	0	0	5	-
Out-ties	3 ± 3	-	-	-	-	-	-
W. Out-ties	8 ± 11	-	-	-	-	-	-
Max. Out-ties	13	-	-	-	-	-	-
Mode Out-ties	0	-	-	-	-	-	-
Btwn. Centrality	0.01 ± 0.02	$0\ .01 \pm 0.01$	0 ± 0	0.01 ± 0.03	0.01 ± 0.01	0.03 ± 0.02	3.45(4, 18)*

Outside Department Socializing Network Characteristics

The data for the outside department socializing network are from the following survey question: "who are very good friends of yours within the physics department, people whom you make plans to see socially or outside of a professional setting? E.g., go to the movies, play sports, see on the weekends for recreational purposes, etc." Three-hundred seventy-one (371) ties exist among doctoral students in outside department socializing. Sixteen doctoral students did not have any connections in this network; four of these students without ties are survey participants. The undirected density is 0.051, meaning that 5.1% of the students are connected to one another.

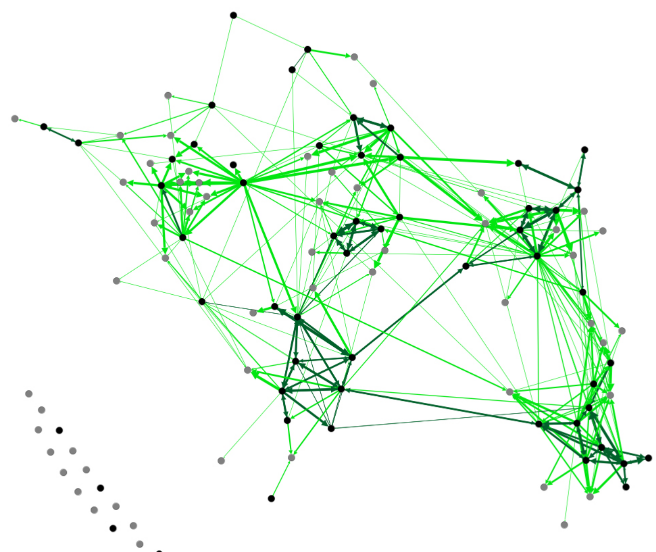

Figure 4·21: Sociogram depicting the social network of outside of the department socializing. Darker olive green lines indicate a reciprocated relationship. Table 4.19 describes the statistics of these connections.

Of the 212 ties are connected to survey participants, fifty-nine percent (58.5%) or 124 ties are reciprocal. Figure 4·21 depicts all of the ties in the outside of the department socializing peer network. The darker olive green represents reciprocal ties, while lighter grass green represents ties in one direction. There are three large denser groups with several nodes bridging the larger groups. Within these dense groups, smaller subsets of nodes appear to have closer relationships as indicated by the reciprocity.

Table 4.19: Network attributes for the outside of the department socializing

	Participants	Non-Participants	t(d.f.	Combined
Not in network	4	12	-	16
In-ties	4 ± 3	3 ± 3	1.82(105)	3 ± 3
W. In-ties.	12 ± 10	8 ± 8	2.05(106)*	10 ± 9
Max. In-ties	10	11	-	11
Mode In-ties	0	3	-	3
Out-ties	7 ± 6	-	-	-
W. Out-ties	20 ± 19	-	-	-
Max. Out-ties	33	-	-	-
Mode Out-ties	0	-	-	-
Deg. Centrality	11 ± 7	3 ± 3	7.60(67)***	7 ± 7
Btwn. Centrality	0.02 ± 0.03	0.004 ± 0.009	3.87(64)***	0.01 ± 0.03

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.19 provides the details of the following results for participants and non-participants. Survey participants have larger means than non-participants for all network attributes. However, non-participants have a larger maximum of in-ties (11) larger than the maximum for non-participants (10), as well as in-tie mode (0 for participants, 3 for non-participants). None of the network attributes can be assumed to have equal variance between participants and non-participants. A t-test shows that the mean differences between participants and non-participants for weighted-in ties is statistically significant for $p \leq 0.05$. Betweenness centrality and degree centrality have mean differences between participants and non-participants significant for $p \leq 0.001$.

The survey question pertaining to faculty and staff in the survey participants' outside the department socializing network is as follows: "Which faculty or staff members of the Jonas University physics department do you make plans to see socially or outside of a professional setting? E.g. Go to the movies, play sports, see on the weekends for recreational purposes, etc.?" The doctoral student named staff, research scientists, postdocs, and faculty as people with whom they socialize outside of the department. Four staff members, three Other Scientists, and two postdocs were named. However, only eleven participants named faculty; forty-one did not. Figure 4·22 displays the sociogram for socializing outside of the department with faculty, staff, and postdocs. The density for this sociogram is 0. Because so few students participate, there are only small groupings of nodes.

Eight (80%) lower prestige, twenty-three (88%) typical prestige, and seven (78%) higher prestige faculty members were not named by any of the survey participants; this is the majority of faculty in the department. Of the participants who named at least one person for this question, the mean in-tie is 2 $\pm$ 1; the mean weighted-in tie is 3 $\pm$ 2. Because there is such low participation in this network, no statistical tests were run.

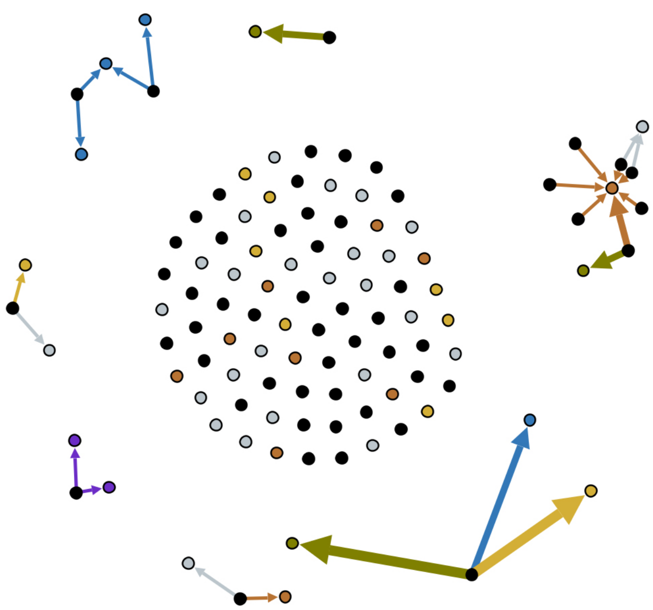

Figure 4·22: Sociogram depicting the connections between students and faculty, research scientists, staff, or postdocs when socializing outside of the department. Because the low participation in this network, no statistics were run.

4.2.3 Doctoral Student Networks Characteristics Multiplex Results

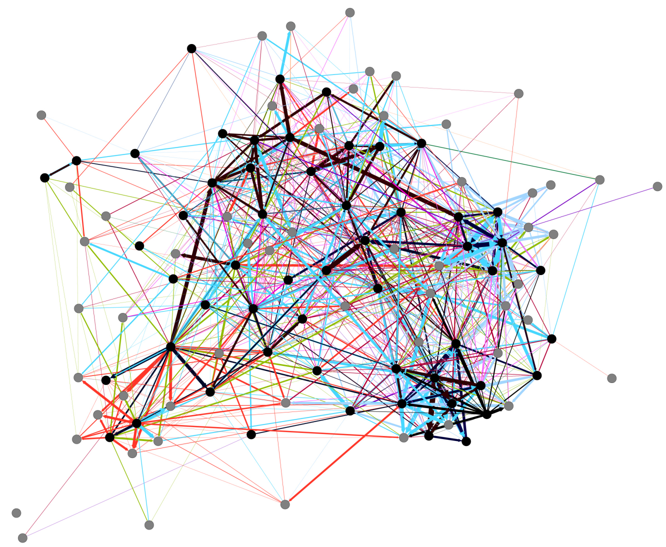

Figure 4·23: Mutiplex sociogram aggregating all network purposes. Table 4.20 describes the statistics of these connections.

A multiplex sociogram, which aggregates all network purposes in one plot, is displayed in figure 4·23. Black lines are reciprocated connections. Colors were otherwise randomly assigned to specific network purposes. Although all doctoral students were selected when creating the individual participants' rosters, one non-participant student has no connections within the network. One group in the lower right of the sociogram is densely connected. One node towards the left acts as bridge to the large main group for one smaller group. The density of this sociogram is 0.14, meaning that 14% of the students are connected to one another.

Table 4.20 displays the network attribute results for the multiplex network. Both participants and non-participants have similar mean number of in-ties and maximum number of in-ties. However, participants have larger weighted in-ties (91 $\pm$ 60) than non-participants (59 $\pm$ 50). Participants also have more betweenness centrality (0.02 $\pm$ 0.02)than non-participants (0.001 $\pm$ 0.002).

T-tests were run on these network attributes for the multiplex data. Equal variance could only be assumed for in-ties. The t-tests for in-ties and weighted in-ties are statistically significant for $p \leq 0.01$. Degree and betweenness centralities are significant for $p \leq 0.001$.

Table 4.20: Network attributes for the multiplex network

	Participants	Non-Participants	t(d.f.)	Combined
Not in network	0	1	-	1
In-ties	11 ± 7	8 ± 5	3.07(108)**	10 ± 6
W-In Ties	91 ± 60	59 ± 50	3.11(105)**	75 ± 57
Max. In-ties	26	23	-	26
Mode In-ties	12	5	-	5
Out-ties	19 ± 10	-	-	-
W-Out Ties	150 ± 110	-	-	-
Max. Out-ties	30	-	-	-
Mode Out-ties	1	-	-	-
Deg. Centrality	31 ± 14	8 ± 5	11.1(68)***	19 ± 16
Btwn. Centrality	0.02 ± 0.02	0.001 ± 0.002	7.96(56)***	0.01 ± 0.01

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Figures 4·24 depicts the multiplex plot for survey participants, faculty, postdocs, staff, and research scientists. Some members of the physics department are not connected to anyone even once in the multiplex sociogram. These include one (18%) survey participant, one (10%) lower prestige faculty member, and five (19%) typical prestige faculty members. There is one main group with many nodes connected to only one other node.

Table 4.21 displays the network attributes for this multiplex. Higher prestige faculty have the highest number of in-ties (11 ± 5). Higher prestige faculty also have the largest mean weighted in-tie (60 ± 40). A staff member has the most in-ties (41), but higher prestige faculty have the highest mode of in-ties (13).

ANOVAs were run to determine whether any significant differences among the 6 groups existed. In-ties and weighted in-ties are significant for $p \leq 0.05$. Post-hoc Tukey tests reveal that the mean difference between those in the Other Scientist category and higher prestige faculty is statistically significant for both in-ties and weighted in-ties.

Table 4.21: Network attributes for the student-faculty/staff network for the multiplex network

	Students	Staff	Postdocs	Other Scientist	Lower Prest.	Typical Prest.	Higher Prest.	F(d.f.)
Not included	1	-	-	-	1	5	-	-
In-ties	-	5 ± 10	2 ± 1	1 ± 2	5 ± 6	5 ± 7	11 ± 5	2.79(5, 77)*
W-In Tie	-	20 ± 52	14 ± 12	7 ± 6	32 ± 37	30 ± 36	60 ± 40	2.63(5, 77)*
Max. In-ties	-	41	2	3	19	28	17	
Mode In-ties	-	1	2	1	1	0	13	
Out-ties	7 ± 4	-	-	-	-			
W. Out-ties	41 ± 30	-	-	-	-			
Max. Out-ties	18	-	-	-	-			
Mode Out-ties	7	-	-	-	-			
Btwn. Centrality	0.02 ± 0.02	0.02 ± 0.07	0.001 ± 0.002	0 ± 0	0.01 ± 0.01	0.01 ± 0.02	0.02 ± 0.02	0.620(5, 77)

Figure 4·24: Mutiplex sociogram aggregating all network purposes for survey participants, staff, postdocs, research scientists, and physics faculty. Table 4.21 describes the statistics of these connections.

4.2.4 Doctoral Student Networks Characteristics Summary

The physics doctoral students connected with various members of their department, for various reasons. Although the physics doctoral students met fellow students in a variety of settings, they primarily are connected to their cohort. Geographic groximity to their peers, which occurs for entering cohorts during the first year of the program, helps create their social networks, as well as aids in sustaining their networks. The interview participants selected their advisors based upon their interest in their advisor's research. Some students chose to switch advisors; few students were asked to leave their advisor. Interaction with faculty is minimal, even with advisors. However, the minimal contact that faculty has with students can be valuable in developing one's network. Some advisors provide advice on which faculty members are suitable for the dissertation committee. This is important, because some faculty members may be unreasonably difficult towards the student.

Tables 4.22 and 4.23 display the results for each network purpose for survey participants. For teaching and coursework, only those who taught or took courses during the 2012-2013 academic year or those named by students in teaching roles or course takers are included in those tables. The survey participant data are used for this analysis, because their networks are complete. The data for non-participants are incomplete as only the in-ties are available; because they are non-participants, the out-ties, or who they would have selected, are not available.

The data show the diversity of the networks in which doctoral physics students participate. Not only do they participate in social networks for various purposes, but also their participation varies. For example, the number of ties varies for each network purpose. The average number of out-ties for each network purpose is greater than the in-ties. Similarly, the average number of weighted out-ties is greater than weighted in-ties.

Reciprocity ranged from 16% (procedural network) to 59% (inside and outside department socializing networks). Five or 50 % of these networks are have a 50% or higher reciprocity. Graph densities ranged from 0.024 (procedural network) to 0.11 (coursework network). The procedural (5 ± 4) and research group (5 ± 5) networks have the lowest degree centralities, while the departmental information (18 ± 11) and inside department socializing (18 ± 13) networks have the highest. The smallest betweenness centrality was for the procedural network (0.005 ± 0.008) and largest for the research network (0.03 ± 0.05).

Because Levene's statistic indicates equal variance cannot be assumed for the network attributes, Welch's test was run to determine if the various networks were statistically different for in-ties, out-ties, weighted in-ties, weighted out-ties, degree centrality, and betweenness centrality. Teaching and coursework data are not included in these statistics, because not all participants taught or enrolled in courses.

Welch's test shows that all network attributes have statistically significant differences among the purposes for $p \leq 0.001$. Table 4.24 displayed the F-test results and degrees of freedom. Post-hoc Games-Howell tests were run to determine which mean differences among the network purposes were significant. The majority of combinations among the network purposes were significant for $p \leq 0.05$. Many pairings are

Table 4.22: The participant-only mean results for each network purpose in the peer networks

	In-Ties	Weighted In-Ties	Out-Ties.	Weighted Out-Ties	Not Selected (P)	Not Selected (NP)
Dept. Info	7 ± 5	23 ± 15	11 ± 8	60 ± 38	0	6
Procedural	2 ± 2	4 ± 4	4 ± 3	6 ± 7	5	21
Coursework	4 ± 2	14 ± 12	7 ± 6	39 ± 12	-	-
Teaching	2 ± 2	19 ± 21	4 ± 4	13 ± 18	-	-
Research Group	1 ± 2	-	3 ± 4	-	7	17
Research	3 ± 2	7 ± 5	4 ± 4	12 ± 12	3	13
Career	2 ± 3	6 ± 7	4 ± 4	8 ± 13	6	20
Crisis	3 ± 3	5 ± 5	5 ± 4	6 ± 7	9	21
In Dept. Social	7 ± 5	23 ± 16	11 ± 9	35 ± 32	2	7
Out Dept. Social	4 ± 3	12 ± 10	7 ± 6	20 ± 19	4	12

The participant-only mean results for each network purpose. Ten different network purposes were considered in this study. "P" stands for participant, and "NP" stands for non-participant.

Table 4.23: The participant-only mean results for degree and betweenness centralities for the peer networks

	% Recip.	Graph Density	Deg. Centrality	Btwn. Centrality
Dept. Info	52%	0.086	18 ± 11	0.02 ± 0.02
Procedural	16%	0.024	5 ± 4	0.005 ± 0.008
Coursework	51%	0.11	11 ± 7	0.02 ± 0.02
Teaching	44%	0.067	11 ± 7	0.01 ± 0.02
Research Group	56%	-	5 ± 5	-
Research	33%	0.036	7 ± 5	0.03 ± 0.05
Career	21%	0.030	6 ± 6	0.02 ± 0.02
Crisis	47%	0.035	7 ± 5	0.02 ± 0.03
In Dept. Social	59%	0.083	18 ± 13	0.02 ± 0.03
Out Dept. Social	59%	0.051	11 ± 7	0.02 ± 0.03

Graph density and the percentage of reciprocal ties are not averages. Ten different network purposes were considered in this study."P" stands for participant, and "NP" stands for non-participant.

statistically significant. The details are in appendix 6.3. Betweenness centrality has the fewest number of statistically significant pair differences.

Which students have the most undirected degree centrality, by purpose, was also examined. For each purpose, a survey participant has the most degree centrality. Each participant has both in-ties and out-ties. One participant had the most degree centrality for three network purposes: departmental information, career or professional advice, and crisis support. Another participant had the most degree centrality for research and coursework. Hypothesis #9 is somewhat supported by these data.

Similar ANOVA analysis was performed on the networks that include faculty for the following networks: research, in department socializing, career advice, and research. These networks were selected because of relatively high student-faculty participation, according to the survey participant. In-degree, weighted in-degree, and betweenness centrality were compared. Because of low participation for staff, research scientists, and postdocs, this analysis was not run for those groups. Table 4.25 displays the data from the previous sections.

Table 4.24: ANOVA results that compare the means for the various purposes for the peer networks

	F(d.f)
In-ties	20.1(8, 179)***
Out-ties	19.5(8, 173)***
Weighted in-ties	25.8(8, 172)***
Weighted out-ties	20.9(8, 170)***
Degree centrality	26.2(8, 174)***
Betweenness centrality	86.5(8, 166)***

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Teaching and coursework networks were not included in this analysis, because not all students taught or coursework during the 2012-2013 academic year. Because lab group members are not formed by social choices, they were not included.

Table 4.26 displays the results of the ANOVA or Welch's test results. For higher prestige faculty, the differences between the four groups are significant for in-ties and weighted in-ties ($p \leq 0.01$). Post-hoc Tukey tests reveal that the mean difference for both in-ties and weighted in-ties is significant for research and the other three network purposes. For typical prestige faculty, Welch's test reveals the differences between the 4 groups are only significant for betweenness centrality ($p \leq 0.001$). This difference is significant for departmental information and the other three network purposes. For lower prestige faculty, there are no statistically significant differences among the four networks. For students, only their betweenness centrality is significant ($p \leq 0.01$). The mean difference is significant for in department socializing and career advice, as well as in department socializing and research purposes.

Table 4.25: Summary of network attributes for the student-faculty networks

		Students	Lower Prest.	Typical Prest.	Higher Prest.
In-ties	Research	-	1 ± 2	2 ± 3	4 ± 2
	Career	-	2 ± 3	2 ± 3	4 ± 3
	Dept. Info	-	3 ± 3	2 ± 3	4 ± 3
	In Dept. Social	-	2 ± 5	3 ± 3	7 ± 3
W. In-ties	Research	-	11 ± 3	6±7	11 ± 8
	Career	-	4 ± 6	4 ± 7	8 ± 7
	Dept. Info	-	7 ± 8	5 ± 7	10 ± 8
	In Dept. Social	-	6 ± 12	7 ± 7	20 ± 6
Out-ties	Research	2 ± 1	-	-	-
	Career	2 ± 1	-	-	-
	Dept. Info	3 ± 2	-	-	-
	In Dept. Social	3 ± 3	-	-	-
W. Out-ties	Research	7 ± 4	-	-	-
	Career	7 ± 4	-	-	-
	Dept. Info	8 ± 8	-	-	-
	In Dept. Social	8 ± 11	-	-	-
Btwn. Centrality	Research	0.02 ± 0.04	0 .03 ± 0.03	0.03 ± 0.05	0.07 ± 0.07
	Career	0.03 ± 0.04	0.01 ± 0.03	0.01 ± 0.04	0.04 ± 0.05
	Dept. Info	0.02 ± 0.02	0.01 ± 0.03	0.009 ± 0.02	0.02 ± 0.02
	In Dept. Social	0.01 ± 0.02	0.01 ± 0.03	0.01 ± 0.01	0.03 ± 0.02

Table 4.26: ANOVA or Welch's test results that compare the means for the various networks involving faculty

	Students	Lower Prest.	Typical Prest.	Higher Prest.
	F(d.f)	F(d.f)	F(d.f)	F(d.f)
In-ties	-	0.24(3, 36)	0.134(3, 100)	N/A
Weighted in-ties	-	0.21(3, 36)	0.383(3, 100)	N/A
Out-ties	2.66(3, 116)	-	-	-
Weighted out-ties	0.935(3, 115)	-	-	-
Btwn. centrality	3.75(3, 114)**	0.031(3, 36)	11.8(3, 46)***	1.84(3, 17)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

The networks represented are research, in department socializing, career advice, and research. Purposes were compared by faculty member; for example, the afore-mentioned purposes were compared for only lower prestige faculty. N/A when at least one of the network purpose groups had 0 variance.

4.2.5 "If doctoral students do not participate in networks within their own physics department, do they participate in other networks and if so, where, how, and why?"

Survey participants were asked to provide the names of people outside of the physics department whom they contact for the reasons on the survey. This subquestion relates to hypothesis #2: "if they do not find adequate support within the department, they will either look outside of their departments or be more likely to consider leaving the program before degree completion." Sections 4.3 and 4.4 delve into the second part of this hypothesis.

To determine whether a survey participant has a tie for a particular purpose, the direction of the tie is considered; I only consider ties named or selected by the participant. The survey participant may not feel as though she or he is a participant in these networks or that his or her needs are being met in these networks, even if she or he is selected by others. Student, faculty, staff, research scientist, and postdoctoral ties are all considered for participation for a particular purpose. Again, for the coursework and teaching networks, only those who were taking coursework or were teaching are considered. Socializing within the department was modified to be at the university-level, because departmental events may not be of interest or open to those not in the department.

For those who provided names to outside ties, sixty-six other people were named. The mean number of non-departmental ties named is 3 ± 3. These contacts are established through a variety of means. Some of them are significant others or contacts established through one's significant other. Contacts established through research are named as well. Other ties are established from the participants' undergraduate institutes or through currently participating extracurricular activities.

Table 4.27 provides the details on the following data. Thirty-four participants listed no outside of the department contacts. Similar to the departmental network, these ties play multiple roles within the survey participants' lives so the overall total of non-departmental ties is greater than the total number of named contacts.

Table 4.27: Networks that the participants have outside of their department

	# of Ties	No Ties Previously Selected	No Ties Selected for Purpose
Dept. info	19	1	1
Procedural	13	2	2
Coursework	3	4	4
Teaching	8	7	7
Research	29	0	0
Career	30	0	0
Crisis	25	2	2
At University Social	13	3	2
Out Dept. Social	15	6	6

Of the nine purposes represented, there are participants with no departmental ties for seven of these purposes. The number of participants with no ties for these purposes range from 1 to 7. Except for socializing within the university, all of the participants who did not name a person associated with the department did not name a person not affiliated with the department. For example, if a survey participant did not have a tie to a departmental contact for career-related advice, the participant would not have a contact outside of the department for career-related advice.

The interview data provide further insight on these outside networks. Ten participants note that their non-departmental connections are people they knew from their undergraduate institutes. Nine interview participants note meeting others through friends they have within the physics department or friends they knew prior to enrolling in the doctoral program.

Two interview participants noted barriers to forming outside networks. These reasons include the difference between being a graduate student rather than an undergraduate student, as well as structural barriers that hinder network formation. Ronan Willis commented on this difference: "I guess that's the difference between being an undergrad and grad student. In my undergrad institute, the department barrier was blurred. But once I came here, we hardly have any interaction with the people outside the department." Glenn observed the doctoral student life does not lend itself to much leisure time away, which hinders on making friends away from the department: "I have lots of friends before the program. But friends I have [here]? I'd say they're almost entirely in the department. Especially as a grad student, I'm here all day pretty much for a very long time. I don't do many activities. Maybe I should've done other activities, but I never did. Maybe if I was younger, I would have."

Six participants noted that outside networks are quite valuable to them. The value behind these networks varies. Some of the value is based on common interests with those outside of the department. However, two participants noted that some of the value is related to the lack of ties within the department. Brenden Briggs observed that he is closer to friends he knew prior to starting his doctorate; part of that, he pointed out is because of duration of those relationships compared to the friendships formed in the physics program. However, he also stated, "I would like to spend more time with people here. I'll often like- people don't want to go out and drink and do things much."

Lysander Barber see this more as a closeness issue. When comparing his friendships within the department to those outside, he stated the following: "I tend not to talk about my own immediate personal life, at least until a much later point, compared to my closer friends. It's partially because I don't think they'll care." His closer friends tend be outside of the department, and personal life matters that he mentioned include whether he is currently dating someone.

Although students may not have connections to others for the afore-mentioned purposes, this may be intentional and not perceived as negative. Max Thompson commented that his lack of ties for coursework was a result of his disinterest in the course and that he only was enrolled to fulfill a requirement. Calvin Schwartz does not have close friends within the department, but he also is not bothered by this.

In summary, the participants have outside network connections for multiple purposes. The survey data suggest that those who lack departmental connections for a purpose do not form non-departmental connections for that purpose. Interview data indicate that networks outside of the department were prior to entering the program. For students who do not have a previously existing group of friends in the area, they may find making connections challenging. These outside networks are valued because of common interests. However, they are also valued because they fulfill general social purposes not found in the department such as emotional intimacy.

Based upon the survey and interview, hypothesis # 2 is somewhat supported. The survey participants do not appear to seek out others in the department when different purposes are not fulfilled by those within the department. The interview data indicate that connections are nuanced. While students may have ties to various people with the department for a given purpose, these connections may not be satisfactory for a variety of reasons. Thus, ties outside of the department fulfill needs that cannot be met by departmental ties.

4.3 "What is discussed in these doctoral student networks?"

In section 4.2, the data show that students participate in network for multiple purposes. However, the question remains what transpires in these networks. Part of the value of participating in a social network is receiving support and information, as discussed in chapter 2. Connections suggest the potential to receive support and information, but this may not occur for many reasons. Section 4.2.5, which discusses networks in which students participate outside of the department, introduced some of the reasons, such as lack of closeness to other students.

The first subquestion examines the conversation topics, information received, and support sought by the doctoral students. The second subquestion considers who is the discussion partner, source of information, or the source of support. Who is providing this information and support is examined, as this may affect the conversation, information, and support. Lastly, network satisfaction is considered; one may have contacts for various purposes, but the contacts may not provide adequate support or be good sources for the participant.

This section draws upon the interview data to answer the questions above. Hypothesis #3 was motivated by this research question. This hypothesis states that the doctoral students look for information for multiple reasons, but they are particularly interested in information related to completing their doctoral programs or developing their careers. Similar to section 4.2.1, the data are arranged according to network purpose.

4.3.1 Departmental Information

When interview participants were asked about discussing the department, they phrased it as departmental gossip. I referred to this as departmental information or "what is going on", because the phrase "departmental gossip" has connotation of being more rumor-based than encompassing both fact and speculation. The data I sought was anything discussed regarding the department, including gossip. However, despite the connotations of gossip, the interview participants did mention both fact and speculation regarding the department when responding to this question.

Sixteen (57.1%) interview participants noted that among physics doctoral student peers, they tend discuss department changes. This includes faculty changes (hiring or leaving), funding issues, and changes to departmental requirements and policies aimed at students. Six participants mentioned discussing their peers. However, fellow students tended to be discussed in relation to to the department policies and situations. These changes include funding matters or faculty leaving. For example, Malcolm Rollins mentioned discussing other students with his peers but in relation to the comprehensive exam policy: “I think three or four, two to three people who started with me, didn’t pass their comprehensive exams for a variety of reasons. There seems to be- the department seems to have gotten a lot stricter about having a third try for the comprehensive exams recently.” He then discussed what he perceived as the department’s differing perspectives on comprehensive exams, suggesting that changes may occur. Overall, though, the participants were unsure whether there is much to discuss regarding the department.

Four students mentioned discussing faculty-faculty interaction dynamics, though again they are unsure if there is much to discuss. Kurt MicKinney described this as follows:

> [The department] certainly intrigued us for years. The professors, the small amount of politics we see. The professors do a pretty good job of hiding that from the outside world, so when we see a little bit of that, we discuss it. Stuff like one professor doesn’t like another, because he stole a graduate student of his years ago.

Other interview participants observed these dynamics at events. They also deduced faculty relationships, such as who is friendly with whom, through their conversations with other faculty members. These conversations may not be explicit, but there are indications such as tone.

As indicated by the survey data, students discuss department information among themselves. Four participants (14.3%) noted that their sources of information come from either being active within the department beyond their doctoral student duties or being friends with someone who is active in the department. Two students said they learned about the department happenings and dynamics through talking to faculty or staff. It is interesting to note that although the students tend not to discuss departmental matters with faculty and staff, the students indicated that the faculty and staff are very interested in discussing these matters and will do so with students.

For departmental information, satisfaction with the amount of information received is unclear. In one case, the interview participant did not realize a primary collaborator was leaving until other students informed him; he found out about a month after the other students knew. The direction of the research, including who would be the lead on the project, was unknown at the time of the interview. This is an example of a participant being dissatisfied with the information received, as the situation was revealed relatively late to the student and was not being discussed with the student.

However, all of the interview participants do not believe there is departmental information to discuss. Two participants did not believe there was any departmental information to discuss. Therefore, their satisfaction is difficult to determine. If there were topics related to the department or such information were known, the participants are interested. Below are three examples illustrating the lack of topics (or perceived lack of topics) but interest in it:

> I don't think there's a lot of gossip, I would say. There's actually a surprising little amount. We could be gossiping a lot more. What professors are leaving and stuff like that. I had a conversation about that yesterday, the direction of the physics department. It felt very rare. We don't tend to gossip about who's doing what. I guess there's not a lot of gossip to be had. I assume in other departments, they gossip more if there's something there, because gossiping is fun. - *Glenn Blevins*

> There's very little gossip inside the department, so when there's any gossip, any piece of information, it spreads quickly. Everyone wants to know what's going on. - *Kurt McKinney*

> And I can't think of any gossip- things that happened, no. I don't think it happened much. And if it did, you should let me know. - *Tyrone Burns*

What is interesting is that students tend to have a lot of ties in the departmental network, as indicated by the data in 4.2.1. With whatever information is available, they appear to discuss it with a relatively large number of students. In summary, the students are interested in discussing their department in terms of policies and faculty dynamics. However, they do not believe there is much to discuss.

4.3.2 Procedural Advice

The interview participants seek out procedural advice. Conversation on this topic entailed finding out what paperwork to file or for which courses to register. Three (10.7%) interview participants felt very comfortable with handling procedural matters in the physics department, having done these multiple times or feeling that the information available via the department's website. They did not feel as though they needed much support on these matters. However, the procedures are not necessarily clear to all of the students. Below are two quotes that discuss the ambiguity in paperwork and the need to have a source:

> There is [information on the website], but I feel like- they keep changing. The problem is- I have an issue when people don't define their terms. So when you go to the website, it says things but it won't define what things mean. Most people will probably come to the first conclusion about it, and they will go, 'It obviously means this.' But I think it's my personality and my nature as a physics person that, [if] you haven't actually defined what this term means, I can't assume this. - *Lysander Barber*

> Well, the paperwork for school feels like magic. Some of the forms- I feel like they look like the same thing, and I can't tell the difference. There's a continuing research one, a summer continuing one that's different from the regular one... We don't even know the course number. Aileen [Brewer, a staff person] knows- there's a list, she looks at it. - *Gavin Braun*

Because of the fine details such as the difference between forms or undefined terms, the students may need support on these matters.

The survey data in section 4.2.1 show that while doctoral students do indeed contact each other for procedural reasons, the majority (65% or 36 participants) rely on a staff person. Sixteen of the interview participants spoke specifically about one staff person, Aileen Brewer. These interview participants discussed Aileen favorably in terms of both her official and unofficial responsibilities. She ensures that the students complete whatever procedural matters but also is personally invested in them. Below are two quotes that illustrate this:

> She's very good at making all problems disappear. Really, she can handle anything. She'll realize you forgot to fill out a paperwork. I haven't had any issues with my advisor, but you know, she's helped some people through issues where they've had some confrontation with some professor and she's very good at that. - *Max Thompson*

> One really useful person is Aileen. She's- um, I don't know what her official title. She's the secretary in charge of- you go to her to make sure you're signed up for classes and to make sure you're registered and- yeah, basically anything procedural... She's like a very, very friendly, really nice person. A lot of graduate students describe her as the mom of the department, because you can go to her office at any time and chat a'bout anything else. - *Racquel Christensen*

Although the students may find the paperwork and procedural matters within the department challenging, they also are able to complete whatever is needed by going to Aileen. They are satisfied with the support Aileen provides on these matters. Other than dissatisfaction with the procedures as written, none of the interview participants had negative comments about Aileen's help on these matters. What is interesting to note that although her initial relationship with the students is for procedural matters and paperwork, tasks that do not entail frequent contact, it appears through that her role extends to that of a caregiver.

4.3.3 Academic Coursework Reasons

Coursework was primarily discussed by students in terms of how to complete problem sets. The discussion partners tended to be be peers. The following quotes show the characteristics of their coursework partners:

> I usually struggled with the problems by myself for awhile. But most problem sets, I needed help from someone. [I selected] friendly people, uh- people I knew who already started working on the assignment. Also, people who also needed help. It was easier to work among them, asking questions. - *Brenden Briggs*

> One of the students, Albert Burgess, was a first year last year... and he seemed approachable. I think I met him at someone other social events in the department, so I tended to ask him questions a fair amount. And- I can't really remember talking to anyone else. Eli is one of my friends, and I tried to ask him for help, but his advice is often not very helpful and he tends to start the homework very late. If I wait until he knows the answers, it's usually way too late for me to finish it anyways. - *Malcolm Rollins*

While students are the primary discussion partners, simply being a student is not enough to be considered as someone with whom others will work. Working with others who are friendly and have similar work styles is important. Brenden's observation that he chose to work with people where discussion is more collaborative is a sentiment echoed by other students; they spoke of working with others, not being tutored or tutoring.

Two students mentioned discussing coursework with the faculty member who taught the course. Cooper Shields occasionally emailed the professor for clarification on course material. Leo Frost mentioned that he discussed the coursework with the professor to find how the course material connected to other fields. The lack of non-student discussion partners for coursework aligns with the survey results. For the thirty-three survey participants who took at least one course, they selected 7 $\pm$ 6 fellow students and 3 $\pm$ 2 faculty and staff members.

The interview participants voiced no complaints regarding coursework partners. Although working with others was done in order to complete assignments and receive satisfactory grades, there was more value in working together for the interview participants. They saw that working with others was a means of making friends and developing their social networks within the department.

4.3.4 Teaching-Related Reasons

Discussion topics for teaching-related reasons were eclectic. Four out of twelve (33.3%) interview participants who taught looked to fellow doctoral students for advice and support, ranging from determining one's role in the classroom to handling student misbehavior to learning about educational research.

However, most interview participants who taught did not discuss anything related to teaching unless required. Their reasons varied, but the common theme was they felt that could rely on themselves for teaching matters. Three (25.0%) participants did not feel discussing teaching was necessary, because they had prior experience with teaching during their undergraduate years; the teaching ranged from teaching a course to tutoring. One participant, who lacked teaching experience, spent hours prior to each class preparing. Glenn Blevins felt that experience and private self-reflection was needed, rather than discussion or teacher training:

> My opinion on how to be a good TF is someone telling you something is very useless. I find that experience is the only way to find out what works and what doesn't. For me, I find I'm a pretty self-critical person and aware of my weaknesses. I can only really find my strengths and weaknesses when I teach the actual kids.

Eight (66.7%) participants said they discussed teaching-related matters with the instructor of the class. Three of these eight participants (37.5%) participants described discussing course material and being involved in the development of quizzes and worksheets. Two participants sought advice and feedback from the instructor.

These two are doctoral students who enjoy and prioritize teaching. For two other interview participants, discussing teaching-related matters was not something they enjoyed. Both felt these discussions took too long; one interview participant stated that the professor did not seem to recognize that doctoral students have competing responsibilities.

Although the interview participants on a whole do not seem to seek out discussions on teaching, four (33.3%) participants mentioned they do feel that providing feedback and advice on teaching is important. Bailey Hudson recommended that the department provides a source for this: “It sort of would be nice to- maybe the director of graduate studies, that would be their job- it would be nice to have a person you could go to for teaching-related concerns who has some expertise... Or maybe that duty is someone’s job, and I just don’t know about it.”

The interview participants had no major or trending complaints regarding their experiences in discussing teaching. However, most interview participants who taught did not discuss teaching and were fine with not having a discussion partner for that; the survey data on teaching show relatively low numbers for peer discussion partners (out-ties: 4 ± 4; in-ties: out-ties: 2 ± 2) and faculty/staff discussion partners (out-ties from students to faculty: 2 ± 2). Any training or discussion related to teaching is initiated by the professor teaching the course.

4.3.5 Research-Related Reasons

Students’ first experiences with research in the doctoral program is often selecting an advisor and research group. In section 4.2.1, the interview participants provided information on how they selected their advisors. When selecting advisors for the first time, only two interview participants mentioned discussing advisors with fellow students.

The doctoral students went directly to faculty members whose research interested them. Discussion with these faculty members was regarding research and whether any openings or funding were available. Because some faculty members primarily do their research at labs away from Jonas University, the logistics of needing to move were discussed. Advisor selection discussions and decisions seem to be informal and casual; the student and the faculty member discuss the professor's research and openings in the group briefly, and then the student makes a decision to become one of the faculty member's advisees if there is availability. Only one interview participant mentioned that the faculty member had prospective advisees read a paper prior to being interviewed and selected by the faculty member. Another mentioned trying out two labs before committing to one advisor, per a faculty member's advice.

As mentioned in section 4.2.1, students tend to switch advisors. Discussion with the original advisor does not appear to occur prior to leaving or when the student leaves the advisor. Orien Barr mentioned that his choice to leave his first advisor was abrupt; Kerr Steele said that when he left his first and second advisors, they were surprised. Sometimes, however, the decision to leave is not from the student. Some of the interview participants said that they were asked to leave their groups. When the advisor asks the doctoral student to leave, there appears to be no discussion. Archie Calderon found this frustrating:

> [The professors] would talk and make decisions and- then, sort of one of them would talk to me and say "Oh, we think you should do this project" or "Oh, we think you should find a new project." Or- whatever the communication is, it is decided away from me. There is no avenue for me to speak to them in the same way they speak to each other.

In summary, when students leave their advisors, either by choice or by being asked to leave, there is no discussion between the student and advisor to attempt to resolve the situation. There appears to be no warning that the situation is unsatisfactory for either the student or the advisor.

The students who switch advisors tend to use the same process to select a new advisor as they did before: see who is doing research that interests them, talk to the professor regarding openings and funding, and select the advisor if he or she has an opening and funding. The process again seems casual, and it appears that students selected the first professor who would agree to have them as an advisee. Two students did consult with a faculty member, Kelvin Warren, when they were in the process of switching advisors. Both were given the same advice on how to select an advisor, which they found helpful and something that they may not have done on their own. Below is the advice given by Kelvin:

> I talked to Kelvin about this, getting help with the process of finding advisors. I should mention that when I was working with [my original group] and didn't know what to do, I felt really lost and was worried about my funding situation for the fall... I emailed Kelvin and talked to him about it... He was like, "I want you to make a list of all these people and check off whether you talked to them. Then talk to the ones you haven't. Write down things you know about their research from their website or papers, and then mark whether you want them or don't want them." It wasn't that complicated to do, but he was there to help me and turn it into a process where I could make a choice. - *Archie Calderon*

Essentially, the advice was to talk to professors and organize the information into a pros and cons list. Although simple, the advice was needed and appreciated.

In terms of discussing research, discussion among students tends to be updates on their progress. Some students participated in journal clubs where they discussed research and worked with others within their labs. Eight (28.5%) interview participants mentioned that their research is so specialized that they do not talk or collaborate with students, even though they are in areas or even groups with multiple students. Below are five examples of specialization hindering discussion:

> Everyone does very different things from each other [in my group]... If I need something, who do I talk to? - *Julie Clarke*

> [Whether I discuss research] depends on whether a person works on some project or field that's related to what I do or not. For a lot of them, it's not the case. They do completely different things. There are some of them who do slightly similar things. - *Douglas Cannon*

> [The students in my group are] mostly studying similar things, but the actual subjects of the projects are different. I wouldn't say I collaborate

> with the other people in my group. I write my own code, they write their own code, and sometimes I ask them for help, sometimes they ask me for help. - *Malcolm Rollins*

> I think my group does collaborate, but I feel like my research is kind- I feel like every group does pretty unique research. So some research areas can be very hard to find collaboration, a starting point, but- yeah. But on the other hand, I was by myself. Looking back, right now, I think I'm more mature than when I started... I would have more initiative to do more work with other people, to get a broader research skill sets. - *Natalie Wilson*

> The research I do is a little different from most of the people in the department and generally, from most of the people in our group. But we will occasionally get requests from people who want to venture a little outside of what they do, so they'll come to us for research advice. That's mainly how it works. [My advisor's students] don't really mingle much because we don't know what each other is doing. - *Flynn Gardner*

The students in the above quotes are all in groups that have more than one person, so even within a group, research discussion or collaboration may not occur.

When students do seek out or receive help, the help is generally computer skills (coding, Linux commands, et cetera). Four students mentioned that the students in their groups do work together, either collaborating or helping fellow students become acquainted with the research and the lab procedures. Most students, however, do not seek out or are offered this help from fellow students.

Postdocs and non-physics department faculty are important conversation partners for six (21.4%) of the interview participants. They provide technical help, but they also provide further insight about physics and science beyond the immediate research project. Terrence Winters talked about his post-doc in these terms, seeing the post-doc's role in his life as filling in for his advisor: "Most of the help I get and most of what I learned about- doing science as a PhD candidate comes from my postdoc, Theo Howe. He's an awesome guy. With a boss that is as hands-off as Rufus, Theo is filling the other 2/3 of the advisory shoes as you would put it." Douglas Cannon mentioned that he and the postdoc in his group discussion research informally which has the potential for concrete benefits: "A lot of times, we just sit and talk about random science that sometimes leads to projects."

Research discussion with one's advisor tends to vary considerably, not only by topic but also by whether such discussion occurs. Six participants characterized their research discussions (and their relationships) with their advisors as more business-like: discussing the student's progress, ensuring that the research project was going well. The following quotes illustrate a more project-focused approach to research discussion:

> I wouldn't say I have as close of a relationship as some people have with their advisors. I wouldn't call him a friend or mentor. I'm not going to have a picture of the two of us hanging out in my office one day, but certainly he fulfills all of the needs I have of an advisor. He has good advice and I know he'll give it to me straight, which is important. - *Terrence Winters*

> [*When asked whether her advisor meets her expectations*] Certainly! I think some grad students really like to be left alone and um, try to work on things on their own for awhile. I- I think- I like to talk to my advisor more often. I tend to be more communicative about what I'm working on and what I'm having trouble with. My advisor's good that way and talks to me a lot. - *Racquel Christensen*

> Regis [my advisor] is the first source of advice on my research. We also have a collaborator, and he's helpful, too, but- Regis is more helpful in terms of the bigger picture and theory type stuff.- *Gavin Braun*

Eight participants describe their advisors discussing broader matters surrounding research. The following quotes illustrate the ways in which the doctoral students and their advisors take on more of a mentoring role related to research:

> I remember the first time I wrote an abstract for a conference. [My advisor] completely tore a lot of it up and had me rewrite it. After I had written it two or three times, it was like a million times better than how I originally written it. So writing properly for your audience and for scientific community, I learned a lot. So those things for an advisor, she's done a lot. - *Cooper Shields*

> He's not shy about sharing the ugly parts of academia... I just talked to him a lot- the great things of academia can be very rewarding, but he also told me about people who will just attack you personally. And if they get your paper, they'll just smear it so it won't get accepted regardless of the intellectual merit. In that respect, I've gotten a lot of mentoring and what I meant as a mentor. Not just technical knowledge but the field in general and what a life would be like pursuing that field. -*Bailey Hudson*

Both of these advisors are developing skills in and sharing knowledge with their advisees that extend beyond the current research project.

Nine participants described their advisors as being more absent in their lives. The reasons vary for why advisors play less of a role in their students' lives. Below are three quotes to illustrate the different reasons why an advisor is absent:

> I think [my advisor] does too many things, so I told him during the day, during the week, I didn't have guidelines in terms of research. - *Keagan Weaver*

> [*Regarding his former advisor*] It's like they want the best, and they aren't parenting out the best. They're reaping the best, they're not sowing the best. I know there are a lot of economic constraints that prevent them from taking just anyone and working with them to become the best physicist they can... But- I don't think they were particularly sorry to see me leave. They were like "Oh, another one left. It happens"- *Archie Calderon*

> So he's a very nice guy. But sometimes, I feel he doesn't listen to me. He just makes his conclusions and doesn't listen to what I'm saying... I never felt like going to him. - *Julie Clarke*

As the above quotes illustrate, time and lack of interest in the students may contribute to not providing the support students need. In Julie's case, the advisor may have been interested in guiding her research. However, he did not cultivate an environment where she was comfortable in discussing her research.

With few exceptions, discussing research with committee members tends to be centered around formalities such as attending the preliminary oral exam or reading the dissertation prior to the defense. Working with the committee in a more formal, policy-defined way is not necessarily negative. Jacques Booth described one benchmark, the departmental seminar, in a positive but policy-defined manner: "So [the departmental seminar is] supposed to be 6 months before you give your thesis defense. You have to basically give a practice talk. They can point out in the next 6 months, here's what you're not going to be able to finish. Here's what you should add, because it's lacking. That's sort of good from a 'round out your thesis, get it complete, and move on' sort of viewpoint, so that was useful. And they helped me."

For the few who did have committee members who were more involved, the involvement varied. Tyrone Burns noted having worked more with a committee member, Regis Hurst, than his advisor. The interaction was described as follows: "[Regis] mentored me, and we'd talk about research. Both his previous research, and a little about my current research. And during the dissertation, I feel like he was the only one who had read it. He was the only one who asked me questions about what I did before the exam actually happened. The questions that arose led to some general physics discussions." Gavin Braun said that one of his committee members was able to provide him with a different perspective on presenting research that his advisor did not have; he felt that the committee member's approach and advice on presenting research was more useful than his advisor's. In both of these students' cases, the committee member filled in a gap left by the advisor.

Discussing research with fellow students, advisors, and other faculty varies. For many students, it is infrequent. The survey data also show a low number of ties directed to fellow students (3 $\pm$ 2) and a low frequency of contact (weighted in-ties: 7 $\pm$ 5). Survey participants also tended to name few non-students (2 $\pm$ 1) and contacted them infrequently as well (weighted out-ties: 7 $\pm$ 5). The qualitative data suggest that the few and infrequent network ties are a result of multiple factors.

The interview participants who have at least one non-student person to discuss research are at least somewhat satisfied; in the cases of poor advising, their perspectives on satisfaction for this network purpose are mixed. Despite the lack of peers to discuss research and the appearance of not being bothered, a few interview participants would like to have peer interaction regarding research. They would like group meetings or to try collaborating with fellow students. Ronan Willis noticed particular value in peer interaction for research purpose, recalling a peer from his undergraduate days who was particularly helpful:

> It was really helpful to have this one person to discuss academic stuff. It sort of clears things in your head, but when it comes to my research, I don't really discuss with anybody except my advisor, so sometimes, I wish I could have somebody I could clear things with. [*When asked what that means*] Just like explain what I'm doing. He would have questions that I really didn't think about, something I'd think was obvious or assuming.

This is perhaps the value students could receive if they were to discuss research among their peers.

4.3.6 Career and Professional Advice

Fellow students' role in career and professional advice tends to be relegated to updates regarding the career paths of more senior students. This type of conversation can provide advice. Lysander Barber described these interactions as follows: "Mostly, I've been talking about with older grad students who are graduating soon. 'So, you're graduating eventually. What are you going to do? How do you figure out what you're going to do?' " The more senior students are acting as role models and providing guidance for the more junior students.

Faculty, particularly advisors, play an active role in providing career and professional advice. Seven interview participants said that their advisors have offered to help provide contacts for postdoc positions. However, the issue noted by nine interview participants is that the advice is not effective. The following quotes depict the perceived lack of effectiveness:

> I started using resources at the career development office. There's a counselor there, very helpful for PhD students for finding out what you really fit in, career interests and skills. I think they're very helpful. For the department, my advisor has given me a lot of advice as well, but he mainly wants me to stay in academia. Um, yeah, he thinks that's the best advice for me, but he's very supportive of me to choose, to follow my own interests. So he gives me some freedom. - *Natalie Wilson*

> Since I'm looking outside of academics, my advisors have helped but they don't have a lot of experience outside of academics. So mostly friends who are in industry who have done this [who I know through from other work.] - *Jacques Booth*

> I find him kind of a poor resource for non-academic jobs. And that's what I want, and that's unfortunate. He basically got me a job- well, not exactly. I helped myself, too. He got me a job as postdoc, but I don't want it. I don't want to go into academia. But I appreciate it, so he's as helpful as I think he can be. - *Orien Barr*

Although the faculty is supportive of non-academic career, the advice that students receive is not effective. Because the faculty are in academia, their advice and knowledge on career paths are in the academic sector. Jacques also mentioned needing to restructure his CV for industry; according to him, industry and academia use different language to convey similar ideas. His friends who work in industry had helped him.

The interview participants primarily spoke of seeking jobs and needing advice on that. Three participants discussed career advice in a more preparatory manner; they wanted to know what skills to develop and how to pick career paths. Below are two quotes related this:

> Yeah, I actually sat down with Professor Pace over the summer and asked him how do I pursue becoming faculty somewhere. What do I need to prepare for? -*Albert Burgess*

> When we have the colloquium speaker lunches[1] with the grad students, the how did you end up doing what you're doing from grad school is a very common topic of conversation. Although I admit it tends to be very skewed towards the academic track because of the selection of invited speakers. But still, it's useful to know how people thought about it different ways.- *Lysander Barber*

The advice offered by the department on preparing for one's career also appears to be rooted in academia, even from the colloquium speakers.

Unless they are interested in pursuing academic careers, the interview participants overall do not receive the career and professional advice they need. Students tend to discuss the individual students' experiences more informally and more as a peer role model or gain a sense of what is in their futures; a few student also spoke with faculty or other employed scientists specifically on the skills they would need for particular careers. When students talk to faculty, they were primarily interested more specifically in finding a job or entering a particular employment sector. This advice is not as helpful, because the career interests of the doctoral students and the career knowledge of the faculty are incongruent. A few students found resources outside of the physics department to help them find jobs or tailor their CVs to the industry in which they were interested. The survey data reflect the findings in this section; the survey participants had few student or non-student discussion partners, and the discussions were infrequent.

[1] The physics department hosts a lunch for the colloquium speaker and the doctoral students. These lunches are only attended by the speaker and the doctoral students. The conversation seems to be informal and directed by the students.

4.3.7 Crisis Support

Interview participants were asked about actually crises that occurred in their lives during their time in the doctoral program. Most participants had nothing they qualified as a crisis. A few participants did have events or situations that I may have categorized as a crisis. They include health problems related to stress and lots of doubts related to one's capabilities for being a doctoral student. A few student participants also had events or situations they were not sure if they were truly crises but discussed them with me. Those were linked academic progress or stress in meeting deadlines for publication. Nothing was done to mitigate stress for publications, but for academic progress, friends had empathy and provided encouragement. Only events or situations that were explicitly noted as crises are discussed in this section.

Three (10.7%) participants mentioned academic difficulties linked to courses, such as studying or performance in the course. Advice and support came from faculty, staff, and friends of the participants. The participants found this advice helpful; friends provided more morale building, while faculty and staff provided definitive answers to questions they had.

Eight (28.6%) participants had crises related to research. These issues covered a broad range of topics related to research. Two participants had difficulties passing requirements within the program. One participant mentioned issues regarding funding, two mentioned stress in selecting a new advisor.

In the five more general situations, faculty were contacted by the student. For the student who had issues regarding funding, he sought out answers to his question regarding funding. For the students selecting a new advisor, the faculty member provided guidance and was source to discuss any concerns from the student. For the students with difficulties passing requirements, faculty provided advice on how to do so. Four were pleased with the support they received, and one appreciated the support but was not sure if it was useful.

The three other students had issues within their research groups. Two students perceived equipment issues, such as ordering supplies or accidentally damaging equipment, as crises. They initially tried to resolve these issues on their own; it is unclear why one of the participants did not seek out help, but other participant was afraid to approach the advisor. Both eventually talked to their advisors; in one case, the faculty member was described as frustrated, the other said the faculty member was understanding. One student was in a stressful lab environment and described being highly dissatisfied: "I think I was really unhappy because I really wanted to work and couldn't work. I couldn't feel any support in that environment at all. I felt pretty depressed. Uh, that's when I- I think I would quit the PhD or die or find another one. *Laughs* I think if I stayed there, I would die from unhappiness." Finding a new research group solved this issue.

Two participants had crises surrounding issues in their personal lives. Friends were able to help them cope. In one case, however, a faculty member exacerbated the difficulties surrounding the situation. The participant had to leave suddenly for a family emergency. The faculty member was upset that the student could not fulfill responsibilities that week. Nothing was done regarding this situation, but the participant felt uncomfortable with this faculty member afterwards.

The interview participants seem to have few crises, either as a group or as individuals. The majority of crises they experience are within the program, either related to research or completing requirements. Faculty play a critical role in mitigating stress, although fellow students do provide interpersonal support and sympathy. The survey indicates that students have a small number of ties, either students they selected (3 ± 3) or being selected by fellow students (5 ± 4). These ties also are contacted infrequently during the time of crisis (6 ± 7). Participants also contacted these ties infrequently (5 ± 5). Faculty are also infrequently named and contacted; however, staff are named frequently (6 ± 10) than students and faculty of any prestige ranking.

4.3.8 Within Department Socializing

Students socialize within the department through making plans to meet up for meals or at departmental events. They tend to talk about, as Tyrone Burns described it, "whatever friends talk about." This ranges from hobbies to movies/music to research to their interactions with professors. Keagan Weaver described the conversations as "very relaxed talking." For colloquia or other events centered around physics research, the conversation tends to be about the event. This not only includes talking about the research being presented but also whether the researcher will be a good presenter.

At departmental events, such as the colloquia or holiday parties, as noted in section 4.2, eleven interview participants noted that they tend to talk to the same people and the same people attend these events. Although students may not venture outside of an established group, there are differences within the social groups at events. Closeness affects the conversation topics. Bailey Hudson explained this: "The people I know less in the department, I mainly talk to them about physics and research. The people I know better, I talk about more personal things."

While these conversations may be more casual and less intimate, the interview participants note that they enjoy the opportunity to catch up with classmates they may not see as frequently. Max Thompson noted that these department events are among the opportunities for more senior students to interact: "Now that I'm not taking classes with anyone, that's how I keep in touch with people from my year. I'm definitely a drop-off in seeing people from my year. I definitely see them at colloquium or uh, graduate lunches and stuff like that."

Conversation with faculty at these events is centered around research, according to ten participants. Kurt MicKinney perceived this as a matter of comfort: "I find them much more open to discussing science than anything else. It is, of course, their expertise. They want to- it puts everyone at ease when you can talk to someone you know a lot about." However, nine interview participants mentioned that they tend not to talk to the faculty at these events much or in great detail. Cooper Shields explained why:

> Some of them are really student-focused. Uh, there's like no faculty interaction really. But the bigger events, there's the Christmas party where everyone is invited and it's worthwhile for everyone to attend. There's some faculty interaction but not a lot. It's still very nichey. You may talk with a faculty while you're waiting in line for food or walking by. You walk into someone and they ask a question of you, but you usually don't walk

> over to their group and start a conversation. It's only natural, because what do you have in common with them? When you're in a course with them or teaching, you have that to talk about. But unless they're in your field, it's- I don't know enough about the faculty to have commonalities with them.

Lack of closeness to the faculty limits interactions with them. The faculty does not seem to approach students during these departmental events; the interview participants focused on the reasons they did not approach faculty, but they did not comment on whether faculty approaches them.

Determining whether the interview participants are satisfied with their interactions with faculty at these events is unclear. Some do wish they had the opportunity to talk to faculty and perhaps have a deeper conversation on the faculty members' career trajectory. Others are indifferent to socializing with faculty at these events; they would not be opposed, but they also are not seeking such interaction. Still others are apprehensive to talk to their faculty for fear of offending the faculty.

Faculty occasionally make plans to socialize with the students during the work day. These include lab or group social events, lunch or coffee with students, and social hours with the doctoral students enrolled in a course. Nine (32.1%) interview participants discussed socializing with faculty when they were invited out by the faculty. The conversation topics varied from research to more silly conversations, depending upon the faculty involved. Glenn Blevins described his research group's lunches: "My advisor tends to be about his group, so we go out for lunch every once in awhile. And those conversations tend to be more about physics." Ronan Willis recalled a more silly conversation at a bar with a professor for a course he took:

> I know [we discussed] particularly, really random things. You know the concept of Icing? It's like- it's a beer. You buy a carton and you put bottles all over the persons workplace. When he finds it, he has to chug it. This is one conversation I remember. Completely random, Seinfeld stuff.'

Several other students recalled socializing with this professor in similar capacities and enjoyed conversing with a professor on non-physics matters.

When socializing within the department at departmental events, the doctoral students tend to socialize with one another. These interactions tend to be a way for students to see fellow students they do not see frequently and to keep updated on their lives. They enjoyed knowing how their fellow students are and view these events as the opportunity to talk to others they do not see often. Socializing with faculty does not occur much at these events, because students perceive lack of commonalties or recognize the difference in status between faculty and students. When interactions occur with faculty, they tend to be regarding research.

When faculty invite students to socialize, the conversations are more varied. However, the students do talk to the faculty member who invited them. Particularly when the events are centered around being purely social (e.g., going to a bar) rather a break in the day (e.g., having lunch with an advisor), students tend to speak of the interactions with the professor in more enthusiastic terms.

4.3.9 Outside Department Socializing

Interview participants enjoy a wide-range of activities when they are socializing outside of the university. The participants said that they talk about similar topics when socializing away from the university. If their socializing is centered around an activity or event, they discuss the activity. These conversations tend be more intimate and personal.

Physics or science was not mentioned as a conversation topic. Students mentioned not discussing physics as much, especially when in the company of non-physics doctoral students. Kurt MicKinney explained that non-physics students, who are present when socializing away from the department, are disinterested: "[We discuss] less science. [My non-physics department friends] don't care as much about research and the difficulties of writing code, stuff like that. Whereas my friends from the department, we'll certainly discuss work and that kind of stuff. I try to keep the shop talk to a minimum when I'm with my outside friends."

Seven (25%) participants specifically mentioned opting to not discuss physics or departmental-related matters. Below are three examples:

> I guess people don't like mixing social life with work. I guess people don't like to bring up those kind of stuff, unless its brought up by the other stuff. I always assume that. People come to have fun. They don't want to talk about research. *Laughs - Douglas Cannon*

> It's very fun to talk to a person from the physics department and forget about physics. - *Julie Clarke*

> It inevitably turns to physics... [When] we would come together and there would be an equal number of physicists and significant others. We sort of paired off. You know, like I said, we would turn to physics but we'd be rescued. - *Jacques Booth*

It is interesting to note that although Jacques Booth said he enjoyed physics at a different point in the interview, he described the change of conversation topics as being rescued.

On a whole, students tend not socialize with faculty outside of the university; the survey also demonstrates this. For the few students who do socialize with faculty outside of the department, the conversations they do have tend to be unrelated to physics or science. In the instances they do discuss physics or research, these tend to be brief conversations and when the students see faculty in passing.

In summary, the conversation topics among peers when socializing away from the department to be the same when socializing within the department. These conversations tend to be more personal. Some students mentioned that they purposely avoid discussing physics or research. As indicated by the survey data in 4.2.1, students do not socialize often with faculty or staff outside of departmental events or events organized by faculty. The conversations between students and faculty when socializing outside of the department to be personal and do not involve discussing physics.

4.3.10 Discussion Topics and Support Summary

The interview participants do discuss a variety of topics in their networks for various purposes. Their discussion partners primarily are fellow doctoral students. As demonstrated in section 4.2.1, students do indeed participate in these networks. However, the participation and discussion are quite different depending on the network purpose.

For departmental purposes, the interview participants discuss and enjoy discussing the department. They are under the impression there is little to discuss. Coursework entails discussing how to complete problem sets. Students tended not to discuss teaching with one another. Career and professional advice mainly was mainly updates on fellow students' job searches. For research purposes, the doctoral students tend to discuss more of updates rather than seeking support or help for their research beyond technical issues in computer coding. They would also default to discussing research when socializing within the department. Any discussion during departmental events tends be catching up with fellow students.

While the above types of discussion are less intimate, fellow students do discuss topics more in depth. For those who had crises, they relied on students for moral support for the majority of situations they named as crises. Students discuss a variety of topics when socializing outside of the university; these conversations tend be less catching up and talking about personal maters or interests. The students tend to not discuss physics or their academic life as much. For some, that appears to be an active choice.

Students on a whole did not speak with faculty on any these topics. Most students sought procedural advice from one staff person, Aileen Brewer; they were unsure how to complete tasks such as filing paperwork. They have cultivated a friendly relationship with Aileen, and some are close enough to discuss personal matters with her. Any discussion regarding teaching tended to be meetings set by the professor of the course for which the interview participant was teaching fellow. The interview participants may discuss job prospects with their advisors.

Research discussion takes many forms. When selecting advisors, students chat with prospective advisors about the faculty member's research. Students who sought support from a faculty member when switching advisors received advice on how select an advisor. Postdocs help the doctoral student make progress in research, but they also discuss physics in overall manner. Advisors tend to just discuss the research at hand, but a few discuss broader research skills and information. However, many participants do not talk much with their advisors. Other interactions with other faculty members regarding research tend to be as required by the department's policies; occasionally, other faculty will act as the advisor when the student's advisor is insufficient.

When socializing at departmental events, participants also tend to discuss research. However, they also tend to not talk much with faculty. If a faculty member invites the students to a purely social event such as going to a bar, the student-faculty conversations tend to be less serious. If the meeting occurs during the work day, conversations tend to gravitate towards research. Faculty/staff socializing outside of the department does not occur very often, but when it does, the discussion tends to be more personal and are not related to physics or science.

The satisfaction varied. Because they did not believe there is much to discuss regarding the department, they are fine with the discussion that occurs. The interview participants worked well with their coursework discussion partners; recall that coursework is one of the reasons they named for the formation of their networks in general. All of their questions regarding procedural advice were answered and resolved. They enjoyed catching up with fellow students at departmental events and seeing one another outside of the university.

The students overall were fine with having few conversations regarding teaching; however, some student recognized that teaching advice would be useful. Regarding research, the students' needs were not met for many cases; they had no students or faculty to find the information they desired. The students who had committees were satisfied with the level of involvement with their committees. For career and professional advice, they did not receive the advice they needed for the careers they desired. Lastly, interview participants did not care that they are not socializing with their faculty. The students who did socialize with faculty, either at the university or outside of the university, enjoyed knowing their professors outside of their professional demeanors. Hypothesis #3 is somewhat supported.

4.4 "Does doctoral student participation within the various networks have any relationship to progress in the program and confidence in PhD completion, and if so, what kind of relationship?"

This section examines whether there is any relationship between participating in social networks and variables related to degree completion. Hypothesis #1 states the following: "doctoral students with more ties in research, coursework, and personal support are more likely to complete their PhDs." Survey data contain the following information:

- Estimated or actual time to degree completion
- Seriously considered leaving
- Seriously considered leaving with a master's
- Perceived progress in the physics PhD program, as compared to their peers in the Jonas University physics PhD program

Table 4.28 display the response frequency for these variables. All fifty-five survey participants answered these questions. "Leaving" and "Seriously considered leaving" responses for the questions pertaining to leaving the program or leaving with a master's were collapsed for each question. No survey participants selected the response, "Leaving without a master's."

Network attributes were examined to see how they are related to the attrition and progress variables. These data includes only the survey participants' responses, because outcome variables are not available for non-participants. Regression was done for estimated or actual time to degree completion; estimated time to degree

Table 4.28: Frequencies on confidence in PhD completion and perceived progress

Leaving the PhD Program	
	Frequency
Did Not Consider Leaving	33
Somewhat Serious Considered Leaving	11
Seriously Considered or Am Leaving	11

Leaving With a Master's	
	Frequency
Always Planned PhD	35
Somewhat Seriously Considered	12
Seriously Considered or Am Leaving	8

Perceived Progress in Program, Compared to Peers	
	Frequency
Cannot Rate Progress	4
Slower Progress	18
Same Progress	27
Faster Progress	6

completion was provided by survey participants who had not completed their degrees during the survey period, while actual time to degree completion was provided by survey participants who had already graduated. These data analysis techniques are further discussed in section 3.4.4.

Variable labels are as follows: C is for career, K is for crisis, P is for procedural, G is for departmental information, R is for research, I is for socializing within the department, and O is for socializing outside of the department. The subscripts indicate the the network attribute and are as follows: "Out" is for ties the participant selected, "WOut" is for weighted ties the participant selected, "In" is for ties directed to the participant, "WIn" is for weighted ties directed to the participant, and "Btwn" is for betweenness centrality. The coefficients on the betweenness centrality variables are larger than the other variables, because the betweenness centralities are less than 1.

4.4.1 Peer Ties

Fisher's exact tests for exiting the PhD program and tie categories yielded no statistically significant p-values. For leaving with a master's, only departmental information network for in-ties yielded a statistically significant $p \leq 0.05$. The complete ontingency table is displayed in table 4.29.

The combination of "Somewhat Seriously Considered Leaving" and "Seriously Considered or Am Leaving", with the columns as 1 to 5 ties and 6 to 10 ties, is significant for $p \leq 0.05$. The odds ratio for this combination is 18.5. This suggests that survey participants who somewhat seriously considered leaving are almost 19 times more likely to have 6 to 10 ties than those who seriously considered or are leaving. In this context, those who are somewhat seriously considered leaving with a master's have more ties than those who seriously considered or are leaving with a master's.

Table 4.29: Contingency table for leaving with a master's

	0 ties	1 - 5 ties	6 - 10 ties	11+ ties
Always Planned PhD	1	10	12	12
Somewhat Seriously Considered	1	2	8	1
Seriously Considered or Am Leaving	0	6	1	1

The results for "Somewhat Seriously Considered" and "Seriously or Am Leaving" for 1-5 ties and 6-10 ties from this contingency table are significant ($p \leq 0.05$).

The tie categories were further aggregated to determine if persistence in the PhD program was related to having at least one tie. Both leaving the program and leaving the program with a master's were analyzed using Fisher's exact test for each network purpose. None of the results are statistically significant.

Multiple regression was used to determine if and how the number of ties (in and out), the weighted ties (in and out), and betweenness centralities relate to time to degree. Because not all participants were enrolled in courses or were teaching, those variables were not included in the regression model.

Thirty-five variables were entered as a backwards elimination regression, meaning that the variables were iteratively removed in order to optimize the model; when two models had the same p-value, I selected the model with the fewest variables. The correlation coefficient for this model is 0.397; r^2 is 0.158, meaning that the model explains 16% of the variance in response. This model's variables are significantly related, $F(1, 51) = 9.36$ at $p \leq 0.01$. The regression model for time to degree, T_{Deg}, in years is below:

$$T_{Deg} = 6.66 - 0.344 I_{WOut} \tag{4.1}$$

where I_{WOut} is for socializing within the department, weighted out-ties. Equation 4.1 suggestions that if one has no social ties related to socializing within the department, she or he will take approximately 7 years to complete the degree. The model has limitations; otherwise, someone with a large number of ties would be able to graduate in no time.

For perceived progress, Fisher's exact test was run for the aggregate categories of ties for each network purpose and the user response for perceived progress. None are statistically significant.

4.4.2 Faculty and Staff Ties

Faculty by prestige ranking, research scientists, post-docs, and staff were all considered as separate entities in this analysis. Weighted ties were disregarded, because the majority of weighted network ties had a weight of 1. None of the Fisher's exact tests yielded statistically significant p-values for the following: lower prestige faculty, post-docs, research scientists, and typical prestige faculty. For higher prestige faculty, the distribution for teaching-related reasons and consideration of leaving with a master's was significant for $p \leq 0.05$. Table 4.30 displays these data. In this network, the percentage of survey participants who considered leaving the program with a master's is higher than those who always planned on completing their doctorates. None of the pairings are statistically significant.

Table 4.30: Contingency table for leaving the PhD program with a master's for networks involving higher prestige faculty ties in the teaching network

	0 ties	1 - 5 ties
Always Planned PhD	14	3
Somewhat Seriously Considered	3	4
Seriously Considered or Am Leaving	1	3

The p-value is less than 0.05; none of the pairings are statistically significant.

For staff, three contingency tables have statistical significance. One is for the teaching network, and the other is for the research network. Table 4.31 displays the data for these networks. The teaching network was significant for leaving the PhD program ($p \leq 0.01$) and leaving with a master's ($p \leq 0.05$). The "Did Not Consider Leaving" and "Seriously or Am Leaving the PhD Program" have statistically significant difference. "Did Not Consider Leaving" and "Seriously or Am Leaving with a Master's" also have a statistically significant difference. For research staff ties and considering leaving the program with a master's, the distribution was significant for p-value is ≤ 0.05.

The distribution of responses for "Did Not Consider Leaving" and "Seriously or Am Leaving the PhD Program" is statistically significant for $p \leq 0.05$. The odds ratio is 12.5. This indicates that students who did not consider leaving are 12.5 times more likely to not have any staff ties for teaching than students who seriously considered or are leaving. For leaving with a master's, the distribution for "Did not consider leaving" and "Seriously or am leaving with a master's" is statistically significant for $p \leq 0.05$. The odds ratio is 31.5. This suggests that students who did not consider leaving are 31.5 times more likely to not have any staff ties for teaching than students who seriously considered or are leaving with a master's. For research-related reasons, the distribution is significant for $p \leq 0.05$. None of the pairings are statistically significant.

Table 4.31: Contingency table of staff-student interaction on how seriously the survey participants considered leaving the doctoral program

Leaving the PhD Program: Teaching		
	0 ties	1 - 5 ties
Did Not Consider Leaving	15	2
Somewhat Serious Considered Leaving	4	1
Seriously Considered or Am Leaving	2	4

Leaving With a Master's: Teaching		
	0 ties	1 - 5 ties
Always Planned PhD	16	1
Somewhat Seriously Considered	4	3
Seriously Considered or Am Leaving	1	3

Leaving With a Master's: Research		
	0 ties	1 - 5 ties
Always Planned PhD	35	0
Somewhat Seriously Considered	10	2
Seriously Considered or Am Leaving	7	1

For terminating with a master's, the teaching network was significant for $p \leq 0.01$ and research for $p \leq 0.05$. For leaving the doctoral program, the teaching network was significant for $p \leq 0.05$.

The percentages of survey participants who considered leaving the program, either generally or terminating with a master's, and talked to staff regarding teaching is higher than the percentages of students who did not consider leaving the PhD program and have no staff contacts regarding teaching. Similarly, the percentage of survey participants who considered leaving the program with a master's and talked to staff regarding research is higher than the percentage who did not talk to staff regarding research and did not plan on leaving the program.

Data were also examined as ranking independent, meaning that data were examined by how many ties one had to a faculty, research scientist, post-doc, or staff member. None of those results yielded a significant p-value when Fisher's exact tests was run. Data were then further aggregated to either having at least one faculty, research scientist, postdoc, or staff contact. Only the in departmental socializing network has statistical significant for leaving the doctoral program ($p \leq 0.05$).

Table 4.32 show these data. The highest percentage of students who had at least one contact were in the "Somewhat Seriously Considered Leaving the Doctoral Program" category. The majority of students who considered leaving have at least one contact with faculty or staff for socializing within the department, while four having none. The distribution for those who did not consider leaving and seriously considered or are leaving is statistically significant for $p \leq 0.001$. The odds ratio indicates that those who did not consider leaving are 7.86 times more likely to have at least one tie for socializing within the department.

Table 4.32: Contingency table for faculty/staff and student connections for socializing within the department

	0 ties	1+ ties
Did Not Consider Leaving	8	25
Somewhat Seriously Considered	4	7
Seriously Considered or Am Leaving	8	3

This contingency table displays the response to this question with consideration to whether the participant had at least one faculty, staff, research scientist, or postdoc connection in the in departmental socializing network. The p-value is less than 0.05.

Multiple regression analysis was conducted for these data by faculty prestige ranking. Only the number of ties were considered, because weighted ties typically have a weight of 1. Staff ties were included. Due to low numbers, research scientists and post-docs were not considered in these models. Again, variables were analyzed through backwards elimination regression.

For higher prestige, typical prestige, and staff, none of the regression models were found to be statistically significant. Only lower prestige faculty had regression models that were statistically significant; the model presented has the lowest p-value. The correlation coefficient for this model is 0.47; r^2 is 0.230, meaning that the model explains 23% of the variance. This model is significant related, $F(4,\ 47) = 4.52$ ($p \leq 0.05$). The regression model for time to degree, T_{Deg}, in years is below:

$$T_{Deg} = 6.30 - 0.804C_{LF} + 0.246C_{WLF} - 0.860O_{WLF} - 0.663R_{WLF} \quad (4.2)$$

where C represents career, O represents outside of the university socializing, and R represents research. The subscript LF is for lower prestige faculty and WLF is for weighted in-ties, lower prestige faculty.

4.4.3 Mentor Ties

Fisher's exact test was run on the perceived progress variable and attrition variables, looking at whether the survey participants identified at least one mentor. The number of mentor ties was regressed for the time in program. There is no statistically significant relationship found using either Fisher's exact test or the regression.

4.4.4 Summary

Quantitatively, the majority of these ties do not make a difference in time to degree, attrition, or perceived progress. For peer networks, only the departmental information network yielded significant p-values for the Fisher's exact tests. The combinations that are significant are the students who did not consider leaving and students who seriously consider or are leaving.

Teaching networks yielded significant p-values for student-staff and student-higher prestige faculty. When not considering ranking of faculty and staff, the departmental information network yielded a significant p-value. Having at least one mentor has no significant relationship to time in program, attrition, or perceived progress.

The only regression models for time to degree that are statistically significant are for peer networks and for lower-prestige faculty. Many of the network attribute variables are not included in either model. Weighted ties are the most frequently included network attribute variables.

4.5 "Do the responses to any of these questions vary by gender, race/ethnicity, student type (U.S. domestic or international), year in program, undergraduate institute type, relationship status, subfield, or research type (experimental or theoretical)?"

This research question answers the following hypotheses: hypothesis # 5, homophily in peer networks; hypothesis #6, homophily in student-faculty/staff networks; and hypothesis #10, which states that these demographic variables will produce differences for the network attributes.

The analyses conducted in sections 4.2, 4.3, and 4.4 were repeated in this section, now with respect to various demographic considerations. Because the *t*-tests yield statistically significant differences between survey participants and non-participants, only participant data are included. Non-participants are present in the data only when selected by survey participants. For example, suppose Devon took the survey but Chuck did not. If Devon selected Chuck as a tie, Chuck counts as one Devon's out-ties. However, Chuck would not be used in any other data such as in-ties.

The network attributes examined are in-ties, out-ties, weighted in-ties, weighted out-ties, and betweenness centrality. Only statistically significant data are presented in the following sections. For the coursework and teaching networks, only those who took course or those who taught are included in the comparison groups. Due to the low number of survey participants with committee members, committee member data are not analyzed in the following sections.

Homophily and reciprocity were analyzed for each category. The total number of reciprocated ties, Ξ for each survey participant was found. Homophily was calculated using equation 3.3 to find the correlation coefficient Ψ for each group, such as men.

Recall that homophily is on a scale from -1 to 1, where -1 is 100% heterophilous and 1 is 100% homophilous; a value of 0 on this scale indicates a proportionately representative group.

A t-test, ANOVA, or Welch's test were used to compare the demographic groups for each network purpose for homophily and reciprocity. These tests have different degrees of freedom (d.f.), due to some participants not having ties in this network and not all demographic information being available.

The regression models in this section used backwards elimination, similar to section 4.4. Variable labels are identical to the previous section and are as follows: C is for career, K is for crisis, P is for procedural, G is for departmental information, R is for research, I is for socializing within the department, and O is for socializing outside of the department. The subscripts indicate the the network attribute and are as follows: Out is for ties the participant selected, $WOut$ is for weighted ties the participant selected, In is for ties directed to the participant, WIn is for weighted ties directed to the participant, Deg for degree centrality, and $Btwn$ is betweenness centrality. The coefficients on the betweenness centrality variables are larger than the other variables, because the betweenness centralities are less than 1.

All regression models examined categorical variables using two methods. One method introduced the demographic variable into the regression equation. For example, gender was introduced into the regression model as a variable. These categorical variables received dummy codes, which are described in each subsection. The second method selected cases by category and then performed the regression. Using gender as an example again, regression was run on the data only for men and then run only for women.

4.5.1 Gender

Survey participants identified as either male or female; no participants identified as transgender, genderqueer, or non-binary gender. Twelve participants identified as female, and forty-three participants identified as male.

Peer Networks

While female and male interview participants shared many commonalities regarding their social network formation, two women specifically mentioned network formations with other women. Racquel Christensen explained why: "The girls in my year kind of bonded over that, being a minority, so I got be good friends with the girls my year."

Two other female interview participants mentioned not being particularly interested in having female friends outside of the physics department. These two participants drew a distinction between women in physics and women in other STEM disciplines. Letitia Lindsey said she is not a part of the graduate STEM women's group, because "there are too many women." She noted that would be more likely to spend time with the women in physics group. Julie Clarke noted she typically has not had many female friends in the past, noting that:

> I'm not girly enough. *Laughs* I don't like to do girly stuff so- [*She was asked to define "girly stuff"*] Oh, like "Let's meet and get our hair done." No. Or- that's how things went. Or the types of conversation people would have. The thing is I wouldn't get involved with girls who weren't in the physics department, because I never felt like I was having a good conversation with them or the interests were different.

Julie prefers having male friends because of how they handle issues in their lives. She explained that "they don't have crisis, there's not crying, which are things I don't like."

In terms of social activities, there were no clear differences among men and women described by the majority of participants. However, one interview participant observed differences in how men and women socialize in the department. Margot Cherry observed that among female physicists, they talk about women in physics issues. She notes she tend to go out for beer with men, whereas she tends to have coffee with women.

Only one participant selected no other student on the survey. This is a female participant. However, she was selected by other survey participants. In section 4.2, I noted that twenty-one participants selected themselves as discussion partners or sources of advice on the survey. This did not appear to be a mistake, as these participants did not select themselves for every question. They also assigned a frequency of contact to themselves. The female participant who selected no other students selected herself on the survey; the other twenty participants who selected themselves are male students. These twenty male participants have varying numbers of alter nodes.

T-tests were run to compare female and male survey participants for each network purpose, as well as for the multiplex network and total number of mutual ties. The only peer network where the gender difference was statistically significant is the coursework network and only for weighted in-ties. The t-test result is $t(31) = 2.22$, $p \leq 0.05$, with women having a larger mean of weighted in-ties (23 ± 15) than men (12 ± 10). Six women and twenty-seven men enrolled in at least one course during the 2012-2013 academic year.

Figure 4·25 features the sociogram for the course network. The color coding is as follows: pink is for female survey participants who took at least one course; navy blue is for male survey participants who took at least one course; light shell pink is for female non-participants; light blue is for male non-participants; burgundy is for female survey participants who did not take course; steel blue is for male survey participants who did not take a course. Black lines indicate reciprocal ties.

The majority of female participants who took at least one course are concentrated in the lower left group. For four of these female participants in this group, five of the ties are reciprocal. One male participant has no ties in this network, meaning he did not select anyone and no one selected him for coursework-related reason.

Gender homophily was analyzed by calculating the correlation coefficient Ψ and comparing the coefficients via t-tests for each purpose. These data are displayed in table 4.33. The correlation coefficient for women is denoted as Ψ_F and for men as Ψ_M.

What is striking is that the homophily correlation coefficient for women, Ψ_F, is approximately 0.1 for eight of the nine purposes; for the ninth purpose, socializing within the department, Ψ_F is approximately 0.2. For men, Ψ_M is approximately

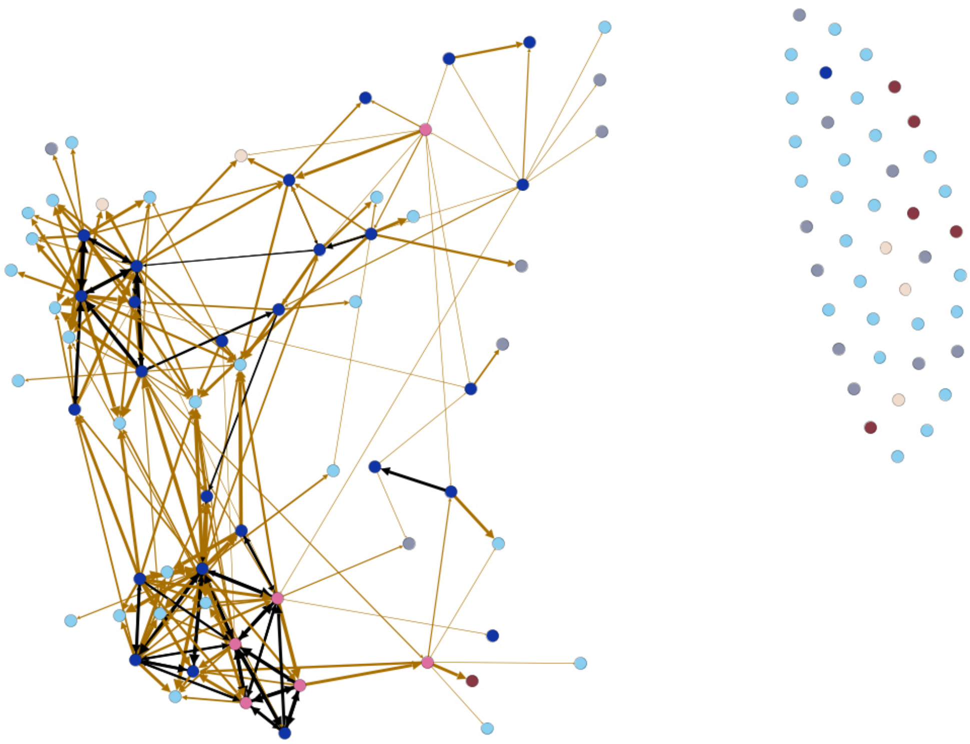

Figure 4·25: Sociogram depicting with whom students talk about course-related matters, color-coded by gender. The color coding is as follows: pink is for female survey participants who took at least one course; navy blue is for male survey participants who took at least one course; light shell pink is for female non-participants; light blue is for male non-participants; burgundy is for female survey participants who did not take course; steel blue is for male survey participants who did not take a course. Black lines indicate reciprocal ties.

0 for five of the nine purposes (departmental information, procedural, crisis, and socializing outside of the department). Men are slightly homophilous for coursework and research. Men are slightly heterophilous for career and socializing within the department; this is statistically different from women. This suggests that while female physics doctoral students tend to form more homophilous networks, regardless of purpose, male physics doctoral students tend to have more varied patterns in their network formation. The more social purposes tend to be more of a representative mix of genders, while the more work-oriented purposes (procedural, coursework, research, teaching, career) tends to be slightly homophilous or heterophilous.

Table 4.33: Homophily t-test results for the gender variable

	Female Ψ_F	Male Ψ_M	t(d.f.)
Dept. Info	0.103 ± 0.09	-0.00671 ± 0.1	2.51(50)*
Procedural	0.0918 ± 0.2	-0.00136 ± 0.1	1.77(12)[1]
Coursework	0.0970 ± 0.1	0.0272 ± 0.1	1.20(26)
Teaching	0.132 ± 0.2	0.000837 ± 0.1	1.20(3)[1]
Research	0.0622 ± 0.09	0.0102 ± 0.1	1.47(45)
Career	0.0939 ± 0.1	-0.0105 ± 0.08	3.31(37)**
Crisis	0.0887 ± 0.1	0.00441 ± 0.09	2.44(45)*
In Dept. Social	0.150 ± 0.09	-0.0105 ± 0.08	3.71(43)**
Out Dept. Social	0.133 ± 0.1	-0.00755 ± 0.1	3.61(46)**

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Not all of these differences between male and female homophily coefficients are statistically significant. All of the more social purposes (crisis, departmental information, socializing within the department, socializing outside of the department) and career purposes show statistically significant differences between the men's homophily correlation coefficient, Ψ_M, and the women's homophily correlation coefficient, Ψ_F. This suggests that there is something unique to how women and men form more socially-oriented networks. The counts for teaching and procedural reasons may be too small for an observable difference. The lack of statistical difference for coursework and research, however, suggest that men and women tend to be homophilous for these purposes.

Reciprocity was examined to determine whether there are any differences between the number of mutual ties men have and the number women have. There are no statistically significant difference between men and women for the number of mutual ties.

Faculty and Staff Networks

Male and female interview participants formed networks with faculty and staff in similar ways, such as meeting faculty in class or approaching staff to complete paperwork. One female participant specifically mentions socializing with female faculty, who invite her out to chat. While male students ranged in no interest to wanting to socialize with the faculty, the five female interview participants enjoyed having chances to socialize with faculty. There were no trends between genders in selecting advisors or committee members. Fisher's exact test indicates there are no gender differences in whether one has a person he or she considers to be a mentor.

Participants discussed the same topics and matters, regardless of gender. However, nine (40%) of the male interview participants discussed departmental matters with me as a critique of how the faculty runs the department; only one female participant did. Below are four quotes to exemplify these conversations:

> For instance, people, uh, there's a- we do a written exam and we do a preliminary oral exam. The preliminary oral is- some people have it inflated in their minds that you have to do a lot of research to do that exam when in fact the requirements are quite low. You don't even have to do any research, although it's encouraged to do some. The formal requirements were not that stringent. But people started pushing it off a little bit because they were nervous. And they were being allowed to do it. And because they pushed it off, they had a better quality- they gave a better quality presentation, because they had more research. And then the professors come to expect better quality, because they themselves aren't reading the formal requirements and now- so it's almost a self-fulfilling prophecy. - *Orien Barr*

> I think the department needs to give more guidelines about research. and because I think, when you get into the program, it takes literally 5-6 years to graduate. But during those 5-6 years, they didn't give you a review every year. They made comments every now and then and some people finished in 5 years, but it's not that often. There isn't a lot of pushing to do this or that. People stay there for 4 years and then you have 1 year to graduate. They rush you to do everything. To take your exams,

> to do research, to prepare for the final exam. Um, in that sense, the department could do better to talk to students and keep them on track. - *Keagan Weaver*

> [The department] really, despite its best intentions, doesn't have the grad students' best interest at heart as much as they could. Sort of support for us, guidance for us Career support but finding an advisor... I have a lot of friends who are in various life sciences PhD programs where they all do rotations. I know there are various administrative reasons for why that wouldn't work here, but it's still frustrating when I hear one of my close friends go, "I got to do research with 4 of my professors, and I got to give talks on all of it! Now I really know what my options are, and I know all these things." I think that's an example where we're often not given the support we could be. And this is a common topic of interest among graduate students when we're talking about the department, the fact that they seem to really be doing things to frustrate us. Also, the comps, which they really seem to be doing to frustrate us. And that happens when there are open meetings with the chair, which have resulted in interesting programs. - *Lysander Barber*

> In the [time] I've been here, the social aspects in the department have improved. When I started, there were very few social activities going on. The number of activities increased and the number of people participating increased. I think people like being more social in the department. Umm, I think the faculty members have done a good job of supporting that. - *Kurt MicKinney*

Percentage-wise, male and female students are comparable in voicing their concerns to faculty. Four male students (17.4%) mentioned discussing departmental matters with the faculty, including the department chair. These concerns include policies such as the ones discussed regarding exams or social support for incoming doctoral students. One female participant (20%) mentioned she had a conversation with the chair regarding the lack of a common meeting area.

Four of the five (80%) female participants expressed that they have had concerns regarding their progress in the doctoral program at least once during their time in Jonas University. For three of the participants, this appears to be their perception of whether they are capable of completing the degree. Faculty had not expressed concerns to them nor were there other signs such as not completing comprehensive exams.

Table 4.34: Statistically significant network attributes for the student-faculty/staff network, by gender

	Women	Men	t(d.f.)
Career, HF	3 ± 3	1 ± 1	2.44(12)*
Crisis, HF	1 ± 1	0 ± 1	2.23(53)*
Social. In. Dept., HF	6 ± 6	0 ± 2	58(12)*
Social. In. Dept., TF	7 ± 7	2 ± 4	3.01(53)**
Multiplex	9 ± 5	7 ± 4	2.09(53)*
Multiplex, W. Out	56 ± 43	36 ± 23	2.20(53)*

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

In terms of analyzing the network interactions quantitatively, gender differences are statistically significant for six network attributes regarding faculty/staff interaction with the survey participants. Three of these six attributes involve higher prestige faculty. Table 4.34 displays these results. For these data, women have higher values for each attribute than men. This indicates that the female doctoral students have more contacts and more frequent contact with higher prestige faculty.

Figure 4·26 displays the sociogram of the socializing within the department data. The color coding for faculty, research scientists, postdocs, and staff is the same as in the previous sociograms. Dark blue nodes are male survey participants, and pink nodes are female survey participants. Although female survey participants on a whole have more ties and more frequent contact with faculty, research scientists, etc., not all female survey participants are in this network. The women who are in this network

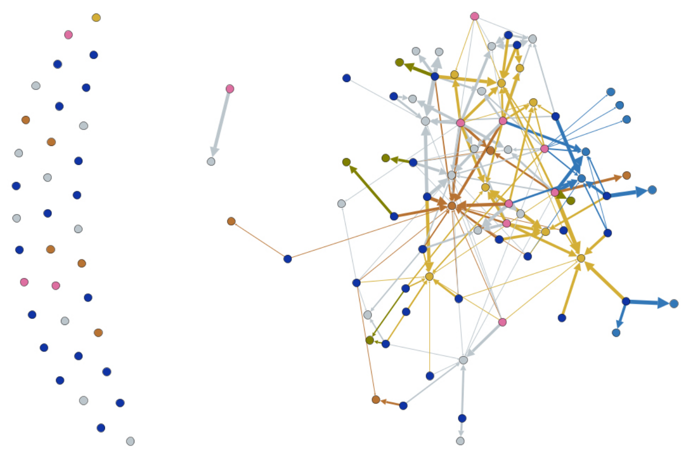

Figure 4·26: Sociogram depicting faculty, research scientist, postdoc, and staff contacts for socializing within the department, color coded for the survey participants' gender identities. The gender differences for the ties to higher and typical prestige faculty is significant.

are quite integrated.

Regression

Regression was examined in two ways. One method introduced gender as a variable in the regression model. Gender was coded as 0 for male survey participants and 1 for female survey participants. The second method entailed selecting only one gender's cases and then creating a regression model. Thirty-five variables were entered and then were removed to optimize the regression model involving the peer network attributes. Gender as a variable yields no statistically significant models.

When considering female and male participant data separately, several statistically significant regression models were found. For male participants, four regression models were found to be statistically significant. One model includes the peer network attribute variables:

$$\begin{aligned} T_{Deg} = 8.86 - 0.545C_{In} - 0.336C_{Out} + 2.03C_{Win} - 0.2899K_{Out} \\ - 0.172K_{WIn} + 80.4K_{Btwn} + 1.11P_{WOut} + 125P_{Btwn} \\ - 1.20G_{WOut} + 0.573R_{Out} - 3.24R_{WOut} + 26.6R_{Btwn} \\ + 0.0770I_{Out} - 161I_{Btwn} - 0.209O_{Out} + 50.0O_{Btwn} \end{aligned} \quad (4.3)$$

This model is significant for $F(16,\ 23) = 3.45$, $p \leq 0.01$. The correlation coefficient is 0.848; r^2 is 0.719 meaning that the model accounts for 72% of the variability among male participants. This model includes both variables related to social purposes (departmental information, crisis) and variables related to academic/professional purposes (research, procedural).

Three models are significant for faculty interaction with male survey participants. One is for lower prestige faculty. This model is as follows:

$$T_{Deg} = 5.99 - 0.009C_{LFW} \quad (4.4)$$

This model is significant for $F(1,\ 39) = 5.58$, $p \leq 0.05$. The correlation coefficient is 0.354; r^2 is 0.125, meaning that the model accounts for 13% variability. For typically ranked faculty, the regression model is as follows:

$$T_{Deg} = 6.16 - 0.691G_{TFW} \quad (4.5)$$

This model is significant for $F(1,\ 39) = 4.34$, $p \leq 0.05$. The correlation coefficient is 0.313, r^2 is 0.098, meaning that the model accounts for 10% of the variability.

When considering all the faculty/staff interactions with male students, the following regression model was produced:

$$\begin{aligned} T_{deg} = 6.16 - 0.15C_{LFW} + 3.37R_{LFW} - 0.029R_{LFW} - 0.007C_{HFW} \\ + 1.44K_{HF} + 0.011I_{HFW} - 1.17P_{HF} - 0.753R_{HFW} \\ - 2.85C_S + 0.039C_{SW} - 0.14I_{SW} - 2.96O_S \end{aligned} \quad (4.6)$$

where the subscript S stands for staff and SW for staff, weighted out-ties. This model is significant for $F(12,\ 28) = 4.502$, $p \leq 0.05$. The correlation coefficient is 0.720; r^2 is 0.518, meaning that the model accounts for 52% of the variability. The majority of these variables are related to academic/professional purposes.

For female participants, none of the variables were statistically significant for peer interactions. For interactions with faculty, only connections involving higher ranked faculty were significant. One variable remained in the one statistically significant model. This regression model for women interacting with higher ranked faculty is as follows:

$$T_{deg} = 7.77 - 0.019C_{HFW} \tag{4.7}$$

This model is significant for $F(1,\ 9) = 5.66$, $p \leq 0.05$. The correlation coefficient is 0.621; r^2 is 0.386, meaning that the model accounts for 39% of the variability.

4.5.2 Race/Ethnicity

Race/ethnic identity was examined in two ways. The first method involved using the following race/ethnic categories: White, Asian (South and East Asian), and "Other Non-White" (Hispanic, Latino, Black, and Middle Eastern). The last category was created due to low counts for the respected ethnicities. Thirty-two survey participants are considered White, sixteen Asian, and seven Other Non-White.

The second method had only two categories: White and "Non-White." The Non-White category included South Asians, East Asians, Hispanic, Latino, Black, and Middle Eastern identifying survey participants. Thirty-two survey participants are considered White, while twenty-three participants are Non-White. The categorization is further discussed in section 3.4.4.

The interview participant breakdown is as follows: twenty White, two Other Non-White, six Asian. For the binary race category, there are eight Non-White participants.

Peer Networks

There were no differences in how interview participants described peer network formation, nor were there any differences in conversation topics or activities. Race/ethnicity as a topic was absent from all interviews. However, four Non-White participants (50%) did mention being closer to their friends outside of the department and how these outside connections were important forms of social support; for at least two of the interview participants, these friends outside of the departments are of the same race/ethnicity.

For the first method, ANOVAs and Welch's test were run to determine if any differences exist among the three categories' network attributes in the survey participants' peer networks. No statistically significant difference was shown for any of the network attributes.

T-tests were run on network attributes for each network purpose using the binary race/ethnicity categories. The only network attribute that is statistically significant is the number of out-ties for crisis purposes. White participants selected 6 ± 5 fellow students they named for crisis contacts, while Non-White participants selected 3 ± 3. The difference between the two group is significant for $t(53) = 2.07$, $p \leq 0.05$.

Table 4.35: Homophily ANOVA or Welch's test results for the more specific race/ethnicity variable

	Asian Ψ_A	Other Non-White Ψ_{ONW}	White Ψ_W	F(d.f.)
Dept. Info	0.100 ± 0.2	0.151 ± 0.1	0.0957 ± 0.1	0.474(2, 49)
Procedural	0.106 ± 0.1	0.0416 ± 0.2	0.0575 ± 0.09	1.15(2, 37)
Coursework	0.00134 ± 0.1	-0.125 ± 0.1	0.187 ± 0.3	3.67(2, 27)*
Teaching	-0.0273 ± 0.1	0.189 ± 0.2	0.0533 ± 0.08	3.50(2, 18)
Research	0.0400 ± 0.1	-0.0398 ± 0.04	0.0513 ± 0.1	1.42(2, 43)
Career	0.0619 ± 0.2	0.167 ± 0.2	0.107 ± 0.09	0.623(2, 5)[1]
Crisis	0.0547 ± 0.1	0.110 ± 0.1	0.0706 ± 0.1	0.318(2, 46)
In Dept. Social	0.104 ± 0.2	0.193 ± 0.1	0.0739 ± 0.1	2.38(2, 44)
Out Dept. Social	0.193 ± 0.2	0.0651 ± 0.1	0.132 ± 0.2	3.61(2, 45)*

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Welch's test used

Homophily was examined for the more specific race/ethnicity categories. The correlation coefficients are as follows: Ψ_A for Asian students, Ψ_{ONW} for Other Non-White students, and Ψ_W for the correlation coefficient for White students.Table 4.35 displays these data. For each purpose, either an ANOVA or Welch's test was used to compare the race/ethnicity categories. Coursework and socializing outside of the department has statistically significant differences for homophily among the three race/ethnicity categories. None of the race/ethnicity pairings had a statistically significant difference for coursework. Post-hoc Tukey tests reveal that Asian survey participants each have a statistically significant difference with White survey participants for homophily in the socializing outside of the department network ($p \leq 0.05$).

Ψ_W is approximately 0.1 for all network purposes. This suggests that White students are slightly homophilous. This is different from Asian and Other Non-White students who do not have the same trend in homophily. Ψ_A is slightly heterophilous for teaching purposes and a representative mixture for coursework purposes. Ψ_{ONW} is slightly heterophilous for coursework and research. The results suggest that racial/ethnic homophily occurs at a higher frequency when one race/ethnicity is well-represented as it the case for White survey participants.

Table 4.36: Homophily t-test results for the binary race/ethnicity variable

	Non-White Ψ_{NW}	White Ψ_W	t(d.f.)
Dept. Info	0.0727 ± 0.2	0.0957 ± 0.1	0.485(49)
Procedural	0.0678 ± 0.1	0.0575 ± 0.09	0.121(37)
Coursework	0.0823 ± 0.1	0.187 ± 0.3	0.635(27)
Teaching	-0.000339 ± 0.1	0.0533 ± 0.08	0.959(18)
Research	0.0446 ± 0.1	0.0513 ± 0.1	0.160(43)
Career	0.0691 ± 0.2	0.107 ± 0.09	0.832(21)[1]
Crisis	0.0661 ± 0.1	0.0706 ± 0.1	0.181(46)
In Dept. Social	0.0851 ± 0.2	0.0739 ± 0.1	0.326(44)
Out Dept. Social	0.135 ± 0.2	0.132 ± 0.2	1.75(45)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Race/ethnicity homophily for the binary race variable was also analyzed by finding the the correlation coefficient Ψ_{NW} for Non-White survey participants. Ψ_W was compared to Ψ_{NW} via t-tests for each purpose. These data are displayed in table 4.36 for the binary categories.

None of the networks purposes have significant difference between Non-White and White survey participants. For the majority of categories, each group's correlation coefficient is approximately 0.1. This means they are slightly homophilous. Non-White survey participants have a proportionately mixed group of network ties for teaching; this is the only category where Ψ_{NW} is 0.

The average number of reciprocated ties among the categories for race were compared. For the more specific categories, there were no statistically significant differences for the majority of categories. The career category did not have an adequate N of the race categories.

The same analysis was also ran on the binary race data. Table 4.37 displays these data. White students have more reciprocated ties for the career and crisis networks than the Non-White students. The results for these networks are statistically significant.

Table 4.37: Reciprocity t-test results for the binary race variable

	Non-White Ξ_{NW}	White Ξ_W	t(d.f.)
Dept. Info	3 ± 3	4 ± 3	1.52(49)[1]
Procedural	0 ± 1	0 ± 1	0.380(53)
Coursework	2 ± 2	2 ± 2	0.119(31)
Teaching	1 ± 1	1 ± 1	0.168(26)
Research	1 ± 1	1 ± 1	2.07(53)
Career	0 ± 1	1 ± 1	2.57(43)[1]*
Crisis	1 ± 1	2 ± 2	2.58(49)[1]*
In Dept. Social	3 ± 4	5 ± 4	1.39(36)[1]
Out Dept. Social	2 ± 2	3 ± 2	1.48(53)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Faculty and Staff Networks

Interviews did not reveal any racial/ethnic differences in how student connect with faculty and staff. The conversation topics and relationships with faculty and staff are all similar.

Quantitatively, three network attributes have statistically significant differences for the non-binary race/ethnicity method. Welch's test shows that weighted out-ties socializing within the department with lower prestige faculty ($F(2,\ 28) = 4.87$, $p \leq 0.05$) and research out-ties to higher prestige faculty ($F(2,\ 28) = 6.73$, $p \leq 0.01$) are statistically significant. Post-hoc Games-Howell tests show no significant differences for any of the pairings for socializing in the department with lower prestige faculty. For higher prestige faculty out-ties, White survey participants have more ties (2 ± 3) than Other Non-White (0 ± 1). This difference is significant for $p \leq 0.01$. Staff socializing outside of the department is statistically significant for $F(2,\ 52) = 3.29$, $p \leq 0.05$. A post-hoc Tukey tests reveals that the difference between Asians (1 ± 1) and Non-whites (2 ± 1) is statistically significant for $p \leq 0.05$.

Regression

Regression was done for time to degree for both the binary race/ethnicity and the more specific race/ethnicity categories. Two different methods were used for each variable; one method introduced the race/ethnicity variable into the regression as a dummy variable. The second method entailed selecting cases by race/ethnicity for each regression performed. For the binary race variable, race was coded as 0 was for White survey participants and 1 for Non-White participants. For the other race variable, two dichotomous variables were created; one variable is "Asian" and the other is "Other Non-White." The regression model used backwards elimination, similar to section 4.4.

The regression models for peer network attributes were not statistically significant for any combination of the race/ethnicity variables and the two methods. For student-faculty/staff network attributes, one regression model is statistically significant. The following model is for Other Non-White survey participants and their interactions with typical prestige faculty:

$$T_{Deg} = 6.12 - 0.265K_{TF} + 4.67K_{TFW} - 0.956G_{TF} - 3.95O_{TF} - 2.75R_{TFW} \quad (4.8)$$

This model is significant for $F(5, 10) = 6.79$, $p \leq 0.01$. The correlation coefficient is 0.879, and r^2 is 0.773. This means that the model explains 77.3% of the variance. The majority of variables are related to social purposes.

4.5.3 Student Type (U.S. Domestic or International)

Survey participants identified themselves as either U.S. domestic or international students. Twenty-nine survey participants are international students, and twenty-six are U.S. domestic. Of the interview participants, nineteen are U.S. domestic students and nine are international students.

Peer Networks

There is one small difference in network formation of international students, compared to U.S. domestic students. Two international students mentioned meeting some of their friends during the international student orientation. However, they still noted having friends who are not international students.

Five U.S. domestic students noted differences between international students and themselves that may hinder their interactions with international students. Malcolm Rollins summarized potential connection formation issues with international students:

> One communications issue that comes up frequently is it's often hard to communicate with international students. There's the language barrier is somewhat difficult. I sometimes have a hard time with people's accents. But bigger than that is the cultural issue. You don't have the same cultural background. I use a lot of sarcasm but that doesn't translate well. It often doesn't work well for people who aren't Americans.

Other participants noted differing interests and perspectives on topics, such as sports or politics, can hinder conversation.

T-tests were run on all network attributes, comparing international students to U.S. domestic students. There is no statistically significant difference for the number of mutual ties U.S. domestic and international students have. The only attribute that has a statistically significant difference is weighted in-ties for coursework purposes. The value of U.S. domestic students' weighted in-ties is 9 ± 8, while international students' is 20 ± 13. Equal variance could not be assumed. This difference is significant for $t(23) = 2.71$, $p \leq 0.05$.

Table 4.38: Homophily t-test results for the student type variable

	International Ψ_{Int}	U.S. Domestic Ψ_{US}	t(d.f.)
Dept. Info	0.0506 ± 0.1	0.0883 ± 0.1	1.01(50)
Procedural	0.0729 ± 0.1	0.0727 ± 0.1	0.006(38)
Coursework	-0.0153 ± 0.1	0.0492 ± 0.3	1.47(26)
Teaching	0.00970 ± 0.1	0.056 ± 0.1	0.841(18)
Research	0.0201 ± 0.1	0.0380 ± 0.1	0.555(44)
Career	0.0724 ± 0.09	0.0335 ± 0.1	1.21(38)
Crisis	0.0661 ± 0.1	0.0706 ± 0.1	0.181(46)
In Dept. Social	0.0529 ± 0.1	0.0367 ± 0.1	0.477(43)
Out Dept. Social	0.0882 ± 0.1	0.0424 ± 0.1	1.22(46)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Student type homophily was analyzed by finding the correlation coefficient Ψ_{Int} for international student survey participants and Ψ_{US} for U.S. domestic student survey participants. Ψ_{Int} and Ψ_{Int} were compared via t-tests for each purpose. These data are displayed in table 4.38.

The correlation coefficients for international students and U.S. domestic students have no statistically significant difference for any of the purposes. Both types of students are slightly homophilous. The exception is coursework, where international students are slightly heterophilous according to the mean.

There are no statistically significant differences in reciprocated ties of U.S. domestic and international students.

Faculty and Staff Networks

International and U.S. domestic students had no differences in how they formed their networks with faculty and staff. Using a chi-square, there were no differences in whether an international or U.S. domestic student named a a mentor.

T-tests revealed several differences in network attributes between international and U.S. domestic students. U.S. domestic students who taught during the 2012-2013 academic year had 1 ± 1 ties to higher prestige faculty, with the mean value of weighted out-ties being 7 ± 5. International students had 0 ± 0 ties to higher prestige faculty, with the mean value of weighted out-ties being 2 ± 4. Equal variance could not be assumed. For both out-ties and weighted out-ties to higher prestige faculty, the difference is significant for $t(21) = 2.75$, $p \leq 0.05$.

The difference between international and U.S. domestic students socializing with staff at departmental events is also statistically significant. International students have 0 ± 1 ties to staff with whom they socialize at departmental events. The weighted in-ties is 0 ± 1. U.S. domestic students have 0 ± 0 ties, with a weighted in-tie value of 0 ± 0. Equal variance could not be assumed. For out-ties to staff, the difference was significant for $t(36) = 2.53$, $p \leq 0.05$. For weighted out-ties to staff, the difference was significant for $t(39) = 2.56$, $p \leq 0.05$

Regression

Regression was performed the peer networks and the faculty/staff networks, with the outcome variable being time to degree. The student type variable was introduced as a variable in one method and cases were selected by student type for the second method. Student type was coded as 1 for U.S. domestic students and 0 for international students.

None of the peer networks had a statistically significant regression model. One model for U.S. domestic students involving higher prestige faculty is statistically significant:

$$T_{Deg} = 6.28 - 0.426C_{HFW} + 1.52K_{HF} - 0.405R_{HF} \tag{4.9}$$

This model is statistically significant for $F(3,\ 21) = 4.23$, $p \leq 0.05$. The correlation coefficient is 0.614; r^2 is 0.377, meaning that the model explains 37.7% of the variance.

4.5.4 Year In Program

Six categories were created for the “year in program during the 2012-2013 academic year” variable. This is referred to as “year in program” or YIP. Twelve survey participants were in their first year, six in their second year, twelve in their third year, eight in their fourth year, seven in their fifth year, and nine in their sixth or higher year. One participant did not provide his or her year.

Four first-year students, two second-year students, seven third-year students, five fourth-year students, six fifth-year students, and five students in their sixth year or beyond were interviewed. To further protect privacy, interview participants are described as either more junior (students in years 1-3) or more senior (students in year 4 or higher).

Peer Networks

There were no differences among the interview participants in various years and how they established their networks. The primary difference between students in years 1-4 in the program and students who were in years 5+ is that the more senior students have a strong appreciation for the current social culture. Three of the more senior students discussed the social culture in a positive light. Kurt MicKinney explained the changes:

> When I started, there were very few social activities going on. The number of activities increased and the number of people participating increased. I think people like being more social in the department. Umm, I think the faculty members have done a good job of supporting that. Specifically, [the chair] did a fabulous job of putting the first year office on the second floor. That’s gotten people more integrated.

These more senior students have seen changes occur in the department and for the most part, they perceive the changes as positive. However, one change has had a negative impact on socializing. Two senior participants noted the need for common space to meet by chance. At one point, there were common spaces where students could gather for lunch. The lack of a common space has made making connections with other doctoral students more difficult.

Being a more senior student in the department may negatively impact one's social life within the department. Seven senior participants noted obstacles to participating in departmental events. Four mentioned lack of time, because they were working to complete their degrees. Three, however, noted that having fewer members of their cohort around hindered their departmental socializing. Calvin Schwartz said that by attending events, he was reminded that he did not graduate yet which he does not enjoy remembering. Flynn Gardner remarked that he has few friends on campus: "[The friends I see are] the ones that are still around. I mean, I honestly don't have a large social group here inside the department." The longer one is in the program, more and more classmates will have left. Students may also feel self-conscious about being one of the few remaining students.

ANOVAs indicate that many network attributes are statistically significant. Levene's test for homogeneity indicated that several of these variables did not have equal variances among the groups. Welch's test was run for the variables that did not have equal variance. The following network attributes are statistically significant, per an ANOVA or Welch's test:

- Career weighted in-ties
- Crisis in-ties
- Crisis weighted in-ties
- Procedural out-ties
- Procedural betweenness centrality
- Coursework in-ties
- Coursework out-ties

- Coursework weighted in-ties
- Coursework weighted out-ties
- Coursework weighted betweenness centrality
- Departmental socializing out-ties
- Departmental socializing weighted in-ties
- Departmental socializing betweenness centrality
- Outside of the department socializing in-ties

The Year in Program variable was further aggregated for coursework network attributes; years 1 through 3 remained the same, but years 4 through 6+ were aggregated into one category due to low counts. Post-hoc Tukey or Games-Howell tests were run on these data to determine which pairings have statistically significant differences.

Tables 4.39 and 4.40 displays the details of these data. All five of the coursework network attributes have statistically significant ANOVAs. In both tables, the majority of significant differences are between newer students (first and second years) and students in their fifth year. More junior students have more ties and more frequent contact with their ties for coursework-related reasons. Fifth year students have more contacts for career-related and crisis-related reasons.

Figure 4·27 depicts the coursework network. The bottom group of green nodes is all first year students. The upper group is more mixed. The node colors are as follows: yellow for second year students, blue for third year students, brown for fourth year students, and red for students in their 6+ year. This suggests that first-year students tend to work with one another while upper level students tend to be more mixed for coursework. These connections are likely due to the structure of the program; first-year students are enrolled in core curriculum courses with their cohort.

Homophily for the "year in program" variable was studied by calculating a correlation coefficient, Ψ, for each network purpose; the numeric subscripts denote which

Table 4.39: Significant ANOVA/Welch Test Results for Year In Program

	F(d.f)	Significant Pairings
Coursework In-ties	4.74(3, 28)**	Year 1 (5 ± 2) & Year 3 (3 ± 2)***
		Year 1 (5 ± 2)& Year 4+ (2 ± 1)*
Coursework Out-ties	5.45(3, 14)[1]***	Year 1 (9 ± 6) & Year 4+ (1 ± 1)**
		Year 2 (12 ± 6) & Year 4+ (1 ± 1)*
Coursework W. In -ties	13.8(3, 14)[1]***	Year 1 (22 ± 12) & Year 3 (6 ± 6)**
		Year 1 (22 ± 12) & Year 4+ (3 ± 2)***
		Year 2 (18 ± 9) & Year 4+ (3 ± 2)*
Coursework W. out-ties	9.42(3, 14)[1]**	Year 1 (37 ± 28) & Year 3 (11 ± 8)*
		Year 1 (37 ± 28) & Year 4+ (3 ± 4)**
Coursework Btwn. Cent.	3.14(3, 28)**	Year 2 (0.04 ± 0.02) & Year 4+ (0.007 ± 0.008) *
Career W. in-ties	3.40(5, 48)*	Year 1(4 ± 4) & Year 5 (14 ± 9)*
		Year 4 (3 ± 2) & Year 5 (14 ± 9)**
		Year 5 (14 ± 9) & Year 6 (4 ± 6) **

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Welch Test

The significant results from ANOVAs ran to compare the means of network attributes by year in program. The results also include which pairings are statistically significant, as indicated by post-hoc Tukey tests or Games-Howell test. Participants who took courses are the only ones included in the coursework data.

Table 4.40: Significant ANOVA/Welch Test Results for Year In Program

	F (d.f)	Significant Pairings
Crisis in-ties	3.38(5, 20)[1]*	None
Crisis W. in-ties	3.42(5, 20)[1]*	None
Procedural in-ties	2.63(5, 48)*	Year 3 (2 ± 2) & Year 4 (8 ± 4)*
Procedural Btwn. Cent.	1.38(5, 16) [1]*	None
Procedural out-ties	2.65(5, 48)*	Year 3 (2 ± 2) & Year 4 (6 ± 5)*
Inside Dept. Social out-ties	2.45(5, 48)*	None
In Dept. Social W. in-ties	3.32(5, 48)*	Year 1 (3 ±1) & Year 6+ (1 ±2)**
		Year 2 (3 ±1) & Year 6 (1 ±2)**
Inside Dept. Social Btwn. Cent.	2.87(5, 48)*	None
Outside Dept. Social in-ties	3.10(5, 48)*	Year 5 (7 ± 3) & Year 6 (2 ± 2)**

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Welch Test

The significant results from ANOVAs ran to compare the means of network attributes by year in program. The results also include which pairings are statistically significant, as indicated by post-hoc Tukey tests or Games-Howell test.

Table 4.41: Homophily ANOVA or Welch's test results for the "year in program" variable

	1st Year Ψ_1	2nd Year Ψ_2	3rd Year Ψ_3	4th Year Ψ_4	5th Year Ψ_5	6+ Year Ψ_{6+}	F(d.f.)
Dept. Info	0.145 ± 0.3	0.189 ± 0.2	0.132 ± 0.2	0.468 ± 0.4	0.458 ± 0.4	-0.0388 ± 0.3	$3.48(5, 48)^{a**}$
Procedural	-0.163 ± 0.07	-0.120 ± 0.09	-0.184 ± 0.06	0.0468 ± 0.07	0.138 ± 0.4	-0.290 ± 0.04	$8.76(5, 47)^{b***}$
Coursework	0.604 ± 0.3	0.259 ± 0.2	0.218 ± 0.2	0.206 ± 0.05	-	-	$5.06(3, 12)^{1c*}$
Teaching	-0.128 ± 0.2	-0.0466 ± 0.1	-0.200 ± 0.03	-0.0781 ± 0.2	-0.0146 ± 0.2	-0.304 ± 0.05	$5.25(5, 48)^{d**}$
Research	-0.0649 ± 0.2	-0.0855 ± 0.09	-0.0721 ± 0.1	0.123 ± 0.2	0.205 ± 0.2	-0.295 ± 0.05	$8.95(5, 48)^{e***}$
Career	0.0326 ± 0.2	0.00371 ± 0.1	0.0659 ± 0.1	-0.00726 ± 0.1	0.427 ± 0.2	0.135 ± 0.1	$6.86(5, 34)^{f***}$
Crisis	0.298 ± 0.2	0.265 ± 0.2	0.292 ± 0.2	0.128 ± 0.2	0.465 ± 0.2	0.0882 ± 0.1	$3.90(5, 40)^{g**}$
In Dept. Social	-0.0155 ± 0.2	0.129 ± 0.2	0.0965 ± 0.3	0.272 ± 0.3	0.704 ± 0.6	-0.280 ± 0.1	$9.14(5, 48)^{h***}$
Out Dept. Social	-0.147 ± 0.08	-0.0276 ± 0.2	-0.131 ± 0.09	0.130 ± 0.3	0.262 ± 0.2	-0.221 ± 0.1	$11.9(5, 48)^{i***}$

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

[1] = Welch's test used

[a] =Two combinations are statistically significant ($p \leq 0.05$). One is Year 4 & Year 6. The other is Year 5 & Year 6.

[b] = Six combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 1 & Year 5, Year 2 & Year 5, Year 3 & Year 4, Year 3 & Year 5, Year 4 & Year 6, and Year 5 & Year 6.

[c] = For coursework purposes, students who were in their 4th or higher year were aggregated into one category. Three combinations are statistically significant ($p \leq 0.05$). One combination is Year 1 & Year 3. The other is Year 1 & Year 4.

[d] = Four combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 2 & Year 6, Year 3 & Year 5, Year 4 & Year 6, and Year 5 & Year 6.

[e] = Seven combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 1 & Year 5, Year 1 & Year 6, Year 2 & Year 5, Year 3 & Year 5, Year 3 & Year 6, Year 4 & Year 6, and Year 5 & Year 6.

[f] = Five combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 1 & Year 5, Year 2 & Year 5, Year 3 & Year 5, Year 4 & Year 5, and Year 5 & Year 6.

[g] = Two combinations are statistically significant ($p \leq 0.05$). The first combination is Year 4 & Year 5. The second is Year 5 & Year 6.

[h] = Five combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 1 & Year 5, Year 2 & Year 5, Year 3 & Year 5, Year 4 & Year 6, and Year 5 & Year 6.

[i] = Seven combinations are statistically significant ($p \leq 0.05$). They are as follows: Year 1 & Year 4, Year 1 & Year 5, Year 2 & Year 5, Year 3 & Year 4, Year 3 & Year 5, Year 4 & Year 6, and Year 5 & Year 6.

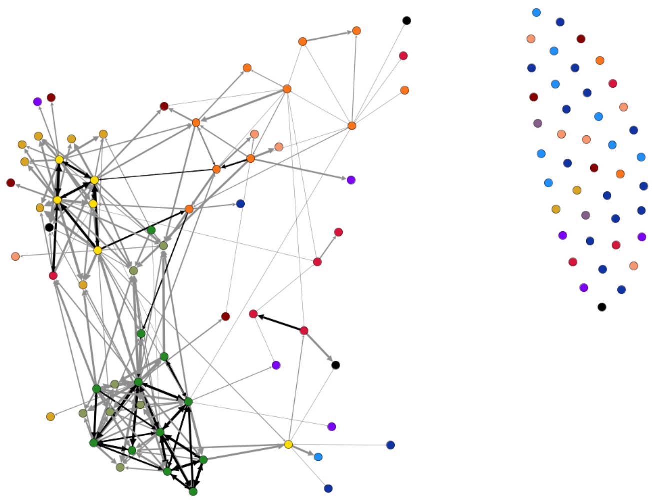

Figure 4·27: Sociogram depicting with whom students talk about course-related matters, color-coded by year in program. The color coding is as follows: green for first years, yellow is second years, blue for third years, brown for fourth years, and red for students in their 6+ year. Grey nodes are unknown years; they are also non-participants. Black lines indicate reciprocal ties.

year in the program. Table 4.41 displays these data. ANOVAs were used to determined if there are any differences in homophily.

There are some striking trends within these data. Similar to the prior data, the ANOVAs indicate statistical differences for the various years. These differences are also primarily involving students who are in their fifth year. Students who are in their sixth or higher year are slightly heterophilous for almost every network purpose. In contrast, students in their fifth year are homophilous for almost every network purpose. It is unclear what the difference within these cohorts is. Students in the other years have mix of heterophily and homophily. Few of the Ψ values are approximately 0; this suggests that participants do not socialize in groups that are proportionately mixed with their cohort and other cohorts. In other words, a participant is either socializing within the cohort or is one of a few present from his or her cohort when socializing.

In terms of purposes, crisis support is the only network purpose where all six Ψ's indicate homophily; coursework, which has only four years represented, also is homophilous for all values of Ψ. The teaching network is the only network where all six values of Ψ indicate some level of heterophily. Students in years 1-3 have more heterophilous networks for both research and procedural networks, while students in years 4-5 have more homophilous networks for the same purposes; this suggests that the more junior students selected more senior students, but the more senior students did not select the more junior students. This may be because the more junior students do not have the same level of experience that the more senior students have. However, it is interesting to note that career networks tend to be more homophilous by year except for the fourth year students.

Table 4.42: Reciprocity ANOVA results for the year in program variable

	F(d.f)	Significant Pairings
Dept. Info	0.072(2, 51)	-
Procedural	5.30(2, 27)^{1*}	$\Xi_{3,4}$ (0 ± 0) and Ξ_{5+} (1 ± 1)*
Coursework	1.94 (3, 28)	-
Teaching	2.07 (2, 24)	-
Research	1.19(2, 31)	-
Career	3.90(2, 30)^{1*}	$\Xi_{1,2}(0 \pm 1)$ and Ξ_{5+} (1 ± 2)*,
		$\Xi_{3,4}$ (0 ± 1) and Ξ_{5+} (1 ± 2)*
Crisis	1.29(2, 51)	-
In Dept. Social	1.59(2,51)	-
Out Dept. Social	2.85(2, 31)	-

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Reciprocity was examined for the year in program variable. These data are displayed in table 4.42. Due to low counts, the following categories were collapsed into three variables: years 1 and 2 ($\Xi_{1,2}$), years 3 and 4 ($\Xi_{3,4}$), and years 5+ (Ξ_{5+}). These new categories were used for all networks except teaching and coursework, which used the afore-mentioned aggregation.

The career and procedural networks have statistically significant differences by year in program. For the procedural network, those in year 5+ have more reciprocated ties than those in years 3 and 4. For the career network, those in year 5+ have more reciprocated ties than those in years 1 and 3 as well as those in years 3 and 4.

Faculty and Staff Networks

Students mostly connected with faculty in similar ways, regardless of year. The only difference is that two of the newer students actively talked to a faculty member regarding research prior to entering the program. Each student spoke with a different faculty member.

Eight of the interview participants who were more senior tended to discuss career prospects with faculty. Students who are earlier in their doctoral careers did not tend to seek out career advice. These conversation were almost always started by their advisors and were mostly centered around helping the student locate jobs or postdoc positions. Margot Cherry noted that her advisor was helping her make connections and making time to advise her on her job search. Tyrone Burns' advisor found a postdoc position for him. Although he had spoken with his advisor for job advice prior to being aware of this position, the only advice Tyrone described is as follows: "His advice was to 'take it, take it, take it, take it.' My collaborator gave the same advice. They both pushed me very hard to leave my girl behind and move for this job." Only one student, who is a more junior doctoral student, had discussed career prospects and the skills needed for particular professions with faculty members.

Several network attributes have statistically significant differences for year in program. Table 4.43 displays these results. The differences primarily are around career networks. More junior level survey participants named more faculty members in the career network than more senior senior participants.

Table 4.43: ANOVA results of network attributes by year in program for the student-faculty/staff networks

	F(d.f)	Significant Pairings
LF Dept. Info Ties	2.76(5, 48)*	Year 1 (0 ± 1) & Year 3 (1 ± 1)*
LF Outside Dept. Social W. Ties	2.49(5, 48)*	Year 3 (1 ± 1) & Year 4 (0 ± 0)*
TF Career W. Ties	3.35(5, 48)*	Year 2 (2 ± 2) & Year 4 (0 ± 0)* Year 2 (2 ± 2) & Year 5 (0 ± 0)* Year 2 (2 ± 2) & Year 6+ (0 ± 0)*
HF Career W. Ties	3.31(5, 48)*	Year 1 (1 ± 1) & Year 3 (0 ± 0)* Year 1 (1 ± 1) & Year 6 (0 ± 1)*
Staff Career W. Ties	3.47(5, 48)**	Year 2 (1 ± 1) & Year 3 (0 ± 0)* Year 2 (1 ± 1) & Year 5 (0 ± 0)* Year 2 (1 ± 1) & Year 6+ (0 ± 0)*
Staff Crisis W. Ties	2.41(5, 48)*	None
Staff Inside Dept. Social. W. Ties	2.81(5, 48)*	Year 1 (0 ± 0) & Year 5 (1 ± 1)* Year 3 (0 ± 0) & Year 5 (1 ± 1)* Year 4 (0 ± 0) & Year 5 (1 ± 1)*

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Regression

Regression was conducted for both peer and student-faculty/staff networks, introducing year in program as a variable and selecting particular cases. Each year was coded as its numeric year, e.g., year one is 1. For the survey participants in their sixth or higher year, this was coded as 6.

For peer networks, the following peer network model had the lowest p-value:

$$
\begin{aligned}
T_{Deg} = 5.51 &+ 0.528Y_{Prog} + 0.189K_{Out} + 0.325K_{WIn} - 0.102K_{WOut} \\
&+ 0.132P_{WIn} + 0.07P_{WOut}45.5P_{Btwn} - 0.240G_{Out} + 0.069G_{WOut} \\
&- 0.174R_{WIn} - 0.076R_{WOut} + 29.1R_{Btwn} + 0.055I_{Out} - 0.447I_{WIn} \\
&- 0.365O_{In} - 0.102O_{Out} + 22.2O_{Btwn} - 0.598C_{In} - 0.391C_{Out} \\
&+ 0.245C_{WIn} + 0.231C_{WOut} - 40.1C_{Btwn} \qquad (4.10)
\end{aligned}
$$

where Y_{Prog} is for the “year in program” variable. The correlation coefficient is 0.881; r^2 is 0.776, meaning that it accounts for 77.6% of the variance. This model is significant for $F(23,\ 28) = 2.69$, $p \leq 0.001$. No models were statistically significant when conducting regression by particular year.

For faculty and staff networks, each category yields a statistically significant model. Equation 4.11 is the model that used the network attribute variables for lower prestige faculty. This equation is:

$$T_{Deg} = 4.77 + 0.374Y_{Prog} - 0.388C_{LF} \qquad (4.11)$$

The correlation coefficient is 0.599; r^2 is 0.332, meaning that the model accounts for 33.2% of the variance. This model is significant for $F(2,\ 49) = 13.1$, $p \leq 0.001$. Equation 4.12 is for typical prestige faculty. This equation is as follows:

$$T_{Deg} = 4.63 + 0.390Y_{Prog} - 0.823O_{TF} \qquad (4.12)$$

The correlation coefficient is 0.591; r^2 is 0.349, which means that the model describes 34.9% of the variance. This model is significant for $F(1,\ 50) = 6.78$, $p \leq 0.01$. For higher prestige faculty, the model is as follows:

$$T_{Deg} = 4.46 + 0.467Y_{Prog} + 0.392C_{HFW} - 0.148R_{HF} \qquad (4.13)$$

The correlation coefficient is 0.630; r^2 is 0.359, which means the model accounts for 35.9% of the variance. This model is significant for $F(3,\ 48) = 10.5$, $p \leq 0.001$.

Equation 4.14 is for staff. This equation is as follows:

$$T_{Deg} = 4.52 + 0.419Y_{Prog} - 0.462I_{SW} \tag{4.14}$$

The correlation coefficient is 0.591; r^2 is 0.349, which means the model accounts for 34.9% of the variance. This model is significant for $F(2, 49) = 13.1$, $p \leq 0.001$.

When using regression on selected cases, four statistically significant models were found. For students in their first year, two models were found. One is for typical prestige faculty and is as follows:

$$\begin{aligned} T_{Deg} = 4.56 &+ 1.05C_{TF} + 1.37C_{TFW} + 0.486K_{TFW} \\ &- 0.566G_{TF} - 6.63O_{TFW} + 1.81P_{TF} - 0.283R_{TF} \end{aligned} \tag{4.15}$$

This model is significant for $F(7, 4) = 75.6$, $p \leq 0.001$. The correlation coefficient is 0.996; r^2 is 0.992, which means that the model accounts for 99.2% of the variance. The second model is for staff. This model is as follows:

$$\begin{aligned} T_{Deg} = 4.75 &+ 2.92C_{SW} - 0.910K_S + 1.60K_{SW} \\ &- 0.514G_S + 0.410P_S - 0.617R_S \end{aligned} \tag{4.16}$$

This model is significant for $F(6, 5) = 7.20$, $p \leq 0.05$. The correlation coefficient is 0.947; r^2 is 0.896, which means the model accounts for 89.6% of the variance.

For students in their third year, one models is significant. The first model involves ties to higher prestige faculty and is as follows:

$$T_{Deg} = 6.06 + 3.87C_{HFW} - 1.490K_{HFW} - 1.59G_{HFW} - 0.665I_{HF} + 0.225R_{HF} \tag{4.17}$$

This model is significant for $F(5, 4) = 13.8$, $p \leq 0.05$. The correlation coefficient is 0.972; r^2 is 0.945., which means the model accounts for 94.5% of the variance.

For students in their sixth or higher year, the model involving ties to staff is statistically significant. This model is as follows:

$$T_{Deg} = 7.25 + 3.08R_{SW} \tag{4.18}$$

This model is significant for $F(1,\ 7) = 6.24$, $p \leq 0.05$. The correlation coefficient is 0.686; r^2 is 0.471, which means the model accounts for 47.1% of the variance.

4.5.5 Undergraduate Institute type

The survey participants' undergraduate institutes are as follows: ten attended a liberal arts college (U.S. or international), twenty-three attended an international university, nine attended a private university, and thirteen attended a public university. The interview participants are as follows: seven attended a liberal arts college, eight attended an international university, seven attended a private university, and six attended a public university.

Peer Networks

No differences were observed in how the survey participants from various undergraduate institutes connected with peers. The one difference among these groups is related to progress and confidence in completing the doctorate. five participants (62.5%) who were graduates of international universities, four participants (44.4%) from private universities, and five participants (71.5%) from liberal arts colleges discussed issues related to progress and confidence in the program; only one graduate of a public institute mentioned any difficulties. Issues related to progress and confidence include switching advisors multiple times, the perception one is not making progress and definitive signs of issues such as failing a requirement.

Of these participants, one trend was observed for liberal arts graduates. Four of the five liberal arts graduate participants specifically discussed perceived issues in related to the research environment. Walter Jenkins attributed his lack of progress on himself: "I think half of this is my sloppiness. I'm not used to research." Throughout the interview, he used the word "sloppiness" and phrase "my fault" multiple times when discussing anything related to research. Other liberal arts graduates also attributed their issues in relation to research as personal shortcomings.

Quantitatively, the only statistical difference in network attributes found is for weighted out-ties in the departmental information network. Because Levene's test revealed the variance is heterogeneous, Welch's test was used. The difference among the participants is $F(3,\ 21) = 3.13$, p ≤ 0.05. The post-hoc Games-Howell test did not reveal any statistically significant differences between pairs.

Undergraduate institute homophily was analyzed. The correlation coefficients for homophily are as follows: Ψ_{LAC} for liberal arts college graduates, Ψ_{IU} for international university graduates; Ψ_{PubU} for U.S. public university graduates, and Ψ_{PrivU} for U.S. private university graduates. Table 4.44 displays these data.

None of the ANOVAs indicate that there are any differences by undergraduate institute. It is interesting to note that private university graduates tend to be slightly homophilous for all network purposes. Liberal arts college graduates have more of mix between heterophily and homophily, with network purposes being almost evenly split. Ψ_{PubU} is approximately 0 for three purposes, the most of any of the undergraduate institutes.

There are no significant difference among the different types of undergraduate institutes for the number of reciprocated ties in each network.

Faculty and Staff Networks

The majority of students connected with faculty and staff, regardless of undergraduate institute. Several differences exist. One observable trend is that three of the private university alums were strategic how they selected advisors, such as receiving advice prior to selecting their first advisor or being interested in a specific faculty member's research. Another trend is that the two interview participants who switch advisors once and early in their graduate career attended private universities.

Having a mentor varies by the undergraduate institute. Eighteen out of 23 international students or 78% named at least one mentor. This is the highest percentage among the four institute categories, which ranged from 50% (liberal arts graduates) to 67% (public university graduates) of the survey participants naming mentor. How-

Table 4.44: Homophily ANOVA or Welch's test results for the undergraduate institute variable

	Liberal Arts	International Uni.	Public Uni.	Private Uni.	F(d.f.)
	Ψ_{LAC}	Ψ_{IU}	Ψ_{PubU}	Ψ_{PrivU}	
Dept. Info	-0.0119 ± 0.1	0.0664 ± 0.09	0.0191 ± 0.1	0.116 ± 0.1	0.620(3, 48)
Procedural	0.0742 ± 0.2	0.0516 ± 0.2	-0.00407 ± 0.1	0.533 ± 0.1	2.00(3, 36)
Coursework	-0.0680 ± 0.2	-0.000404 ± 0.1	0.0500 ± 0.2	0.0611 ± 0.07	1.051(3, 25)
Teaching	0.0867 ± 0.2	-0.0757 ± 0.09	0.0812 ± 0.1	-	3.54(2, 17)^{a}
Research	-0.0144 ± 0.08	0.0366 ± 0.1	-0.0228 ± 0.1	0.0746 ± 0.2	1.40(3, 41)
Career	-0.0189 ± 0.05	0.0700 ± 0.09	0.0298 ± 0.1	0.0940 ± 0.1	1.71(3, 36)
Crisis	-0.0732 ± 0.2	0.0394 ± 0.08	0.0158 ± 0.1	0.0952 ± 0.09	0.959(3, 43)
In Dept. Social	0.0496 ± 0.1	0.0366 ± 0.1	-0.00233 ± 0.2	0.0952 ± 0.1	0.719(3, 41)
Out Dept. Social	0.0305 ± 0.1	0.109 ± 0.2	0.00736 ± 0.1	0.100 ± 0.1	1.81(3, 44)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Welch's test used
[a] = Due to low counts, Ψ_{PubU} and Ψ_{PrivU} were combined.

ever, Fisher's exact test did not indicate that the differences among groups is statistically significant.

The only network attribute that is statistically significant is the weighted-ties for socializing with typical prestige faculty outside of the department. The ANOVA indicated this significant for $F(3,\ 51) = 2.85$, $p \leq 0.05$. The post-hoc Tukey test indicated that the difference between private (1 ± 1) and public (0 ± 1) university graduates is significant for $p \leq 0.05$.

Regression

For the regression analysis, the undergraduate institute variable type was split into three dichotomous dummy-coded variables for private universities, public universities, and liberal arts colleges. Data were analyzed using regression both with introducing the undergraduate institute variable into the model and by selecting cases according to category.

Four regression models are statistically significant. The first model introduces the undergraduate institute variables in the model:

$$T_{Deg} = 6.15 + 1.32\upsilon_{LAC} - 1.36C_{LF} + 0.207C_{LFW} + 0.808K_{LF} - 0.783O_{LFW} - 0.868R_{LFW} \quad (4.19)$$

where υ_{LAC} is for liberal arts college graduates. Having graduated with a bachelor's from a liberal arts colleges increase the time to degree by approximately 1.32 years. This model is significant for $F6,\ 45) = 4.31$, $p \leq 0.01$. The correlation coefficient is 0.604; r^2 is 0.365, meaning that the model accounts for 36.5% of the variance.

The other models were created by selecting cases. The following model was developed using the cases of students who attended private universities for their undergraduate degrees. This model only involves the staff network attributes and is as follows:

$$T_{Deg} = 4.91 - 3.57C_{SW} - 0.234K_{SW} + 1.60P_S \quad (4.20)$$

This model is significant for $F(3,\ 5) = 16.3$, $p \leq 0.01$. The correlation coefficient is

0.953; r^2 is 0.907, meaning that the model accounts for 90.7% of the variance.

The other two statistically significant models were developed using the cases of students who attended public universities for their undergraduate degrees. The first model involves higher prestige faculty network attributes:

$$T_{Deg} = 5.87 - 1.40C_{HF} - 0.223K_{HFW} \quad (4.21)$$

This model is significant for $F(2, 12) = 4.21$, $p \leq 0.05$. The correlation coefficient is 0.676; r^2 is 0.457, meaning that the model accounts for 45.7% of the variance. The second model for public university graduates involves typical prestige faculty network attributes:

$$T_{Deg} = 5.91 - 0.685K_{TFW} + P_{TF} \quad (4.22)$$

This model is significant for $F(2, 10) = 7.77$, $p \leq 0.01$. The correlation coefficient is 0.780; r^2 is 0.608, meaning that the model accounts for 60.8% of the variance.

4.5.6 Relationship Status

Survey participants described their relationship statuses as follows: seventeen are single, nineteen participants are in dating relationships, seven are engaged, and twelve are married or in domestic partnerships. This variable aggregated engaged and married/domestic partnership categories. The new "engaged/married" category has a total of nineteen.

Interview participants described their relationship status as follows: seven are single, twelve are in dating relationships, and nine are engaged/married.

Peer Networks

There are no differences among how students of these three relationship statuses form peer networks. Conversation and activities are similar. The main difference among the peer networks is that those in relationships (dating or engaged/married) tend to socialize with their significant others and their significant others' friends outside of the university more than they do with their friends in the department. Ten participants talked about socializing with their spouses and their significant others' friends. Five of the participants mentioned spending time with their peers in the physics departments and their peer's significant others. These five participants have formed close groups with their peers and their peers' significant others

ANOVAs and Welch's tests were run. Welch's tests indicate that the differences among the relationship groups for out-ties and weighted out-ties for procedural-related reasons are statistically significant. The out-ties difference is significant for $F(2, 28) = 3.88$, $p \leq 0.05$. The weighted out-ties difference is significant for $F(2, 28) = 5.82$, $p \leq 0.01$. Games-Howell post-hoc tests were run for both network attributes. For procedural out-ties, the difference is significant between single survey participants (4 ± 4) and engaged/married survey participants (2 ± 1) for $p \leq 0.05$. For procedural out-ties, the difference is significant between single participants (10 ± 9) and engaged/married survey participants (2 ± 3) for $p \leq 0.05$.

Table 4.45: Homophily ANOVA or Welch's test results for the relationship status variable

	Single Ψ_S	Dating Ψ_D	Engaged/Married Ψ_{EM}	F(d.f.)
Dept. Info	0.0406 ± 0.2	0.0339 ± 0.1	0.0512 ± 0.2	0.0630(2, 49)
Procedural	-0.00418 ± 0.1	0.0218 ± 0.1	0.0476 ± 0.2	$0.725(2, 22)^{1}$
Coursework	0.0409 ± 0.1	0.0629 ± 0.1	0.0541 ± 0.06	$0.058(2, 16)^{1}$
Teaching	0.00151 ± 0.1	-0.0553 ± 0.1	-0.0206 ± 0.1	0.289(2, 17)
Research	0.00997 ± 0.2	-0.0242 ± 0.1	0.0860 ± 0.1	2.61(2, 41)
Career	-0.0134 ± 0.2	-0.0254 ± 0.08	0.0991 ± 0.1	$6.00(2, 18)^{1a**}$
Crisis	0.0460 ± 0.1	0.352 ± 0.1	0.104 ± 0.2	$3.98(2, 41)^{b*}$
In Dept. Social	0.0739 ± 0.1	0.0127 ± 0.2	-0.00834 ± 0.1	1.48(2, 41)
Out Dept. Social	0.0475 ± 0.1	0.00287 ± 0.2	0.0955 ± 0.1	1.489(2, 44)

* = *p ≤0.05*; ** = *p ≤0.01*; *** = *p ≤0.001*
[1] = Welch's test used
[a] = Ψ_D and Ψ_{EM} have a statistically significant difference ($p \leq 0.01$).
[b] = Ψ_D and Ψ_{EM} have a statistically significant difference ($p \leq 0.01$).

Homophily was examined for the relationship variable. Table 4.45 displays these data. The correlation coefficients are as follows: Ψ_S is the correlation coefficient for students who are single; Ψ_D is the correlation coefficient for students who are in dating relationships; and Ψ_{EM} is the correlation coefficient for students who are engaged, married, or in domestic partnerships.

The majority of networks are slightly homophilous by relationship status. Single students have the majority (3) of correlation coefficients that are approximately 0, indicating a proportionately mixed network of single students and non-single (engaged or married/domestic partnership) students. These networks are for procedural, research, and teaching purposes. Two network purposes, career and crisis, have statistically significant differences among the Ψ values. A Games-Howell post-hoc test revealed that the difference between Ψ_D and Ψ_{EM} is statistically significant for career purposes. Ψ_D is slightly heterophilous while Ψ_{EM} is slightly homophilous. A post-hoc Tukey test revealed that the difference between Ψ_D and Ψ_{EM} is statistically significant for crisis-related purposes. Ψ_D is moderately homophilous while Ψ_{EM} is slightly homophilous.

Only one type of network has statistically significant differences among the groups: the career network. A Welch's test revealed $F(2, 3) = 4.31$, $p \leq 0.05$. A Games-Howell test revealed that the difference in reciprocal ties for those who are engaged/married (0 ± 1) and those who are single (1 ± 1) is statistically significant ($p \leq 0.05$).

Faculty and Staff Networks

There are essentially no differences regarding how students of different relationship statuses form networks with their faculty and staff. The one difference is that five of the interview participants mentioned considering their significant others when making decisions regarding advisor selection or accepting jobs after they complete their degrees; some advisors expect their students to live outside of the Jonas University area in order to collect data. There are no differences in conversation topics or descriptions of their relationships with faculty/staff.

The only network attribute that is statistically significant is the crisis weighted out-ties to higher prestige faculty. An ANOVA shows the difference is significant for $F(2, 52) = 3.19$, $p \leq 0.05$. The post-hoc Tukey test showed a significant difference ($p \leq 0.05$) between single students (0 ± 1) and engaged/married students (1 ± 1).

Regression

Regression was conducted by introducing the relationship status variable into the regression model and by selecting cases by relationship status. The relationship status variable was split into two dichotomous variables: dating and engaged/married.

One peer network model is statistically significant. This model introduced the relationship variables:

$$\begin{aligned}T_{Deg} &= 8.69 - 1.34\rho_D - 0.105K_{WOut} - 0.344P_{Out} + 0.193P_{WOut} \\ &+ 0.634G_{In} - 0.113G_{WIn} + 0.033G_{WOut} - 101G_{Btwn} + 0.647R_{In} - 0.318R_{WIn} \\ &+ 15.0R_{Btw} + 0.224I_{In} - 0.278I_{Out} + 46.1I_{WOut} - 0.222O_{Out} + 36.4O_{Btwn} \\ &- 0.338C_{Out}0.173C_{WOut} - 34.3C_{Btwn} \quad (4.23)\end{aligned}$$

where ρ_D is for the dating relationship variable. According to this model, being in a dating relationship decrease the time needed to complete the degree by approximately one year and a semester. This regression model is significant for $F(20,\ 31) = 3.03$, $p \leq 0.01$. The correlation coefficient is 0.814; r^2 is 0.662, meaning that this model explains 66.2% of the variance.

Five models featuring faculty/staff network attributes are statistically significant. The first model was created by introducing the relationship status variables into the regression model for student-typical prestige interactions:

$$T_{Deg} = 6.29 - 0.600\rho_D - 0.355C_{TFW} \quad (4.24)$$

This regression model is significant for $F(2{,}49) = 3.30$, $p \leq 0.05$. The correlation coefficient is 0.344; r^2 is 0.119, meaning that the model explained 11.9% of the variance.

The following models were created by selecting cases according to relationship status. Two of the models are for single students. The following model involves network attributes for higher prestige faculty:

$$T_{Deg} = 6.41 - 11.1K_{HF} - 17.4K_{HFW} + 16.5G_{HF} - 1.32G_{HFW} + 0.335I_{HF} - 8.24O_{HF} \quad (4.25)$$

This regression model is significant for $F(6,\ 9) = 11.1$, $p \leq 0.001$. The correlation coefficient is 0.938; r^2 is 0.881, meaning that this model explained 88.1% of the variance. The second model involves staff network attributes:

$$T_{Deg} = 6.50 + 0.467C_S - 0.3G_S + 2.07O_S \quad (4.26)$$

This regression model is significant for $F(3,\ 12) = 3.13$, $p \leq 0.001$. The correlation coefficient is 0.662; r^2 is 0.439, meaning that the model explained 43.9% of the variance.

The other two models were developed using married student cases. The first model features typical prestige faculty:

$$T_{Deg} = 6.22 - 0.421C_{TFW} \quad (4.27)$$

This regression model is significant for $F(1,\ 15) = 4.75$, $p \leq 0.05$. The correlation coefficient is 0.490; r^2 is 0.240, meaning that this model explained 24.0% of the variance. The second model features staff network attributes:

$$T_{Deg} = 5.33 + 5.02K_{SW} - 2.99G_S \quad (4.28)$$

This regression model is significant for $F(2,\ 14) = 4.32$, $p \leq 0.05$. The correlation coefficient is 0.618; r^2 is 0.382, meaning that the model explained 38.2% of the variance.

4.5.7 Research Subfield

Survey participants provided their research fields. The research subfields in the physics department were then categorized as biophysics (BIO), condensed matter physics (CM), and high energy physics (HE). Fourteen survey participants are in

BIO, thirty-three in CM, and eight in HE. The interview participants' fields are as follows: nine BIO, sixteen CM, and three HE. To anonymize the data further, field names are not used in any qualitative data.

Peer Networks

In section 4.2.1, the interview participants observed that physical proximity aided them in forming connections with fellow students. Physical proximity is also needed to maintain relationships. The department is spread across three buildings. The greatest distance between two buildings is 0.5 miles. Bailey Hudson commented that for at least two of the buildings, "the physical separation- Building A for Subfield A and Building B for Subfield B, kind of lends itself for the Subfield A gets done over there, Subfield B gets done here.' Everyone I know in Subfield A occupies [space] in Building A."

Five participants noted that they do not see members of their cohort as frequently because of being in separate buildings. Only one participant mentioned specifically visiting others who work in a different building. This suggests one must make a conscientious effort to maintain relationships with students who work in a separate building. Jacques Booth noted that transitioning from coursework to research tends to affect one's socializing: "When you join a research group, [your primary location] turns into the group's lab space. You don't see the day-to-day interactions with these friends [from your cohort]."

The only two network attributes that have statistically significant differences among the three groups are procedural weighted out-ties and betweenness centrality for socializing outside of the department. Welch's test indicates that procedural weighted out-ties are statistically significant for $F(2,\, 18) = 5.12$, $p \leq 0.05$. Games-Howell post-hoc test indicates that BIO (2 ± 3) and CM (7 ± 8) are significant different for $p \leq 0.05$. Welch's test indicates that socializing outside of the department betweenness centrality are statistically significant for $F(2,\, 30) = 3.42$, $p \leq 0.05$. Games-Howell post-hoc test indicates that CM (0.03 ± 0.04) and HE (0.009 ± 0.008) are significant different for $p \leq 0.05$.

Table 4.46: Homophily ANOVA or Welch's test results for the subfield variable

	BIO Ψ_B	CM Ψ_{CM}	HE Ψ_{HE}	F(d.f.)
Dept. Info	0.0418 ± 0.09	0.0374 ± 0.1	-0.00145 ± 0.1	0.563(2, 49)
Procedural	0.0792 ± 0.1	0.0554 ± 0.09	0.122 ± 0.2	0.706(2, 7)[1]
Coursework	-0.00371 ± 0.1	0.151 ± 0.2	-0.194 ± 0.2	6.63(2, 26)^{a**}
Teaching	0.0344 ± 0.2	-0.0128 ± 0.1	-0.0386 ± 0.07	0.446(2, 17)
Research	0.114 ± 0.1	0.101 ± 0.06	0.250 ± 0.2	0.137(2, 11)[1]
Career	0.0720 ± 0.2	0.0641 ± 0.07	0.128 ± 0.08	0.265(2, 11)[1]
Crisis	0.0769 ± 0.09	0.365± 0.1	0.0538 ± 0.2	0.545(2, 44)
In Dept. Social	0.0170 ± 0.1	0.0489 ± 0.1	0.0521 ± 0.1	0.273(2, 42)
Out Dept. Social	0.0196 ± 0.1	0.0169 ± 0.1	0.0174 ± 0.2	0.002(2, 45)

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Welch's test used
[a] = Ψ_{CM} and Ψ_{HE} have a statistically significant difference ($p \leq 0.01$).

Homophily was analyzed using ANOVAs to compare the subfields. The correlation coefficients are as follows: Ψ_B is for biophysics, Ψ_{CM} is for condensed matter, and Ψ_{HE} is for high energy. Table 4.46 displays these data.

Each subfield was slightly to somewhat homophilous. The F-statistics for the majority of network purposes are below 1. The only network purpose that has statistically significantly differences among the subfields is coursework. A post-hoc Tukey test indicates that Ψ_{HE} and Ψ_{CM} have statistically significant difference. The HE survey participants are somewhat heterophilous. The CM participants are somewhat homophilous. Fo coursework, BIO participants have representative mix of ties.

Reciprocity was examined. The procedural network has statistically significant difference between the group, per Welch's test ($F(2, 19) = 4.53$, $p \leq 0.05$). The difference is significant between BIO (1 ± 0) and CM (1 ± 1).

Faculty and Staff Networks

There are no differences in how students of these various subfields connect with faculty and staff. Advisor selection was slightly different. Six interview participants entered the doctoral program interested in Subfield A. While one student became more interested in Subfield C, the other five students worked in field A. Three of them left Subfield A, because they received little to no guidance and made little to no progress. All three seemed satisfied with their new subfields. One participant was surprised how welcoming and community-oriented Subfield B was compared to Subfield A:

> With the current group, we share what we're doing with everyone. Everyone questions, and the questions range from clarifying something to completely blowing your mind and putting you on a whole new tangent. It just feels communal kind of thing, and I think that has been a lot more healthy for me, in terms of my productivity.

Two interview participants observed tension between faculty in Subfield A and Subfield B. While one participant also observed faculty tension within his own subfield, he has noticed the separation of the two subfields. The other participant observed snide comments from Subfield B regarding Subfield A but not vice-versa.

None of the network attributes have statistically significant differences among the subfields.

Regression

Regression was run both by introducing the subfield variable into the regression model and analyzing cases by subfield. The subfield variable was split into two variables, one for BIO and one for CM.

For peer networks, introducing the subfield variable into the equation produces a statistically significant model:

$$\begin{aligned} T_{Deg} = 6.61 + 1.24\Phi_{BIO} + 0.130K_{Out} + 0.123K_{WIn} - 0.056K_{WOut} + 0.646P_{In} \\ - 0.432P_{Out} + 0.321P_{WOut} - 0.153G_{Out} - 0.050R_{WOut} + 20.2R_{Btwn} \\ - 0.350O_{In}0.047O_{Out} + 0.141C_{WOut} - 71.9C_{Btwn} \end{aligned} \quad (4.29)$$

where ΦBIO is the biophysics research subfield variable. In this model, having one's research in biophysics increase the time to degree by approximately a year and a semester. This model is significant for $F(14, 37) = 3.70$, $p \leq 0.001$. The correlation coefficient is 0.767; r^2 is 0.589, meaning the model explains 58.9% of the variance.

When considering cases by subfield, four student-faculty/staff models are statistically significant. The following model is for BIO doctoral students and their connections to higher prestige faculty:

$$T_{Deg} = 5.47 - 0.910C_{HF} + 3.78K_{HF} - 1.34P_{HF} + 1.80P_{HFW} \tag{4.30}$$

This model is significant for $F(4, 8) = 11.8$, $p \leq 0.01$. The correlation coefficient is 0.925; r^2 is 0.856, meaning the model explains 85.6% of the variance.

The following three models are for CM doctoral students. The first model involves network attributes to lower prestige faculty:

$$T_{Deg} = 6.29 - 1.37C_{LF} + 0.314C_{LFW} \tag{4.31}$$

This model is significant for $F(2, 28) = 3.43$, $p \leq 0.05$. The correlation coefficient is 0.444; r^2 is 0.197, meaning the model explains 19.7% of the variance. The following model is for typical prestige faculty network attributes:

$$T_{Deg} = 6.20 - 0.400C_{TFW} - 0.339K_{TF} - 1.76O_{TF} + 0.552P_{TFW} \tag{4.32}$$

This model is significant for $F(4, 30) = 2.90$, $p \leq 0.05$. The correlation coefficient is 0.556; r^2 is 0.309, meaning the model explains 30.9% of the variance. The following model is for staff network attributes:

$$T_{Deg} = 5.97 + 3.92P_{SW} - 1.62R_S + 3.13R_{SW} \tag{4.33}$$

This model is significant for $F(3, 27) = 5.10$, $p \leq 0.01$. The correlation coefficient is 0.601; r^2 is 0.362, meaning the model explains 36.2% of the variance.

4.5.8 Research Type

Survey participants selected either "Experimental" or "Theoretical/Computational" as their research type. Twenty-five experimentalist and thirty theorist doctoral students participated in the survey. Of the interview participants, thirteen experimentalist and fifteen theorist students were interviewed.

Peer Networks

Network formation was similar as were activities and conversations of the interview participants for both research types. While the interview participants generally did not collaborate with other students regardless of research type, five (20%) students conducting experimental research mentioned having another student available to help with research would be useful. Kerr Steele saw having other doctoral students around a means to make up for an absent advisor: "I thought [working alone] would be good for me. And it was, to a certain extent. I learned a lot of things about myself and made a lot of mistakes. But, uh, after a while, I realized- if I didn't have the professor there, I at least need more grad students around to help me."

However, merely having other students working in the same lab does not ensure students receive the help they need. Cooper Shields self-taught himself how to use lab equipment, even though another student worked in the same lab:

> It was difficult in my first year, because there was no one else in my lab really working on the same project. So it was a big learning curve to take a whole semester to learn how to do something that if there was someone else in the lab, like a postdoc or someone, I probably could've learned it in maybe a month. Instead, it was more like 4-5 months. It was sort of my schedule, because I was teaching at the same time and I couldn't be in the lab all the time... There are techniques I wasn't familiar with. There- theres someone else in the lab, but they weren't working on the same project, so I had to teach myself.

Two other participants also mentioned that while there are other doctoral students working in their labs, the students do not work together and must learn to use the equipment on their own.

Several network attributes have statistically significant differences found through t-tests. Weighted in-ties for the procedural network, weighted out-ties for socializing outside of the department, and betweenness centrality for socializing outside of the department show significant differences between theoretical/computational and experimental. None of these network attributes can be assumed to have equal variance for the two groups. Table 4.47 displays these attributes. Survey participants in theoretical/computational had larger values for all three network attributes. There are no statistically significant differences between the two group for the number of mutual ties.

Table 4.47: Network attributes by research type

	Experimental	Theoretical	t(d.f.)
Procedural W. In-ties	2 ± 3	5 ± 5	2.55(50)*
Out Social. W. Out-ties	14 ± 11	25 ± 22	2.31(45)*
Out Social. Btwn. Cent.	0.01 ± 0.01	0.03 ± 0.04	2.17(36)*

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

Table 4.48: Homophily t-test results for the research type variable

	Theoretical/Computational Ψ_{Theor}	Experimental Ψ_{Exp}	t(d.f.)
Dept. Info	0.101 ± 0.1	0.0258 ± 0.1	2.28(50)*
Procedural	0.135 ± 0.06	0.0418 ± 0.1	3.60 (34)[1]***
Coursework	-0.0333 ± 0.08	0.0771 ± 0.1	2.89(27)**
Teaching	-0.0481 ± 0.09	-0.0233 ± 0.1	0.576(17)
Research	0.0174 ± 0.06	0.114 ± 0.1	2.15(33)[1]*
Career	0.0118 ± 0.09	0.0545 ± 0.08	2.25(37)*
Crisis	0.0682 ± 0.09	0.0293 ± 0.09	1.38(44)
In Dept. Social	0.114 ± 0.08	-0.0269 ± 0.08	5.69(43)***
Out Dept. Social	0.0533 ± 0.09	-0.0118 ± 0.1	2.27(45)**

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$
[1] = Equal variance not assumed

Homophily was analyzed for research type by using t-tests to compare correlation coefficients. Table 4.48 displays these data. Ψ_{Theor} denotes the correlation coefficient for theoretical research, while Ψ_{Exp} denotes the correlation coefficient for experimental research.

Ψ_{Theor} tends to be slightly to somewhat homophilous for social purposes (departmental information, crisis, socializing in the department, and socializing outside of the department. Survey participants in experimental research are more varied, with Ψ_{Exp} being slightly heterophilous for socializing inside and outside of the department. Ψ_{Theor} and Ψ_{Exp} have statistically significant differences for seven purposes; the network for teaching-related reasons, as well as the network for crisis purposes, has no significant difference between the two correlation coefficients. The network for teaching-related purposes is the only network where both Ψ_{Theor} and Ψ_{Exp} are heterophilous.

Reciprocity was analyzed. The research network is the only network where the experimentalists (1 ± 1) and theorists (0 ± 1) have a statistically significant number of mutual ties ($t(35) = 2.28$, $p \leq = 0.05$).

Faculty and Staff Networks

Networks with faculty and staff are mostly similar. The main distinction is that the students conducting experimental research must learn how to use specialized lab equipment. Six students noted their advisors are not available or able to teach them how to use the equipment, so the students had to learn use the equipment on their own. Kurt MicKinney's explanation is applicable to the other five students who learned how to use equipment independently:

> My boss doesn't really work in the lab anymore... Because of that, there are some lab issues. Like how to fix certain equipment, because I have to figure it out on my own without you know, someone who's very experience behind me.

The students conducting theoretical/computational work do not necessarily have more involved advisors, but they also do not have the same issues related to learning to use equipment. Six of them mentioned having research scientist collaborators or being able to go to their peers for help with computer programming.

Quantitatively, several differences between students in theoretical/computational research and students in experimental research exists. A chi-square test (χ^2(1, 55) = 4.29, $p \leq 0.05$) shows that research type is statistically significant for whether one has at least one mentor. Table 4.49 displays these results. A higher percentage (80 %) of those in experimental research have at least one mentor. Fifty-three percent (53.3%) of those in theoretical research have at least one mentor. The odds ratio suggests that students in experimental research are 3.5 times more likely to have a mentor than students in theoretical/computational.

Table 4.49: The contingency table for having a mentor, by research type.

	Does Not Have a Mentor	Has 1+ Mentor(s)
Experimental	5	20
Theoretical	14	16

In terms of network attributes, the following attributes show a statistically significant difference for the two research types: weighted out-ties to staff for teaching-related purposes, weighted out-ties to higher prestige faculty for crisis purposes, and weighted out-ties to staff for research-related purposes. Table 4.50 displays these results. Only the crisis weighted-out ties for higher prestige faculty have equal variance between the two samples. Although each research type has low means for each attribute, students conducting experimental research have higher values for these weighted out-ties.

Table 4.50: Network attributes in the student-faculty/staff networks by research type.

	Experimental	Theoretical	t(d.f.)
Teaching Staff W. Out-ties	0 ± 1	0 ± 0	2.49(17)*
Crisis HF W. Out-ties	1 ± 1	0 ± 1	2.56(53)*
Research Staff W. Out-ties	0 ± 1	0 ± 0	2.24(30)*

* = $p \leq$ *0.05*; ** = $p \leq$*0.01*; *** = $p \leq$*0.001*

Regression

Regression was run both by introducing the research type variable into the regression model and analyzing cases by research type. The research type variable was introduced as a dichotomous variable for experimental research.

One model for peer network attributes is statistically significant. This model is as follows:

$$T_{Deg} = 6.36 - 0.82\eta_{Exp} + 0.082K_{Out} - 0.236P_{Out} + 0.089P_{WIn} + 0.152P_{WOut} - 0.91G_{Out} - 0.249I_{WIn} - 0.169C_{Out} + 0.060C_{WOut} \quad (4.34)$$

where η_{Exp} is the experimental research variable. The weight on this variable indicates that being in experimental research reduces the time to degree by almost a year. This model is significant for $F(9, 42) = 3.61$, $p \leq 0.01$. The correlation coefficient is 0.661; r^2 is 0.436, meaning that the model explains 43.6% of the variance.

Six student-faculty/staff models are statistically significant when performing regression on particular cases. Three of these models were developed using theoretical/computational cases. The first model involves student interactions with lower prestige faculty:

$$T_{Deg} = 6.64 - 0.892K_{LF} - 1.36R_{LFW} \quad (4.35)$$

This model is significant for $F(2, 19) = 3.56$, $p \leq 0.05$. The correlation coefficient is 0.522; r^2 is 0.273, meaning that the model explains 27.3% of the variance. The second model involves student interactions with typical prestige faculty:

$$T_{Deg} = 7.206 - 0.461P_{TF} - 2.55P_{TFW} + 0.507R_{TF} \quad (4.36)$$

This model is significant for $F(3, 18) = 5.90$, $p \leq 0.05$. The correlation coefficient is 0.601; r^2 is 0.361, meaning that the model explains 36.1% of the variance.. The third model involves student interactions with higher prestige faculty:

$$T_{Deg} = 6.91 - 1.04K_{HF} - 1.54P_{HFW} \quad (4.37)$$

This model is significant for $F(2,\ 19) = 8.15$, $p \leq 0.01$. The correlation coefficient is 0.679; r^2 is 0.462, meaning that the model explains 46.2% of the variance..

The other three of these models were developed using experimental cases. The first model involves student interactions with lower prestige faculty:

$$T_{Deg} = 5.70 - 0.913K_{LF} - 1.18O_{LF}01.95P_{LFW} \tag{4.38}$$

This model is significant for $F(3,\ 26) = 5.76$, $p \leq 0.01$. The correlation coefficient is 0.632; r^2 is 0.399, meaning that the model explains 39.9% of the variance. The second model involves student interactions with typical prestige faculty:

$$T_{Deg} = 5.65 - 0.261K_{TF} - 0.824K_{TFW} + 0.166G_{TF} + 0.201G_{TFW} - 2.65O_{TF} + 0.533P_{TFW} \tag{4.39}$$

This model is significant for $F(6,\ 23) = 4.54$, $p \leq 0.01$. The correlation coefficient is 0.736; r^2 is 0.542, meaning that the model explains 54.2% of the variance.. The third model involves student interactions with staff:

$$T_{Deg} = 5.51 - 0.138I_S \tag{4.40}$$

This model is significant for $F(1,\ 28) = 5.27$, $p \leq 0.05$. The correlation coefficient is 0.398; r^2 is 0.158, meaning that the model explains 15.8% of the variance.

4.5.9 Regression with All Demographic Variables

Regression analysis was conducted by including all demographic variables along with network variables. Backwards elimination was used to refine the model.

The following model is for peer network ties:

$$T_{Deg} = 3.76 + 0.945\gamma_F + 0.498Y_{Prog} + 1.20\upsilon_{LAC} - 0.791\rho_D - 0.680\rho_{EM} + 0.723\eta_{Exp} - 0.237G_{In} + 0.058G_{WIn} - 0.125R_{Out} + 8.10R_{Btwn} \tag{4.41}$$

where γ_F is for gender; Y_{Prog} is for year in program; υ_{LAC} is for liberal arts colleges;

ρ_D is for being in a dating relationship; ρ_{EM} is for being engaged, married, or in a domestic partnership; and η_{Exp} is for conducting experimental research. Y_{Prog} is an ordinal variable. Each dummy variable is coded as 1 for having that demographic category; for example, if you attended a liberal arts college, υ_{LAC} is 1 and 0 for all others. γ_F is coded as 1 is for women, 0 is for men. This regression model is significant for $F(10, 41) = 9.67$ ($p \leq 0.001$). The correlation coefficient is 0.838; r^2 is 0.702, meaning that the model explains 70.2% of the variance..

Being female, being further along in the program, conducting experimental research, and having graduated from a liberal arts college all increase the time to degree. Being in a relationship of some kind (dating, engaged, married, or domestic partnership) decreases the time to degree. Race/ethnicity, subfield, and student type variables have no significant effect on in this model.

No regression model was significant using all demographic variables for faculty/staff ties.

4.5.10 Network Demographic Variations Summary

Both social demographics, such as gender or race, and academic program demographics, such as year in program, have qualitative and quantitative differences among the various groups contained in each demographic variable. Qualitatively, the differences tended to be more internal issues that may affect socializing with others. An example are issues related to confidence in conducting research. Students did not report feeling alienated by others because of their demographic statuses; that is, no students reported being excluded based upon gender, race, and so on. Some of the differences are more neutral, such as students who are married or dating spending time with other married or dating couples.

Table 4.51 lists the purposes for peer networks that have statistically significant differences among the groups within each demographic variable. The variable that has the most differences among the demographic categories is “Year in Program.” The network attribute that has the most demographic differences is coursework weighted in-ties; three demographic variables have statistically significant differences among the

Table 4.51: Peer Network Purposes with Differences in Demographic Categories

Network Purpose	Network Attribute	Frequency	Demographic
Dept. Information	W. Out-ties	1	Undergrad. Institute
Procedural	Out-ties	2	Year In Program, Relationship Status
	W. In-ties	1	Research Type
	W. Out-ties	2	Relationship Status, Subfield
	Btwn. Cent.	2	Year In Program, Subfield
Coursework	W. In-ties	2	Gender, Student Type, Year in Program
	In-ties	1	Year in Program
	Out-ties	1	Year in Program
	W. Out-ties	1	Year in Program
	Btwn. Cent.	1	Year in Program
Teaching	-	0	-
Research	-	0	-
Career	W. In-ties	1	Year in Program
Crisis	Out-ties	1	Binary Race
	In-ties	1	Year In Program
	W. In-ties	1	Year In Program
Social. Inside Dept.	Out-ties	1	Year in Program
	W. In-ties	1	Year in Program
	Btwn. Cent.	1	Year in Program
Social. Outside Dept.	In-ties	1	Year in Program
	W. Out-ties	1	Research Type
	Btwn. Cent.	1	Research Type
Multiplex	-	0	-

categories in each variable. The only demographic to show a difference in mentoring is research type. Physics doctoral students in experimental research are 3.5 times more likely to name a mentor than those in theoretical/computational research. Table 4.52 lists the purposes for student/faculty-staff networks that have statistically significant differences among the groups within each demographic variable. The "Year in Program" variable has the most differences in network attributes. Career and socializing inside of the department have the most demographic variable differences.

Table 4.52: Student-Faculty/Staff Network Purposes with Differences in Demographic Categories

Network Purpose	Network Attribute	Frequency	Demographic
Dept. Information	Out-ties (LF)	1	Year in Program
Procedural	-	0	-
Coursework	W. In-ties	1	Gender
Teaching	Out-ties (HF)	1	Student Type
	W. Out-ties (HF)	1	Student Type
	W. Out-ties (Staff)	1	Research Type
Research	W. Out-ties (Staff)	1	Research Type
Career	Out-ties (HF)	1	Gender
	W. Out-ties (LF)	1	Year in Program
	W. Out-ties (HF)	1	Year in Program
	W. Out-ties (Staff)	1	Year in Program
Crisis	Out-ties (HF)	1	Relationship Status
	W. Out-ties (Staff)	1	Year in Program
	W. Out-ties (HF)	1	Binary Race
Social. Inside Dept.	Out-ties (HF)	1	Gender
	Out-ties (TF)	1	Gender
	Out-ties (Staff)	1	Student Type
	W. Out-ties (Staff)	1	Year in Program
Social. Outside Dept.	W. Out-ties (LF)	1	Year in Program
	W. Out-ties (TF)	1	Undergrad. Institute
Multiplex	Out-ties	1	Gender
	W. Out-ties	1	Gender

Homophily was examined for each demographic variable using point-biserial correlation coefficients, which are represented as Ψ with subscripts denoting which population is being discussed. Regardless of identity, the survey participants tended to be slightly to somewhat homophilous for each network purpose; the correlation co-

Table 4.53: Statistically Significant Differences in Homophily by Network Purpose

Network Purpose	Frequency	Demographic
Dept. Info	3	Gender; Year in Program; Research Type
Procedural	2	Year in Program; Research Type
Coursework	4	Race/ethnicity, non-binary; Year in Program; Subfield; Research Type
Teaching	1	Year in Program
Research	2	Year in Program; Research Type
Career	4	Gender; Year in Program; Relationship Status; Research Type
Crisis	3	Gender; Year in Program; Relationship Status
Social. Inside Dept.	3	Gender; Year in Program; Research Type
Social. Outside Dept.	4	Gender; Race/ethnicity, non-binary; Year in Program; Research Type

efficients are infrequently heterophilous or a representative mix of demographic categories. Some populations tended to be more homophilous than their counterparts; for example, women are more homophilous than men for several network purposes.

These categories within each variable were analyzed using *t*-tests, ANOVAs, or Welch's tests. Table 4.53 displays data on the number of times that a network purpose has a statistically significant demographic difference. Every network purpose has at least one demographic variables where the categories have significant differences. The "Year in Program" variable has statistically significant differences among its categories for most network purposes. This indicates that some years are more homophilous than others. The network purposes that have the most demographic differences are coursework, career, and socializing outside of the department. Differences among the categories for career purposes may have a straightforward explanation for the "Year in Program" variable. Junior students selected senior students but not vice-versa, due to the direction of advice or benefits in the communication.

Table 4.54: Regression Models Per Demographic, Variable Method

	Student	Lower Pres.	Typical Pres.	Higher Pres.	Staff	All
Gender	0	0	0	0	0	0
Binary Race	0	0	0	0	0	0
Non-binary Race	0	0	0	0	0	0
Student Type	0	0	0	0	0	0
Year in Program	1	1	1	1	1	0
Undergrad. Inst.	1	0	0	0	0	0
Relationship Status	1	0	0	1	0	0
Subfield	1	0	0	0	0	0
Research Type	1	0	0	1	0	0
Total	5	1	1	2	1	0

Recirpocity was also analyzed by network with respect to demographic variable. The binary race variable indicates that White students have more reciprocated ties than Non-White students for career and crisis purposes. For the “Year in Program” variable, the procedural and career purposes have significant differences. For both networks, those in their 5+ year tended to have more reciprocated ties. The number of reciprocated ties for career purposes were significantly different between single and married participants, with single participants having more reciprocated ties. BIO and CM participants have differences in reciprocity for procedural networks, with BIO having a smaller range of variance.s Experimentalists tended to have more reciprocated ties for research than theorists. The career network showed the most differences within each demographic variable.

Table 4.54 is a frequency table of the regression models when the demographic variable is introduced into the model. The majority of the regression models for this method are for peer networks. However, few models involving faculty or staff network attributes are statistically significant for this method. The majority of the demographic variables related to academic careers, such as year in program or undergraduate institute.

Table 4.55 displays the frequency of regression models when cases were selected.

Although staff have the highest number of regression models (8), the number of regression models is similar for the faculty and staff network attributes. Relatively few models are statistically significant, but the case selection model for faculty staff yields a higher percentage (11.5%) than the variable method (9.26%). This is an interesting contrast to the variable method where the majority cases are for peer networks, 9.26% for the variable method and 0.641% for case selection.

In summary, there are statistically significant differences for each demographic category. While qualitative differences appear for some of the demographic groups, quantitative differences appear for all of the demographic variables. When examining network attributes through t-tests, ANOVAs, or Welch's test, various groups within the demographic variables have significant differences. These differences vary for peer networks and faculty/staff networks, with some network purpose not showing no statistical difference for any of the demographic variables.

However, all network purposes show a difference when comparing groups within a demographic. The regression model show differences between the demographic variable and case selection methods; more models that are statistically significant are for peer networks are created when the demographic variable is inserted into the model, while more faculty and staff regression models that are statistically significant are created though case selection.

Table 4.55: Regression Models Per Demographic, Case Selection Method

	Student	Staff	Lower Pres.	Typical Pres.	Higher Pres.	All
Male	1	1	1	0	0	1
Female	0	0	0	0	1	0
Non-White	0	0	1	0	0	0
White	0	0	0	0	0	0
Asian	0	0	0	0	0	0
Other Non-White	0	0	1	0	0	0
International	0	0	0	0	0	0
U.S. Domestic	0	0	0	0	1	0
1 Year	0	1	0	1	0	0
2 Year	0	0	0	0	0	0
3 Year	0	0	0	0	1	0
4 Year	0	0	0	0	0	0
5 Year	0	0	0	0	0	0
6+ Year	0	1	0	0	0	0
Private University	0	1	0	0	0	0
Public University	0	0	0	1	1	0
Liberal Arts College	0	0	0	0	0	0
International University	0	0	0	0	0	0
Single	0	1	0	0	1	0
Dating	0	0	0	0	0	0
Engaged/Married	0	1	0	1	0	0
BIO	0	0	0	1	0	0
CM	0	1	1	1	0	0
HE	0	0	0	0	0	0
Experimental	0	1	1	1	0	0
Theoretical	0	0	1	1	1	0
Total	1	8	6	7	6	1

4.6 "Do other factors hinder or help doctoral students in physics participate in social networks? And if so, which factors and social networks?"

While the study was designed to be thorough in its questions and analysis, the interviews delved into other topics that are relevant to understanding how and why physics doctoral students connect with each other and their faculty/staff. The following sections are based on these qualitative data.

4.6.1 Physics Identity

Hypothesis #4 states that students with strong physicist identities will be better connected in research, coursework, and personal support networks. No questions on the survey or in the interview protocol delved into the physicist identity, but I anticipated that the interview participants may indicate signs that they identify with the career. While the majority of students did not mention being a physicist or scientist, either literally (e.g., "As a physicist....") or as general way of life, five (17.9%) students did. Below are two quotes exemplifying identifying as a physicist:

> I really like hanging out with professors, because they always have so many smart opinions. I'll give you an example... So this time, I was hanging out with some other professors and we saw some Chinese writing. But we couldn't figure out all the characters. Because we're scientists, we had to figure it out. Everyone tried to figure out what the letters were and had different ways. That's kind of a fun thing. I really enjoy those stuff. - *Natalie Wilson*

> [*Response regarding procedural support*] The problem is- I have an issue when people don't define their terms. So when you go to the website, it says things but it won't define what things mean. Most people will probably come to the first conclusion about it, and they will go, "It obviously means this." But I think it's my personality and my nature as a physics person that you haven't actually defined what this term means. I can't

> assume this. How do I know this is what it is? I start thinking in circles.
> - *Lysander Barber*

What is interesting is that four of these five students mentioned having difficulties within the doctoral program.

One participant's interview response suggests that one's physicist/scientist identity is relative according to who one is around. Kerr Steele's physicist identity changed when he switched labs:

> I felt more intimidated by the people in Spencer's lab. They were much older, ready to graduate, but it wasn't just that. They- they knew a lot about everything and were very serious about it. They were physicists, and I was intimidated by the way they'd discuss things. Whereas when I went into the other lab, I was the only physicist and I could be the expert in the field. I could talk to people and share ideas. Also, I could be intimidated by all the words they were using, because they were in a different field, but I could also add something useful. Like an important part.

In Spencer's lab, he explicitly described other doctoral students as physicists even though Kerr is also a physics doctoral student. When he switched labs where there were no other physics doctoral students, he referred to himself as physicist.

4.6.2 Barriers to Doctoral Students-Faculty Socializing

Several barriers exist that impede the doctoral students from socializing with faculty members. A constant theme throughout the interviews is that interview participants perceived their faculty members as being powerful in such a way that prevented them socializing with faculty. Nine (32.1%) participants mentioned feeling intimidated by faculty due to the faculty's status. The hierarchy in status was explicitly expressed as well; seven (25%) interview participants used the word "boss" to describe their advisor. Below are five quotes where participants describe feeling intimidated:

I find it requires a lot of mental effort to speak with faculty because you have to come up with topics- you care more if you offend them. Because I don't know them as well, I don't know as much stuff outside of physics to talk to them about. And they're also a different age as me, so it makes them more difficult to talk to. - *Malcolm Rollins*

[*On why he does not talk to faculty*] It's a combination of 2 things. I don't know them, and two, I know they're distinguished in their field. - *Albert Burgess*

With my professors and advisor, there's a power balance. I want something from him. Obviously, it's going to impact how we interact socially. He's your boss essentially, right? That colors your relationship an incredible amount, right? Especially when you're starting out. Maybe in a couple years, it'll be more peer-like. And with other professors- there's that. With students, they're just my peers. I interact with them socially. - *Glenn Blevins*

I don't feel that comfortable with socializing with faculty. I guess it's like an age difference and power kind of thing. That person is your boss. If I go to talk them, they are nice and will talk. I have done it in the past, but I don't particularly- I don't particularly go talk to faculty. - *Douglas Cannon*

I don't feel comfortable just talking to faculty I don't really know. Sometimes, I feel I would love to- not only research, but how did they do during their PhD program. If they found some sort of problem or if they were happy and stuff. Sometimes, I feel like talking to them but I don't feel like they are willing to. I feel like that could make my- how they see me, that could change. It could affect my whatever it is at Jonas University.- *Julie Clarke*

As Malcolm and Douglas pointed out, there is also a relatively large age difference between faculty and doctoral students. Including Malcolm and Douglass, six interview participants (21.4%) mentioned age as a factor that contributed to whether they talked to faculty; they tended to relate more to the younger faculty. Brenden Briggs explained this: "[The faculty member] is really young, so it's easy to talk to him. He's not so distant from the grad student experience." Other students suggest that they tend to have more in common with younger faculty.

Four participants pointed out that faculty tends to cluster with one another at events, which affects whether the students talk to faculty. Jacques Booth noted that the faculty he talked to were "whoever was friendly enough to talk." Letitia Lindsey said that faculty will talk to students if the students "bug" them enough. This suggests that faculty do not seek out students at social events.

4.6.3 Intimidation or Fear of Others' Perceptions

For some of the participants, their intimidation to talk others is much more pronounced and specific than a general feeling of differing statuses. Seven interview participants noted specific ways or reasons they would not discuss issues with faculty or students. Calvin Schwartz did not provide specific examples for me, but he said he did not discuss difficulties or issues at work because he does not "want to start controversy." Natalie Wilson was worried about having a stigma attached to discussing issues she faced: "During times of crisis, I couldn't talk much to other students because I don't want to become a complainer. I talked mostly to my friends [who are not in the department." Keagan Weaver concurred with Natalie: "I don't think you [discuss personal issues in the department]. The emotional things- you tend to keep them separate from work."

Julie Clarke sensed that the doctoral students are in denial of their issues: "I'm not sure but I think people try to pretend things are okay, because they don't want people to think less of them so- I actually don't think I'm alone in this situation... I think it's easier to think everything is fine than to talk about it. But I like to talk about it and that's my problem." When I had asked about women in physics groups as a place to discuss these issues, she did not see that as the place: “No, no. Even though I feel like- it’s a sign of weakness to talk about things in an open way in a group, so people wouldn’t do that so openly. They would talk individually to people they know.”

While some students may be able to deny having any issues, others may have evidence such as struggling with particular requirements. Feeling as though one is a failure can have serious consequences in connecting to the faculty. Although Terrence Winters has been successful in the doctoral program, he still did not feel connected to the department because of his past failure:

> There are all sorts of people who do these sort of extracurricular stuff in association with the department. They’re on the grad student council, they’re going to these seminars and chatting up the professors... Part of the reason I’m not like that, and if you’re looking to get into my head- at the ways I don’t socialize with the rest of the department... It’s a little embarrassing to be at a seminar and look around and see [faculty members who know I did not perform well]. They know exactly how poorly I did... I never felt like I belonged with this group. I also don’t want to give you the false impression that the professors would give me dirty looks or anything. It’s sort of in my own head: “Man, that dude must think I’m an idiot.” I never felt like I could’ve talked to anyone except whoever my advisor was on the time or my colleagues, my classmates. I would’ve felt like the professors had an unfavorable impression of me... You know, I still don’t know what they actually think of me. But in my head, it’s that they think I’m a big dummy, that I don’t actually belong here.

Perhaps the denial of issues that Julie suggested is not just about what others think, but also about how the student perceives herself or himself. Terrence having faced issues in the program has had ramifications on his perception in belonging and his participation in the department. Although he is quite aware that these issues are his perception, he also has not resolved them.

4.6.4 Alcohol and Socializing

Eleven participants mentioned that alcohol is typically involved in their socializing with faculty. This is generally perceived as a positive aspect. Some of the socializing around drinking is going to a bar or pub for a drink with faculty, as previous described in section 4.3.8 by Ronan Willis. The holiday party tends to be the event where students and faculty drink and socialize. Gavin Braun pointed out that it is an incentive to attend the holiday party and socialize with the faculty: "The holiday party, I always go to. I think everyone does. It is the one event that is- there's free booze. That's why everyone goes. And everyone is there. I guess the most I talk to [the faculty] in a social setting is the holiday party, because they're all so drunk. They're more friendly."

Although the majority of participants were neutral or appreciative that alcohol was present at these events, one participant pointed out that providing alcohol at events can have some negative sides. The participant observed there was somewhat a bit of social pressure to drink: "[I was surprised] how much I'm expected to drink at social events. So in that respect, it's sort of awkward when someone offers you drink and you're like 'No.' And then they're like, 'What's wrong?'... So that has led to some awkward conversations." Ultimately, alcohol is perceived as a "social lubricant", allowing faculty and students to converse more freely, but can have its downside when students feel pressure to drink.

4.6.5 Interest in Departmental Events

While many of the interview participants saw departmental events as an opportunity to see peers they do not see as frequently, attending departmental events is contingent on interest in the event. Seven participants discussed how they selected what to attend. Flynn Gardner pointed out that the departmental events can be awkward if they are purely social and one does not know anyone. However, he will attend events that are of interest to him: "I do go to the lunch time seminars where someone gives a talk that's interesting to me. Usually, biologically related. Uh, any time someone uses physics in a novel way or if someone just seems extra smart."

Tyrone Burns was selective by what transpired at the event and the redundancy of topics: "Free food. I would not miss free food. Yes, maybe at a 50% rate of the colloquia. Depending on how interesting the talks sounded. It really varies. I guess- at one point, there was nothing going on in particle physics, but we were waiting for the big, new collider to be built. And every other talk was 'What's going to happen when this big thing gets built?' And I got really sick of those. You know, the same talk over and over." Gavin Braun made a similar observation: "Yeah, I think the colloquium should be about [atypical topics aimed at a general physics audience]. Because if you wanted a more specific thing, the condensed matter theory seminars are better for those."

Some students are not selective by topic but the speaker's ability to give an engaging talk. Brenden Briggs used the colloquium lunch to determine if the speaker will give a good talk: "I would say, even if I- most of the time, I understand the first half and then I lose my concentration and it's hard for me to get back. They're an hour. Some of the speakers are real good, and they make it easy for people to pay attention. Sometimes, if the speaker goes too deep or uses words I'm not familiar with, I'll stop paying attention. The content and- at lunch, we can sort of vet the speaker. Gauge the personality and how we think the talk is going to be." In summary, participants do not attend departmental events just to see others but if there is something of interest to them.

4.6.6 Age/Lifestyle Differences

In addition to the age differential between faculty and students, five interview participants commented on how differences in age that can affect connecting with fellow students. Douglas Cannon noticed age groups defining social groups: "I guess sort of the age difference becomes bigger and bigger. And also, they hang out with themselves. The groups are sort of separate." Calvin Schwartz saw himself " beyond the phase of going to talks", such as attending all of the colloquia. Although he still attends talks that are of interest to him, he felt that many of the talks are more for younger grad students.

Age difference is not merely being older or younger. The age difference can also indicate a difference in lifestyle and interests. Some of these differences in lifestyle and interests may be a result of being enrolled in a doctoral program. Gavin Braun explained his disinterest in particular activities, which he attributes to the graduate student lifestyle:

> I feel like [my non-grad school friends] want to do old people things I don't want to do. Like run half-marathons and do crap like that. And like themed parties. I hate themed parties. Themed dinners are even worse than a themed party. It's like when you invite people over for dinner and it acquiesces into some random theme... I feel like when you're a grad student- I don't want to call it arrested development. I don't, uh! It's not even- it's stuff people do when their in their early to mid 30s. That's why I call it old people stuff... I think once you're not in grad school, you don't have to interact with people very much... Like it's a smaller group than even in grad school that you need to do half-marathons to meet people.

Although Gavin was talking about his personal disinterest in activities such as half-marathons, his reasoning perhaps may partially explain how age and lifestyle factor into network formation. He pointed out that that people who are the same age but not in graduate school may need other ways to make friends. They also may have different interests, due to not being in graduate school and/or being older. The graduate school experience may mean that similarly-aged people do not participate in these activities.

4.6.7 Time

Nine participants felt that time was a factor that affected their participation in various aspects of the department. Research frequently was mentioned a reason that affected how much time that interview participants would dedicate to activities such as teaching or to social events. Letitia Lindsay noted that one of the faculty members with whom she taught does not recognize that teaching fellows have multiple responsibilities and that she would prefer to be less involved in teaching because of those responsibilities. Archie Calderon also acknowledged that teaching is time consuming, but he does not mind taking the time to work on teaching-related matters.

The number of hours may not be the only issue regarding time. The hour in which events are held may also be an issue; four participants noted the scheduling of events was not always ideal as they working during those hours. Even if the work hours are flexible, the time scheduled may not be ideal. Glenn Blevins explained this:

> I like the ice cream social, but then you're suppose to talk to- especially in the middle of the day, when I'm in a work mode. So at the beginning of the year, we had a social program- the grad students paid for some pitchers for the first years to come out. And that was fun. That was very social. I made a point of being social with new people. When you go to a bar afterward, it's after work and I can get more into a social mode. But during the day, when I'm in my nerdy work mode, I find those things forced. I end up hanging out with my own friends anyway.

When events are scheduled may not only affect attendance but also affect how students socialize with another one.

4.6.8 Need for Physics Friends

Six participants discussed that they appreciated having physics friends, suggesting that there something different about their friends with physicists doctoral students than in other disciplines. In section 4.5.1, Julie Clarke and Letitia Lindsay's disinterest in women in STEM groups suggest that there may be something different about women in physics than in other STEM disciplines.

For other students, having friends within the department may mean they receive relevant and specific advice and support Leo Frost said that when he switched advisors, it was helpful to talk to other students about the process and to receive advice on who to select. There also may be a rapport that may be found outside the department. Kurt MicKinney described his experience as a community:

> For the majority of people I know in the university, it's similar to being friends. It isnt a strict work relationship, which is nice... You don't have

> to worry about saying stupid stuff. You can pick up some bad opinion on politics, and you can argue it for fun. You might not like a movie someone else likes, and you can call them out on it. We can just be buddies about it. It's not that serious amongst graduate students. There is no hierarchy among whose- theres no hierarchy among graduate students at all. We know what each others going through. Band of brothers type of idea.

While they may be able to find others outside of the physics department with whom they can talk about some of these topics, locating someone outside of the physics department who understands the life of a graduate student in the Jonas University physics department may not be easy to find.

4.6.9 General Personality Traits

Four interview participants described themselves or others as being shy or not good at approaching others. Two participants attributed that to the personalities of physicists. My experience during the data collection concurs with the observation that many students may be shy.

As noted in section 3.2.4, I learned from colleagues and friends that potential survey participants had questions regarding the study and myself; however, no one contacted me during the data collection. One interview participant mentioned that this study was a topic of conversation among his friends and they had questions about the study. Even though we had just completed the interview, he still hesitated to ask his questions. None of his questions were offensive; he and his friends were interested in the purpose of the study and my funding situation. I believe my experiences in data collection provide additional evidence that the doctoral students may indeed be shy.

Chapter 5

Discussion and Conclusions

In section 5.1, the results from chapter 4 are discussed in the order of the research questions. This is followed by a discussion of areas for further research, recommendations for the department, and final conclusions. Although the recommendations were written based upon the analysis of the data from Jonas University, these recommendations may be applicable to other departments.

5.1 Results Discussion

5.1.1 Doctoral Student Network Participation

Peer Networks

As indicated by the quantitative data, the results from section 4.2 show that the physics doctoral students participate in networks for every purpose included in this study. The ties in these networks are largely established in the first year, within one's cohort, as indicated by interview participants. Hypothesis #8 does not appear to be supported based upon the data, because interview participants focused on their connections to their cohort and not their research group.

The literature on collaborations in section 2.3.1 shares many commonalities with how network ties form within one's cohort and how students worked together; the interview participants mentioned geographic proximity to helping form ties. Prior research also shows collaborators share similar status, knowledge base, and research interests. Because they are all in the same cohort, they are presumably of similar status and have a similar knowledge base. However, the same reasons that draw doctoral students in their first year to work together should also apply to the research environment. Not only does prior research suggest that but also the reasons that promote collaboration exist. Although they may not have similar levels of knowledge initially in their research groups, they do have geographic proximity to others and the difference in knowledge on the research subfield would decrease over time. Members of one's research group would meet other criteria for collaboration, such as similar research interests and being the same subfield. Given that doctoral students spend, at a minimum, 4 years working on research, there must be something unique that makes these cohort ties so strong.

Recall that Granovetter's strength of ties theory suggests that the length of the relationship, emotional intimacy, frequency of contact, emotional intensity, and reciprocity are needed for a strong relationship. For the doctoral students who were interviewed, the time-independent variables of emotional intimacy, emotional intensity, and reliance may be more important in creating strong bonds than the length of the relationship or frequency of contact. The length of the relationships to either the research group or cohort would be similar, especially when one approaches degree conferral. Frequency of contact may be better defined as frequency of contact through effort. For example, making plans to have lunch requires more effort than simply seeing someone in one's office. Although some participants believed that having the opportunity to meet other by chance is important, for bonds to truly be strong, effort may be needed. While this may be obvious that effort is needed to form strong bonds, whether and why effort is or is not being made to make connections in the research group is not obvious. From common interests to working in the same lab space, many of the elements that lead to cohort bonds should lead to bonds within the research group and yet there are few strong research ties.

Meeting students outside one's cohort is not just relegated to the lab. Although there are departmental events that provide opportunities to have cross-cohort interactions, the interview participants noted that they tend to socialize with people they knew from their cohort. Hypothesis #7, which states that departmental events will not help students make new connections, is supported. The interview participants stated that the same people tend to attend the departmental events; however, they also noted they tend to talk people within their entering cohort. Because the interview participants who attended departmental events are from different cohorts, there is still some opportunity to talk to people with whom they are less familiar. Some interview participants speculated that it may be a personality trait of physicists to not actively seek out new connections. Although students may not form new network ties at departmental events, they still find value in these events; these events are an opportunity to sustain ties to their cohort, particularly cohort members they do not see otherwise.

There are several striking aspects to the quantitative data. One is surrounding survey participants and non-survey participants. For every network purpose, survey participants have more in-ties, more weighted in-ties, and higher betweenness centrality than non-survey participants. T-tests were run to compare participants and non-participants. Although participants and non-participants are within one standard deviation of each other for all of the network attributes, the majority of t-tests are statistically significant.

The interview data provide no explanation to explain why there would be a statistically significant difference between participants and non-participants; the survey data also dispel any of the explanations I have considered. One explanation is that the non-participants may be primarily connected to one another and not as well connected to the survey participants. In other words, there may be two groups of students that are not well connected and for whatever reasons, one group was more inclined to participate in the survey. Another explanation is that students who have few connections may be less willing to take the survey. Lastly, I considered demographic differences; perhaps students of certain demographics, such as racial minorities, may have feared being identified if they are not in the majority. More senior students may lack the time because of working to complete their degrees or have already graduated and are busy in their careers.

However, one-hundred nine (109) out of 110 participants were selected at least once for the network purposes. Data on the maximum number of in-ties indicates that some non-participants are sought-after resources by survey participants. This suggests the non-participants are not necessarily social isolates. Standard deviations for both participants and non-participants are comparable, further indicating that the range of data within each group may be comparable. Perhaps a combination of the above explanations would explain why some students chose not to participate.

The statistically significant differences between network attributes by purposes can be seen in table 6.3. The mean betweenness centrality for each purpose tends to be similar for all network purposes. Betweenness centrality is also low, suggesting that the majority of students are not acting as bridges to other peer groups. As seen in table 4.22, the categories with the highest averages for ties (in, out, weighted-in, weighted-out) are for departmental information and socializing within the department. These plots also tend to be denser than the plots for other purposes; only the coursework network is denser.

The results for departmental information are particularly interesting, because the interview participants in section 4.3.1 did not believe there was much, if anything, to discuss regarding the department. This would suggest that they would discuss departmental matters less frequently. Perhaps their perceptions on the amount of discussion surrounding the department are relative in that they believe that "office gossip" would be more prevalent in a different situation, such as if they were in a different department or working a full-time job. The difference between the qualitative and quantitative data may also be that they genuinely do not discuss departmental matters that often with peers, but they discuss other matters even less.

Hypothesis #9 stated that being more central for degree centrality would vary by network type. This is somewhat supported, as one participant is most central for three purposes and another for two. For the participant who is most central for two purposes, the two purposes (coursework and research) are somewhat related; this may be indicative of physics knowledge or skills. For the participant who is most central for three purposes, the relationship among the three purposes is less clear. This participant is most central for departmental information, career or professional advice, and crisis support.

Reciprocity, which was found for just survey participants, varied for the networks.

Survey participants tended to have more out-ties than in-ties. Why this occurred is unclear. For some of the purposes, the difference may be explained because the flow of information would not be mutual. If one is seeking career advice, one may seek out more senior students who have more knowledge and experience. The more senior student would not necessarily seek out a more junior student for career advice.

For other purposes, such as discussing research, a reason behind the direction does not necessarily have an obvious answer. Perhaps students perceive research discussion as receiving advice. Then, similar to career or professional advice, the information would be directional. For example, Hermes may go to Leila for research advice and would select Leila as a tie for research-related reasons. Because Leila provided information and did not receive advice, Leila may not select Hermes as someone with whom she discusses research. For the socializing within the department or outside of the department, the reciprocity issue is even less clear; there does not seem to be a hierarchy or direction that would suggest a difference in perception of the question. For example, if Leila and Hermes have dinner together during the weekend, this should be mutual.

Student-Faculty/Staff Networks

Interview participants mentioned meeting the faculty by enrolling courses that faculty members taught. In addition to meeting through courses, students set up appointments with faculty when they searching for an advisor. When selecting their advisors, the interview participants selected their advisors primarily based upon the research topic. Practical considerations, such as the availability of funding, were also considered. The literature in section 2.4 strongly demonstrates the importance of the advisor and how circumstances beyond the research topic or practical matters can affect degree completion and future prospects.

Despite the research on doctoral student and advisor relationships emphasizing the critical nature of these relationships, these decisions appear to be made rather quickly and without much consideration to other points such work-style compatibility or the needs of the student. This suggests that the bridge between the research on advisors and students applying the research to advisor selection may not exist. This can lead to an increase in the time to degree and cause unhappiness within the program; Natalie Wilson described a very negative situation with her first advisor where she was quite unhappy. Perhaps had she known to inquire further about the advisor's management skills, she would have avoided this situation.

Committee member selection is done with a bit more consideration. This is partially because the department has requirements that mandate the students to select faculty of different attributes. While there are formal requirements to follow, some students looked at other aspects of potential members. However, these considerations are influenced by the advisor who provided feedback on who should be asked. Although the majority of students who have committees seem to interact minimally with their committee members, more care and advisement appears to occur for committee selection than for advisor selection. The amount of care that committee selection receives, compared to advisor selection, is peculiar because of how little a student's committee appears to do.

Mentoring relationships developed either because of the advisor being a mentor or because faculty actively took a role in becoming a mentor. In other words, the interview participants did not actively seek out mentoring. The faculty member was the impetus in establishing the mentoring relationship. Similar to other literature on mentors, the mentors serve a variety of purposes. However, although they provide more practical advice, the role of the mentor seems to be primarily emotional support.

The advisor relationships are complicated and difficult to generalize. Some interview participants have good relationships with their advisor, while others have had horrific experiences with the same advisor. Although every advisor is not the right person for every student, the contrast in experiences is extreme. There is no obvious pattern to indicate why two people may have completely diametric experiences with the same advisor. Advisor compatibility may be quite individualized, but the high contrast in experiences is surprising. Determining who is a suitable advisor for a student may require more comprehensive understanding of the student and the prospective advisor.

Mentoring relationships in this study are also complicated. One point the literature mentions frequently is the student's advisor is not always the best choice to be the mentor for many reasons, including interest and time to be a mentor. In this study, Greg Hardin was named as mentor. However, some of Greg's students indicated that he may not be a good research advisor. This suggests that the converse of the advisor not being the best mentor is true, that the mentor may not be the best advisor. This also suggests that being a good research advisor and being a mentor to doctoral students in physics may require different skill sets. The research advisor may need to have skills and knowledge similar to pedagogical content knowledge, meaning that they need to know how to teach one how to conduct research. The mentor may need to be personable and able to provide emotional support, but could possibly lack the skills needed to teach one to do research.

Staff members also provide emotional support for students. In particular, Aileen Brewer, who is a department coordinator, was frequently named as someone who is emotionally invested in the students. Similar to mentoring relationships, Aileen puts forth effort into knowing the students and developing friendly relationships with them. What is different is that students appear to be more comfortable in approaching Aileen than most faculty; the quantitative data also suggest this. While some of the ease in talking to her may be due to Aileen's personality, this also be due to a difference in status.

Quantitatively, survey participants did not interact frequently with faculty. Six faculty members were not selected for any purpose. Higher prestige faculty members were more frequently named and noted as being contacted more frequently than typical or lower prestige faculty. Typical prestige faculty were named less frequently by survey participants than lower and higher prestige faculty; this is true even when examining the data as percentages. This may be because typical prestige faculty do not tend to have large groups or not be involved in teaching introductory undergraduate courses that have teaching fellows. The interview data indicate varying levels of interest in talking to faculty; thus, typical prestige faculty would have fewer opportunities to interact with students. Regardless of the faculty's prestige rankings, students may not feel comfortable talking to faculty, due to power dynamic issues or lacking commonalities; these are further discussed in section 5.1.5.

Survey participants did not always have a person for each network purpose, either peer or non-peer (faculty, staff, et cetera). Hypothesis #2 suggests that students will seek connections outside of the department if they do not have connections for particular purposes within the department. However, this hypothesis is not demonstrated in these data. If the survey participants did not have a contact within the department for the purpose, they did not indicate that they had a tie outside of the department.

For some of these purposes such procedural, they may not need support from anyone. For other purposes, the results suggest that some students lack adequate support. Survey participants may not have included ties for times of crises if they did not experience a crisis and perhaps would not feel confident in hypothetically naming someone. Having no one with whom they socialize either at or outside of the university is concerning. Given the long hours spent working on the doctorate, having no one with whom they socialize within the university suggests that they may be lonely. Having no one with whom they socialize outside of the university suggests they not have close friends. Although some participants may have skipped this question, several of the ones who have no contacts for various purposes did not skip the question; they provided names for purposes where they did have departmental contacts.

5.1.2 Information and Support in Social Networks

The interview participants discussed a variety of topics with peers within their social networks. As indicated by the quantitative data from section 4.2, the physics doctoral students tend to interact with one another more than they do with faculty or staff. The literature in section 2.3 suggests that doctoral students tend primarily rely on one another but do form ties with faculty. While the doctoral students in this study do have ties to faculty, they are mostly weak relationships; this affects what information is provided to doctoral students.

Hypothesis #3 predicts that doctoral students are interested in multiple types of information, but they are particularly interested in information that is related to degree completion or their careers; this hypothesis is somewhat supported, as they were less interested in matters that had no minimal bearings on their degree, such as teaching or fulfilling elective coursework, but they also sought purely social connections. Also, interest for items related to degree completion varied.

Information for degree completion includes the following topics: procedural, coursework, and research. Students primarily named Aileen Brewer, a staff person, as an excellent resource to help navigate paperwork and other procedural matters. Aileen has managed to form relationships with the students; Racquel Christensen even said Aileen is described as the "mom" of the department. This result is particularly interesting, because the students likely do not need handle procedural matters more than a few times during the semester. Procedural matters do not seem to be topics that would foster closeness. The former suggests there is more complexity to Granovetter's strength of ties theory; these doctoral students feel close to her and yet likely do not see Aileen frequently. The latter demonstrates the limits to defining purposes; while conversations may be primarily about one topic, they can deviate into other topics such as inquiring about one's family after discussing research. The interview participants must have discussed other matters with Aileen or vice versa for them to feel so warmly about her.

Students completing their core coursework worked together to understand how to complete problem sets. For elective coursework, these discussions did not appear to occur. Students also did not seem particularly interested in discussing the topics in the elective courses. This may a result of core coursework being more challenging than elective coursework; Cooper Shields' description of the course he had taken suggests that there are fewer assignments and they may be less challenging. Network formation for coursework may be a result of how the course is structured, either explicitly requiring students to work together or creating challenging assignments.

Research information was primarily provided by the advisor or if available, a postdoc or research scientist. The postdoc or research scientist may be a critical person to have available to doctoral students, because they have more experience than a fellow doctoral student and may be more available than one's advisor. Perhaps this role could somewhat be filled by other faculty, such those on one's committee. As demonstrated in dire situations, such as Tyrone Burns', faculty are willing to work with students who are not their advisees. This may be advantageous for student to receive at least adequate support. However, there may be reasons why this does not occur except in extreme situations.

The information students receive regarding research varies. If they do discuss research with fellow students, they discuss research updates or technical help with computer programming. Some students received broader research advice from their advisors, such as how to write grant proposals. Other students mostly discuss the current research being done with their advisors. Still other students tend not discuss research with their advisors. Regardless of the topics surrounding research discussion, the interview participants are largely on their own to learn the techniques and practices that will allow them to participate in research.

Three important aspects regarding research do not appear to be communicated to the doctoral students. One point not being communicated is how to select an advisor. At least one faculty member appears to have a method for advisor selection that appears to works well. Why this is not communicated with students prior to selecting an initial advisor is unknown; considering the significance of one's research advisor, as discussed in the literature, discussing how to select an advisor would presumably be an essential discussion to have with doctoral students. This information does not appear to be passed down through the peer networks, but the students largely are unaware of how to select an advisor even if they have a good relationship.

Another aspect that is absent for all of the interview participants is whether they are making progress within research. Some interview participants voiced concern whether they were making progress; some even switched advisors because this was unclear. For Kerr Steele, who switched advisors twice, he may have been making satisfactory progress but did not realize it; both advisors being surprised he wanted to switch suggest that. Discussing the doctoral student's progress may help the student realize that she or he is making progress. Doctoral students have less research experience than faculty and may have unrealistic expectations of what progress is in research. This may also facilitate opportunities to talk to faculty and improve upon relations between students and faculty.

The third aspect that may not be communicated is ways in which students can collaborate or discuss research with one another. Interview participants mentioned how different their work is from their peers and how that prevents discussing or collaborating on research. There may be areas in which they can collaborate with their peers that they do not recognize. Natalie Wilson's comment suggests that novice researchers, such as doctoral students, cannot see areas in which they can collaborate with others. Collaborations that do occur are guided by the advisor, indicating that the advisor may be suitable person to facilitate this. If collaboration cannot occur, research discussion with students on different projects may be valuable; Ronan Willis pointed out that a research discussion partner could challenge assumptions that he makes and help him clarify those aspects. A doctoral student working on a different project would be suitable for such a role, as she or he would likely have more questions due to unfamiliarity.

The discussions surrounding careers tend to be about job searches. More junior doctoral students want to know about graduating students' searches. Advisors are sought by the graduating students for help in finding a job. For graduating students, the advice received is ineffective because they are mostly looking for jobs outside of academia. For students seeking careers in academia, the advice and information they receive may not be effective. While students did note that their advisors are helping them obtain postdoctoral positions, there appears to be very little discussion on the job skills or experiences needed to obtain a faculty or postdoc position. Similarly, there appears to be no discussion on the job skills needed for non-academic positions. For example, someone who is interested in working in a particular field may need to know how to use specific software or work with specific types of data. Someone who is interested in working in academia may need to develop strong teaching skills or be published in particular journals. If this information is not received early enough, graduating doctoral students may struggle to find employment in the area of their choosing.

What is discussed in networks more for social reasons varies on location and with whom they are talking. At departmental events, students may default to discussing research if they do not know the other student as well. Students tend not to talk with faculty at departmental events; if they do, it will be small talk or brief discussions on research. The interview participants enjoy catching up with their peers. They do not seem interested in talking to faculty more than they do; some appear to be uninterested.

However, some students do enjoy socializing with faculty in other settings. One faculty member invites the doctoral students who are enrolled in his course out for drinks; these conversations, albeit silly, are appreciated and remembered fondly by the students. They seem at ease with socializing with this faculty member; this may be because the faculty member is making an effort to be social with the students. The students may also just prefer this faculty member due to other characteristics.

When socializing outside of the departmental, students tend to have more personal conversations; this makes sense, because presumably they are among friends with whom they are close. A striking trend, however, is they are deliberately not discussing physics. I noticed this, because I had asked the participants what they discuss when they are socializing out of Jonas University; I did not ask or suggest that they discuss science or work, nor did I ask what they did not discuss. The language they used when mentioning the lack of physics discussion was also striking. The choice to not discuss physics appears to be almost avoiding the topic. I am not sure why this trend occurred. They may simply want to take a break from discussing that aspect of their lives. They may be unhappy in the program and want to avoid discussing unpleasant topics; Douglas Cannon seems to indicate that discussing research is not enjoyable.

Some of these personal conversations may be regarding situations or events that are crises. Crises are primarily in regards to research. These situations illustrate the different but important roles that faculty/staff and peers have in networks, as discussed in section 2.3. Faculty and staff can be instrumental in resolving the crisis, while peers can lend emotional support. While the students who have experienced crises may feel the situations were unjust, they overall are satisfied with the support they received. However, perhaps many of these crises surrounding research were preventable and did not have to become a crisis.

Defining a crisis is challenging, as several participants pointed out to me. However, I am unsure why a few participants had difficulties that strongly appeared to be crises but would not define them as such; experiencing health issues due to stress would suggest a crisis because of the amount of stress that would cause health issues. Given the amount of discussion and level of detail, I do not believe this example, or the other instances, is linked to discomfort in disclosing such information to me. More important than the word that describes the situation, I am unsure whether these interview participants received the support they needed. While they claimed to have resolved the situations, they did not describe how or seemed to rely on themselves to resolve challenging and serious issues. When I became concerned about these situations and showed sympathy, these participants reassured me that they were fine and de-emphasized the gravity of the situations.

5.1.3 Social Network Outcomes

Network outcomes in this study include persistence in the PhD program, perceived progress, and time to degree; these results are in section 4.4. Hypothesis #1 is not supported; students who have more ties in research, coursework, and personal support networks had no statistically significant difference in degree completion. However, other network purposes do make have a difference. The departmental information network for peers was significant for whether survey participants considered somewhat seriously leaving or seriously considered leaving with a master's. The students who somewhat seriously considered leaving mostly have 6-10 in-ties, while the the students who are seriously or were leaving the program mostly have 1-5 in-ties.

Linking departmental discussion to program persistence is unexpected, especially considering that the interview participants viewed this topic as office gossip. Discussing the department is not social, academic, or research support; those purposes would presumably contribute to one's well-being and abilities to complete the program. This result is especially unexpected, because students seem to not believe there is much to discuss regarding the department. Similar to how correlation does not equal causation, this relationship is likely not a simple relationship; that is, discussing the department with few students does not lead to serious consideration of leaving with a master's.

Discussing the department may be symbolic of something else. One possibility is that having more discussion partners for departmental matters contributes feeling as though one belongs and aids in persistence in the program. Students who have not considered leaving the program may already feel as though they belong, regardless of discussion partners, or they are so dedicated to completing the degree that feeling as though they belong does not matter as much.

For students ties to faculty and staff, the results are again unexpected for persistence in the program. The majority of significant contingency tables involve staff ties. Students who were more likely to leave, either seriously consider leaving or were leaving the PhD program, tend to have at least one tie to staff for research or teaching purposes. Students who always planned on completing the PhD program tend have no ties to staff for these purposes. These results are unexpected because previous literature emphasizes the importance of doctoral student-faculty, not doctoral student-staff, relationships. They are also unexpected, because administrative staff generally does not seem to be involved with research or teaching.

As noted previously, this relationship is likely not simple and may indicate other issues. The interview participants saw Aileen Brewer as someone who is supportive and a good resource to resolve issues; students who are seriously thinking about leaving may go to a staff person, such as Aileen, for already existing issues. For example, students may discuss teaching with staff if they are considering becoming a K-12 teacher and not completing the PhD program. If they have issues with their advisor, who is linked the students' research, they may go to staff person; Max Thompson said that students discuss advisor issues with Aileen.

The data for faculty and staff suggest that ranking may not be important. Students who have at least one tie to a non-student (faculty, research scientists, postdocs, or staff) for socializing within the department tend to not consider leaving. Students who have 0 non-student ties for this network tend seriously consider leaving. Having at least one contact, regardless of ranking, for socializing within the department may be important for persistence. Again, this could be because students feel like they belong or are welcome in the department if they have a non-student contact with whom they can socialize.

What should be noted with the contingency tables is the direction of these outcomes is difficult to determine. Does persistence and progress in the program leads to network behaviors (such as having more ties), or do network behaviors lead to persistence? Terrence Winters' comments suggest that progress in the program leads to network behaviors. His past difficulties affect how he chooses to interact with others, at least in his interactions with faculty. Other students, who noted difficulties in the program, have no one with whom they can discuss research. This suggests that lack of social network ties may lead to persistence issues. Because social relationships are complex, the relationship between persistence and network behaviors may not be straightforward.

The two regression models for time to degree include different variables than the ones for the significant contingency tables. Why the relationship of these variables for persistence and time to degree would be different is unclear. Both variables seem to be related and measure similar outcomes; students who did not consider leaving the PhD program would, in principle, take less time to complete their degrees, because they, in principle, would struggle less in the program. Students who struggle more in the program would be more likely to take longer to complete their degrees and be likely to consider leaving the program. The variables related to these outcome variables would presumably be the same.

The regression models themselves are unexpected. Equation 4.1 displays the peer regression model. This regression model has a negative relationship with weighted out-ties for socializing within the department; according to this model, the more one socializes in the department, the earlier one will complete the degree. Frequently socializing with others within the department seems as thought it would increase time to degree, rather than decrease it; frequent socializing would take away time from completing research.

Several reasons may explain this result. This result may be a matter of perception; recall that the mean of out-ties and weighted out-ties is greater than the mean of in-ties and weighted in-ties. Feeling as though one frequently socializes in the department may also be indicative of feeling as though one belongs. The conversation topics when socializing within the department may be related to research; students tend to default to research as topic of conversation at events. Although the interview participants claimed these are mainly updates, perhaps there are subtle effects, such as asking for clarification, that enhance the research. Students may also feel the need to assimilate if peers within one's cohort are approaching their dissertation defense; recall that Lomi et al.'s (2011) study of MBA students suggests friends' grades tend to assimilate to one another. For a doctoral program in physics, perhaps one does not have to be close friends to have a similar effect on degree completion.

Only the regression model for lower prestige faculty was significant. Equation 4.2 displays this regression model. While frequent contact with faculty, regardless of prestige ranking, for research makes sense to decrease, the reasoning behind the relationships of the other variables and time to degree are less obvious. Frequently socializing with lower prestige faculty outside of the department and having career ties with lower prestige faculty decrease time to degree. For socializing outside of the department, these faculty may be more invested in their students which is why they socialize with the students outside of the department. They may also contribute to helping students feel as though they belong.

Frequency of contact for career purposes could increase the time to degree. This may not be negative but as a way of increasing viability on the job market. Students who are in more frequent contact with faculty regarding career purposes may receive better advice, due to a stronger relationship. They may learn that they should develop other skills while still a doctoral student and thus, graduate at a later date.

One issue remains is why only lower prestige faculty ties produced a statistically significant model. The rationale in the previous paragraph are applicable to any faculty. Perhaps the lower prestige faculty have a more uniform relationship with the general physics doctoral student body.

5.1.4 Demographic Variations

The primary motivation of this study was to examine how general affects social networks among physics doctoral students. I examined other demographic variable to determine if the effects observed were truly because of gender. Hypotheses #5 and #6 are in regards to homophily for peers and faculty, respectively. For peers, this is qualitatively mixed. Quantitatively, students overall tend to be homophilous for the various demographics. What is particularly interesting is that unlike the Ibarra study, both men and women are homophilous within their genders. Recall that Ibarra found that the male participants tended to be homophilous, while the female participants were heterophilous. There are many homophily differences between the various years in the program. For faculty, there are too few faculty connections to truly determine this. However, the interview participants emphasized being able to relate better to younger faculty.

Although demographic groups are almost always weakly to somewhat homophilous for all network purposes, homophily in peer networks may be an issue. The point biserial correlation coefficient accounts for the availability of a given demographic. If a demographic category, such as gender or student type, does indeed play a role in one's network ties, this may be limiting for students to find meaningful connections even if the network is weakly homophilous. For example, suppose a female student chooses to form network ties only with other female students. Given how few women there and that social relationships are based on more than gender, the female student may not receive the support she needs or desires.

Furthermore, homophily in one's network may not be a choice. Perhaps other students are consciously or unconsciously choosing to not socialize with others. For example, the homophily data show that students are slightly homophilous by student type. The interview data indicate that some U.S. domestic students are hesitant to socialize with international students. Although the U.S. domestic students may not consciously or maliciously exclude international students, U.S. domestic students may not make much effort into socializing with international students. This may then lead to international students socializing with each other by default and not by a true choice.

Hypothesis #10, suggesting that demographic variables will affect the prior research question, is supported. The results were unexpected based upon the literature in chapter 2. Regarding gender, there are two specific results that do not appear as linked to the other variables. The first is selecting oneself as a source of advice or information on the survey. Of the participants who selected themselves, only one was a woman and she was her only peer contact. She also commented on survey that she experienced loneliness in the department. All of the male participants who selected themselves all varied in terms of other demographics and number of contacts; none of them indicated being lonely. I am not sure how interpret this result beyond what has been presented.

The second surprising result is that two of the female interview participants mentioned not looking to socialize with other women and suggested that women in physics are different from women in STEM. Although they do have some female friends, even within their own department, they seem to have negative experience with socializing with women. No other demographic mentioned being disinterested in socializing with others who shared that demographic category. This result is quite different from countless other literature that suggests when people are in fields where they are currently and historically a minority, they seek each other; this is why countless specialty organizations and cohort hiring exist, to alleviate some of the isolation issues faced by various demographic groups. Although these two women may be an anomaly, they and others may perhaps feel as though they want to divorce themselves from being a minority in their field and try to blend in with the general physics population. In other words, they may be “undoing” gender. They may also internalize sexism or gender stereotypes they have heard from male colleagues.

Besides these two aspects, the other demographic differences are not prominently linked to one demographic variable. Non-White students tended to have fewer peer crisis out-ties. I cannot determine if this is due to a lack of crises, Non-White students simply preferring fewer peer contacts for this purpose, or these students being more isolated. The qualitative data do not indicate these students feel less supported than the White students.

Other peer network results are more distinctly negative. Both liberal arts graduates and women sense they have difficulties in making progress in research. It is unclear whether they are genuinely having difficulties or these are perception issues related to lack of understanding of research or self-confidence. The data do suggest that liberal arts graduates may experience more difficulties; several note that they lack research experience. Less experience would lead to more difficulties, as they may be unfamiliar with research techniques. Experimentalists also tend to face difficulties in research; they are learning how to use unfamiliar equipment on their own, because they have no one in their lab to teach them. However, this also could be a lack of understanding what progress in research is. They may be making progress, but they do not realize it.

Socially, some U.S. domestic students are apprehensive to interact with international students due to the perception of having fewer common interests and fear of being offensive. The international students did not voice a similar concern. I say "perception" because none of the U.S. domestic students indicated what caused them to be apprehensive. Perhaps they have had negative experiences that would cause apprehension, but it may be a lack of opportunities to move beyond their perceptions as Malcolm Rollins' comment suggests. It is unclear whether homophily by student type is a result of this hesitancy.

Students are homophilous by relationship type and year in program, as indicated by the interview data. Regarding relationships, single students have more procedural network out-ties than engaged/married students, as well as higher values for procedural weighted out-ties. This may be a coincidence, because relationship status does not intellectually appear related to knowing what paperwork to file or for which course to register.

The majority of networks differences occurred within the year in program variable.

Students in their first year were better integrated into the coursework network than students in subsequent years. While this may be a result of being primarily with one's cohort for all courses, the qualitative data suggest that this may be partially linked to curriculum; the course may not be optimally designed to encourage more collaborative work, or students in later years may just be enrolled in coursework to fulfill requirements and have little interest in the material. Although no one claimed the elective coursework was easy, it is curious that many of the interview participants felt that the core curriculum coursework was challenging to the point that working in collaborative groups was necessary. Because of the interview data, one would expect differences in whom was selected but not necessarily with the number of ties.

Some of the differences within the year in program categories suggest that students may become isolated the longer they remain in the program. As an example, students in their fifth year have larger values for career weighted in-ties than students in their sixth or higher year. In principle, students in their fifth or higher year should be similar. Students at the fifth or higher year presumably would be at nearing the end of their doctoral students careers and would have similar frequencies in contact for career purposes. The interview data show that students who are in their sixth or higher year chose to actively attend fewer events than students in other years.

Besides interview participants making a few observations that faculty members in one subfield do not appear to get along with faculty members in another, the interview data do no indicate any differences for each demographic interacting with faculty or staff. Ties to faculty also varied by demographic in unexpected ways. Female students named more faculty contacts than male students. This was unexpected, because literature suggests that women have been excluded from socializing with men who are in authoritative positions; while female students did name female faculty, they predominantly named male faculty.

At this stage in one's careers, perhaps women are not having the same experiences as women who are no longer students. This may also suggest that the situation for female doctoral students in physics is improving in some sense. I tentatively suggest this as a possibility, because four of the five female interview participants all struggled with not knowing whether they were making progress towards their doctorates. This may be a confidence issues or a matter of faculty not discussing this with the female students. It could also be that faculty do not discuss whether one is making progress, regardless of gender, but women are more affected than this than men.

The binary Non-White category students indicates that these students have fewer research ties to higher prestige faculty. Other Non-White students have higher values for weighted out-ties to staff for socializing outside of the department than Asian students. There is no indication why this is. What is particularly interesting about the weighted out-ties to staff result is that this is a difference between the Asian and Other Non-White categories, but the difference for research ties to higher faculty is for the binary race/ethnicity categories. As also indicated by the literature regarding race/ethnicity, different populations have both shared and unique experiences. The interactions within networks may be an example of this.

The only quantitative difference for faculty/staff ties and in terms of relationship status is engaged/married students have larger values than single students for weighted out-ties to higher prestige faculty. Why this occurs is again not clear. Although relationships status is likely irrelevant to the nature of the support, this may be indicative of homophily. Faculty members are likely to be married, and engagement/marriage could be indicative of having a similar lifestyle to faculty. However, why this would be specific to higher prestige faculty is unclear.

Similar to peer networks, the majority of the network differences are for year in program. Students who are earlier in the program (first or second year) tend to have more career ties to faculty and staff than students who are further along in the program. This may be indicative of first and second year students, or it could indicate a shift in the student body. This shift could mean that Jonas University is admitting doctoral students who are more ambitious or career-conscious than they have in the past; this change may go beyond Jonas University and indicate a change in doctoral students in physics, STEM, or the general doctoral student body.

Subfield data did not yield any quantitative differences. For research type, students who are experimental work are more likely to name a mentor than those in theoretical/computational. Students who work in experimental fields may be more likely to have a mentor, due to working together on experiments or even traveling to work in labs away from the university. However, this result was surprising because there were no definitive trends in faculty interactions or advisor relationships in the qualitative data. There are interview participants in experimental work who have a more mentoring relationship with their advisor or another faculty member, but there are also interview participants who did not. The same is true regarding theoretical/computational interview participants.

The regression models show the complexity of the networks; the variables which remain in each model are different. One important aspect of these models to remember is that the the coefficients do not completely explain the effect. For example, a crisis out-tie variable may add time to the degree. This would be considered a negative aspect. However, this may be due to the crisis itself; perhaps having many crisis out-ties is indicative of the severity of the crisis. As indicated in the literature, having support, rather than not having any issues or crises, may be what is most important. If the student did not have a person with whom she or he could discuss the crisis, the student may have left the program or taken even more time to complete the degree.

When introducing demographic variables into the regression model, five peer models are significant. The liberal arts variable increases the time to degree; the previous data explain and agree with what the regression model predicts. The other four categories are less less clear as to why they would produce their effects. Biophysics and having spent more time in the program increases the time to degree. Biophysicists may be expected to understand two disciplines, biology and physics, whereas other students may not. This issue does not appear to be unique to biophysicists; condensed matter physicists also study social or finance networks similar to what those in the social sciences study, so one would assume they would need to have some understanding of disciplines as well.

Being in a later year also increases the time to degree. Multiple reasons could explain this. Students in earlier years could be optimistic that they will graduate sooner and thus, they inaccurately estimate their time to degree. Students in their later years are able to better estimate their time to degree. The department has changed departmental chairs and the university has new university officials; newer cohorts may may benefit from new policies or other changes that support a short time to degree. There also may be something characteristic about more recent cohorts, such as having more research experience.

Not all of the variables have coefficients that increase the time to degree. The binary variables for being in a dating relationship and being an experimentalists decreased the time to degree. The dating relationship variable suggests that these students receive social support that single students would not, but the social support argument would also apply to engaged/married students. It may that students in dating relationships receive social support and also are not burdened with some of potential issues that arise when one is engaged or married. These potential issues include financial matters (paying for a wedding, cohabitation) and needing to consider both partners' careers. A dating relationship may be more compatible with doctoral programs; these relationships may be less serious, so the commitment level and expectations, such as spending together, is lower than that of an engagement or marriage.

Placing all of the binary variables into the regression models led to including two variables that were previously excluded. These two variables are gender (coded as 1 for female) and marriage. The subfield variable for BIO, however, is not significant in this model. This suggests that these demographic variables may interact with one another.

The difference between the two regression methodologies is notable. More student models were created by introducing categorical variables into the regression models than by selecting by case. More faculty models were introduced by selecting by case than introducing categorical variables. This suggests that peer interactions, as represented by network attributes, are similar. While demographic variables do change the time to degree outcome, the coefficients remain the same. The experiences with faculty and staff may vary such that including categorical variables cannot account for the difference in time to degree.

What is intriguing about developing regression models by case is that not only do they suggest introducing a demographic variable, such as gender, may not refine the model adequately to account for differences but also that some demographics may have fewer homogenous experiences. For example, I could develop a statistically significant regression model for male students but not for female students. I have considered that the lack of cohesion is a result of having only 12 female participants, but similar situations occurred for categories with larger sample sizes. The U.S. domestic and international student categories have similar sample sizes, yet only a statistically significant regression model was able to be developed for U.S. domestic students and their interactions with higher prestige faculty. Statistically, a non-significant measure would indicate the result is by chance. Interpreting this further, this could mean that certain demographics, such as U.S. domestic students, have a more homogenous experience than other demographics, such as international students.

5.1.5 Other Considerations in Networks

Additional factors played a role in how the students in this study socialized within the network. Time and being shy can hinder connecting with others. What is notable about time being an issue is that it is less straightforward. The issue is not simply the amount of time but when events are scheduled. Students may have other things scheduled or have preferred hours of the day for socializing. For the latter, work is their first priority and some students are too engrossed to stop working to go socialize.

Students do not socialize at the university for the sake of socializing; they are selective in what events they attend. This generally involves piquing their academic interests; for example, the interview participants on a whole were not interested in attending the colloquia to see their fellow students. They would attend if the topic or speaker was of interest. If part of the purpose of these events is to encourage socializing, knowing what interests the doctoral students and how they decide on what to attend is imperative for their attendance. Some students use the pre-colloquium lunch to gauge their interests, but not all students attend these lunches. Other students use the advertisements or their knowledge on these topics; it is unclear if the advertisements and their knowledge determines whether they attend the pre-colloquium lunch or if they attend the lunch regardless.

Socializing with faculty at these events does not occur frequently. What is evident for almost all of the students is that they avoid talking to faculty for fear of embarrassing themselves. For the majority of students, the reason is the differential in status; they are aware of this as indicated by describing their advisors as their bosses. While faculty do not appear to emphasize this, the students are cognizant that faculty has great influence over their careers. Students want to be liked and respected by their faculty. These concerns appear to affect their relationships with faculty, as seen in the quantitative data.

These concerns may be indicative of feeling unconfident and as though they do not entirely belong. Terrence Winters explicitly stated his feelings of being unconfident and not belonging affected his relationships with faculty. Other students may feel the same if they truly believe that they cannot socialize more freely with faculty; if one felt as though she or he belonged, they likely would not be concerned that a minor mistake could permanently damage the relationship. I assume the students are concerned about relatively minor mistakes, because they mentioned the faculty knowing more than they do and not that they made some egregious mistake.

Alcohol aids in socializing with faculty. According to the interview participants, both students and faculty feel more comfortable interacting with one another in settings where they are drinking. While the students suggest that the alcohol is what encourages socialization, alcohol may not be the cause. This may be the effects of alcohol, the people who attend events where alcohol is served, or the nature of these events. While these events are viewed positively, they may inadvertently exclude students who do not feel comfortable around drinking. These events also do not appear to be enough to sustain meaningful student-faculty relationships; more meaningful or frequent opportunities to interact are needed to create and sustain closer relationships.

Some students are also concerned with how they are perceived by their peers as well, which appears to limit conversation topics; they do not want to discuss concerns or difficulties. Similar to discussing issues with faculty, this appears to be a perception; no interview participant mentioned having a negative experience with their peers when discussing issues. Worrying about peer perception can potentially hinder finding adequate support if they have no one to discuss these issues.

Other literature indicates that one's identity and affiliation with a field is linked to retention. Social connections help develop such identities. The literature is on undergraduates and high schoolers, however. Despite having completed a physics undergraduate degree and enrolling in a physics doctoral program, the students in this study do not seem to have a strong identity within the field of physics. Although no interview questions were specifically asked about one's identity within the field, the interview participants overall did not appear to have a strong identity with the field. Interestingly, the interview participants who experienced difficulties within the program are predominantly the ones who mentioned their scientist or physicist identities. These were characteristics of themselves and generally, positive. It may be more important for these students to assert that identity than for students who face fewer difficulties.

Several interview participants in this study seem to want to divorce themselves from their physics identities. Whether it is the actual topic or their work environment, many of the interview participants see discussing physics in their personal lives as something undesirable. While one does not expect them to only discuss physics or their research, one would expect them to enjoy discussing this occasionally; pursuing a doctorate is not a trivial matter and is typically considered a demonstration of one's interest and passion for a field. Why these students avoid the topic of physics avoided is uncertain. Avoiding discussion surrounded the field suggests unhappiness or less interest. This may be characteristic of graduate students in general; they may be engulfed in research and wish to discuss something different. Perhaps this is a characteristic of the work environment for physics or STEM, for whatever reasons.

Despite some hesitations in how peers may perceive them and their lack of physics identities, forming friends within the department is important. Gavin Braun suggested that those in full-time doctoral programs may have more challenges in relating to others who are not. Kurt MicKinney pointed out that the experience is unique and one needs peers who can understand the experience. This experience is likely unique to the program itself, as another physics doctoral student would not know the faculty or one's peers.

5.2 Further Research

Although this project has covered many topics, there are still many other areas to explore. In this section, areas for further research are discussed. With the exceptions of section 5.2.1 and 5.2.2, demographic considerations are typically not mentioned. However, they should be considered as part of each question as they may alter the results for each area of further research.

5.2.1 Physics Program Differences

Because this is a case study, repeating this study would be worthwhile to determine if Jonas University's physics programs is an anomaly. Characteristics of this physics department may affect the results. If Jonas University's physics department is an anomaly, one way to determine this is to find similar physics departments and compare the results from those physics departments to Jonas University. Similarities include number of students, geographic location, and subfields offered.

Characteristics of the university and program may also affect how social networks form. Jonas University's physics program is a high-ranked, fairly large, and at urban New England university. Each part of the description may be relevant to network formation among physics doctoral students. The experiences of physics doctoral students at higher or lower ranked department may be different. Similarly, smaller or larger departments may be different, as well as more rural or suburban universities in other geographic settings.

5.2.2 STEM Field Differences

Similar to physics program differences, STEM fields may have different network dynamics. Conducting this study in different STEM departments at Jonas University may help determine whether the social networks in the physics department are unique to the culture of physics or physics at Jonas University, or whether this is a more prevalent culture in STEM.

In section 5.2.1, I discuss how the attributes and setting of Jonas University may affect the results of this study. Studying other physics programs with varying attributes may help determine whether Jonas University's physics program is an anomaly. Similarly, studying different STEM fields' network interactions at different universities would help determine if the results are unique to the Jonas University culture or STEM in general.

5.2.3 Advisors: Selection, Experiences, and Choice

This study indicates there are many areas where advisors and doctoral student-advisor relationships can be further studied. The goal of studying advisors is ultimately to aid in developing and maintaining strong, fruitful relationships between doctoral students and advisors. Learning what advice or methods in selecting advisors are most useful is one area. The physics doctoral students do not seem to have a method of selecting advisors, which can lead to dissatisfaction with the advisor. Lysander Barber suggested that rotations, where doctoral students do small projects to learn more about the research and work environments of different groups, may be important in making an informed decision on an advisor. However, participating in lab rotations may not make a difference. Rotations also may be scheduled in different ways, so part of the research would encompass determining which rotation models are ideal.

Some of the students in this study have completely different experiences with the same advisor. While a faculty member who is a good advisor for one student may not be a good advisor for another, the difference is so extreme that it is not just a matter of being a less ideal fit. The question remains whether this is by chance or if there are identifiable reasons why this occurs. Identifiable reasons include demographic reasons, selection process patterns, or experiences; perhaps students who have good or functional relationships with their advisors have more research experience, or the advisor has more training and interest in advising.

Some of the interview participants claimed to not have a choice in advisors. Despite not having or feeling that they had a choice, they seem satisfied with their advisors and their research. Gaining further understanding of how lack of choice in advisors affects the doctoral would be interesting to study. The advisor could be more sympathetic to these students who lack choices. The students could feel unconfident and feel as though they do not belong; they could also feel as though they need to prove themselves and produce outstanding work.

5.2.4 Research Communication and Training

As discussed in section 4.2, some students are unsure whether they are making progress in their programs. While some participants had clear signs they were not making adequate progress, others did not. Understanding what doctoral students perceive as progress and how they determine this would be important to understand whether their expectations are in alignment with the nature of research. Perhaps they have unrealistic expectations of themselves or working in research. This would provide guidance to faculty as to how to communicate this with students.

Another area to explore is different ways advisors do research training and what training is effective. The students in the study have varying relationships with their advisors and committees, where some receive minimal training and others have more comprehensive discussions on science and research. Studying research training would include use of equipment, more general research skills such as grant writing, and developing a viable research project. These skills are valuable, not only for the completion of the doctorate but also to foster independent researchers.

5.2.5 Prestige Model

The prestige model suggests that quantifiable differences exist among student-faculty relationships according to prestige. Refinement of this model would help to further understand these quantifiable differences. Qualitative data would provide more explanation why this differences exist. This study focused on the doctoral student experience; perhaps learning more from the faculty side would provided better understanding why some students are better connected to some of the prestige levels and the benefits of having faculty ties for each prestige model. There may be some characteristics of faculty by prestige level, such as interest in interacting more with students or be more active in the department.

5.2.6 Collaboration

Although research collaborations between peers did not frequently occur, there were a few. While the advisor is the impetus behind these initial collaborations, there is no information on subsequent collaborations for physics doctoral students. If students participate in one successful collaboration with peers, will they seek out other collaborations with peers? If the experience is negative, what is the effect on willingness to collaborate with peers?

Other research studies suggest that multiple factors that account for why STEM faculty may collaborate. However, they do not consider whether experiences in collaboration as doctoral student have any role in collaborations as an employed scientist or academic. Scientists who engage in collaborations as doctoral students may be more likely to collaborate once they are no longer students. Understanding the effects of early experiences in collaboration may help gain further understanding on how to encourage collaboration.

5.2.7 Departmental Role

Much of the discussion is in regards to faculty and may be seen as placing the onus for improvement on individual faculty members. Although individuals do contribute to these efforts, the department as a collective group may be what truly facilitates cultural change. The question remains to what extent can a department support its doctoral students. For example, the students in this study seemed to receive no guidance on how to select an advisor. Other departments may have structures or policies, such as rotations, that help students choose satisfactory advisors.

Throughout the study, the majority of interview participants sensed a power dynamic issue with faculty. They hesitated to socialize with faculty because of this, even though none of them had negative experiences in socializing with faculty. There may be ways in which the department can help ease these students' fears and help create stronger student-faculty ties. Similarly, the department may be able to facilitate ties across cohorts.

5.2.8 Further Studies on Demographic Variables

The demographic considerations show that students of different demographic attributes have different experiences, but these differences are more subtle and not straightforward. There are several avenues that should be further explored. The results in the discussion section generated questions to explain the results further. Beyond those research questions, some of the demographics can be further explored.

Studying gender in physics was the motivation for this study. While there are gender differences, there were not as many as literature suggests. This could have multiple interpretations. Gender may not be a major issue at the doctoral level for physics students. The interview participants, regardless of gender, indicated that the department on a whole does not operate as a community and their needs are not met for many purposes. Women may not be more disadvantaged if few students receive adequate support. Female physics doctoral students may have developed strategies to avoid gender being an issue when interacting with others; recall that two of the interview participants perceived women in physics as being different from women in STEM. They may also ignore issues potentially related to gender, or deny them as being related to gender, as a coping mechanism. Understanding how women in physics at all level negotiate and "do" gender would contribute in understanding their experiences and determine whether and the ways in which gender issues exist.

The year in program variables showed many of the differences within the program. Knowing how to interpret this variable is still unknown. Year in program may be a straightforward as being a more advanced student. However, it can be indicative of age/maturity; this may affect social networks. The year in program variable also could suggest a difference in more recent cohorts. Each of these meanings would have different implications; a straightforward interpretation would suggest this is something inherent to more advanced students, while a difference in more recent cohorts could indicate a change in admissions criteria or a change in the general graduate student population.

Studying undergraduate alma maters is just a starting point for understanding the doctoral students' backgrounds and how they may differ in social networks. The categories in this study were used to characterize prior experiences, but this can be further refined. Universities and colleges are also ranked, and some have strong reputations for physics or science. Further differentiation of these categories may indicate more differences.

If possible, studying the intersections of these variables would be useful. These variable interactions may further explain different experiences. For example, doctoral students who attended liberal arts colleges as undergraduates may have more difficulties in certain subfields than doctoral students who attended universities and are participating in the same subfields.

Lastly, doctoral students often enter programs with prior experiences in research and academia. These experiences are almost certain to have an effect on these students. A longitudinal study would understand how prior experiences affect the doctoral student socializing.

5.2.9 Scientist Identities

The doctoral students in this study gave few indications that they did identify as physicists or scientists. While they were never explicitly asked any questions regarding their identity, some readily identified themselves as such. More of the doctoral students, however, preferred to keep that aspect of their lives separate when they socialize.

Exploring how doctoral students claim this identity is important. As suggested earlier, this identity may be more important to those who are in vulnerable situations. Knowing how doctoral students construct these identities needs further study; Kerr Steele's physicist identity seems contingent upon whether he could contribute to the lab. This identity also may be relative; undergraduates may more readily identify themselves with a field, because it draws a distinction between them and other students. Doctoral students in one program cannot draw that distinction. They may also hesitate to identify as such, because they realize they have a lot to learn; there is a stereotype that the advanced student recognizes how little she or he knows, whereas an intermediate student believes she or he knows a lot. Perceptions of one's knowledge may alter how she or he identifies.

5.3 Recommendations

Based upon the study results, I recommend the following items as a means to improve upon the current condition:

- **Discuss how to select an advisor**: The doctoral students would greatly benefit in receiving advice on advisor selection. Although the research topic is important, there are many nuances to this crucial relationship that students are not considering.

- **Monitoring students and advisors**: If is not already done, the department may want to examine if there are trends in which students are taking longer than expected and whether they are linked to particular advisors. Similarly, the department may want to determine if there are any trends in switching advisors. The purpose would not be to shame anyone but to figure out why this occurs and how to prevent issues from forming.

- **Progress report discussion**: Doctoral students file reports on their research status, but they do not appear to discuss these reports with anyone. Such a discussion would be useful for both the advisor and the student; the advisor could provide better support, and the student could have any concerns alleviated.

- **Mitigating power dynamic issues**: The faculty can provide a wealth of information and support to students, yet there is a general hesitancy to approach faculty. Faculty will always have power over students, but it should not be to the extent that students are fearful of talking to faculty. This issue is complicated, as the fears do not appear to be based on experiences. However, this is a worthwhile endeavor to foster community between faculty and doctoral students.

- **Practical career advice through alumni network**: The interview data suggests that many students do not receive the career advice they need, because the faculty are less familiar with non-academic jobs. Alumni of this program may be a valuable resource for these students if the alumni are employed in areas in which the students are interested.

- **Encouraging collaboration and research discussion among students**: Many of the students do not see points of interaction for research collaboration or feel that they can discuss research beyond general status updates. This is even within a subfield. For the collaborations that do occur, the advisor initiates them. Faculty are a key component to facilitating research collaborations, and they may be needed to begin research conversations among students to guide them to cross-disciplinary discussions.

- **Maximizing student attendance and participation at events**: The students are selective in what they attend and attend out of interest, not habit or expectation. The study identified several aspects that influence attendance, including interest in the topic if the event is a talk, the time the event is held, and one's year in program. As for participation, one of the benefits is to socialize as a community. However, the doctoral students mostly socialize with one another and faculty socializes with faculty. While one cannot force informal socializing, there may be ways to encourage this. Something as simple as encouraging faculty to talk to students may be what is needed.

- **Figure out how to do multi-year socializing**: Cross cohort socialization does not typically occur. This is to the detriment of the doctoral students, as there is a wealth of knowledge more senior students have. This also decreases the likelihood of making friends. If one only seeks friends within the cohort, they have approximately 20 students with whom to find rapport. Cross cohort socialization would allow information and knowledge to transfer, and it would increase the chances of the students making friends. Similar to participation at events, this is something that may be encouraged rather than enforced. For example, creating opportunities for students of various cohorts to work together such as organizing events or being involved in research or teaching fellow training.

Ultimately, the goal is to foster a true community where doctoral students, faculty, and staff interact with and support each other. These recommendations are not likely to be easy or quick to implement, but facilitating these changes are important to provide the highest caliber of doctoral education and produce the highest caliber physics doctorates.

5.4 Conclusions

Although the physics doctoral students at Jonas University participate in social networks, their networks may not benefit them to the fullest extent. The students are working towards degree completion and they will likely complete their doctorates, but they may not be engaged in a lifestyle or activities that will help them become, borrowing Archie Calderon's description of his previous group, the best scientists they can be. For example, many of the interview participants talked about receiving little to no training and engaging in little to no discussion regarding research. A doctoral program should strive to train independent researchers, but the program needs to provide training to the students who enter the program.

The issue lies in the missed opportunities to connect with peers and faculty. While some faculty members cannot advise multiple students due to funding, others do have multiple students and yet these peer connections are not being made. Research is not discussed frequently among peers in a manner that would enhance the work being done. Students are training themselves how to use experimental equipment, rather than being taught by peers or faculty. There are areas in which senior students could pass along their knowledge and experience, but as the data show, students are mostly connected to their cohort. Faculty involvement is minimal for many of these students.

In summary, the physics doctoral students are often left to figure out how to conduct research on their own. Given that these are novice researchers, not seasoned professors or postdocs, this can cause needless frustration and hinder to the time to degree. These missed connections go further than the immediate research-related matters. There may be other types of knowledge and experience not being passed along, such as important job skills and knowledge on how to obtain these jobs.

One may argue that the doctoral students need to take initiative in seeking out help if they need help. Doctoral students do need to more independent than undergraduates; they enter with more experience, knowledge, and skills than an undergraduate possesses. However, they are students. They are novice researchers who lack adequate experience with research in general and may lack experience with specific equipment or techniques. The departmental culture may not support an environment where doctoral students can freely seek support, and novices may not know what they do not know.

Faculty members are vital component to these networks. The data show that faculty are responsible for collaborations among students; this is likely due to having more experience in research. Literature indicates that faculty can influence the long-term careers of students. They clearly do have power in the students' lives. However, the students are intimidated to talk to them. This is regardless of prestige. For these students, power is a double-edged sword; the faculty can have great influence on their research and careers due to the power and influence they possess, but the power that faculty possesses also impedes students from forming relationships with faculty.

This study was designed to examine gender in physics. I considered other variables to ensure that any differences were related to gender. By studying other variables, a complicated landscape of experiences is revealed. The demographic variables indicate differences in experiences based upon identity. This more complicated quantitative examination of the students agrees with the qualitative data; there overall are no distinct trends, such as women being universally excluded or disadvantaged. These identities and attributes demonstrate the complexity and heterogeneity of what initially seemed to be a somewhat homogeneous sample. The differences that have arisen are worthwhile to note; the long-term impact of these differences is unknown. What seems inconsequential may have serious consequences.

As the literature on gender in physics emphasizes, providing a fair and high quality physics experience for women benefits men as well. The idea is that what supports women in physics are generally good practices to cultivate a community. These practices include being supportive and welcoming of all students. Similarly, supporting various demographics within the doctoral program would be about cultivating a community. Acknowledging that some students in the doctoral program have different challenges and supporting those students does not hurt the students who are not disadvantaged. Such differences need to be noted by faculty and those students need to receive the support they need. While these students may enter the program with fewer advantages, that does not mean they are less capable of the more advantaged students.

The physics department at Jonas University has a functional doctoral program. Plenty of graduate students leave with their doctorates, and the program is well-regarded to be within the "Top 50." There are positive experiences within the program. Doctoral students have formed some genuine and close friendships with their peers, and the students overall noted that they care about one another. The staff was also noted as sincerely caring about the students. There are faculty members who are invested in the success of the students, regardless of whether they are the advisor.

However, the department has not truly become a community that fosters learning and professional development. There are multiple issues and challenges that prevent or hinder meaningful connections from forming. Ultimately, the doctoral students have not received a level of support that they need which has implications for social support and professional indoctrination. These missed connections are evident from the data. Without strategically resolving the issues discussed in this study, Jonas University will not have a community that cultivates and supports doctoral students to become the best physicists they can be.

Chapter 6

Appendix

6.1 Survey Recruitment Letters

6.1.1 Survey Recruitment Letters- Sent by Department

Dear Physics graduate students,

My name is Alexis Knaub, a doctoral student in the School of Education at Boston University. The research for my dissertation is on doctoral student social networks in a physics department. I have selected Jonas University as the site for my research.

You are receiving this email because you were a doctoral student in the physics department during the 2012-2013 school year. I am hoping you will participate in a survey asking about the different connections in your personal network. The survey will take approximately 20-30 minutes and at the end, you will receive $10 in cash as a token of my gratitude. Attached to this email is the informed consent form, outlining confidentiality policies. The link to the survey is here: LINK . Although I recommend taking the survey in one sitting, the survey will save itself in your browser via a cookie.

Please email me at avknaub@bu.edu to discuss any questions/concerns. Thank you so much for cooperation!

-Alexis Knaub avknaub@bu.edu

6.1.2 Second email from me

Dear GRAD STUDENT NAME My name is Alexis Knaub, a doctoral student in the School of Education at Boston University. PERSON had sent an email to you from me last week regarding my dissertation research on the social networks of doctoral students in a physics department. I'm sending a follow-up email as a reminder in hopes you will participate in my study.

If you choose to participate, you will participate in a survey asking about the different connections in your personal network. The survey will take approximately 20-30 minutes and at the end, you will receive $10 in cash as a token of my gratitude. Attached to this email is the informed consent form, outlining confidentiality policies. The link to the survey is here: LINK.

Please email me at avknaub@bu.edu to discuss any questions/concerns.

Thank you so much for cooperation!

-Alexis Knaub avknaub@bu.edu

6.1.3 Clarification email sent by me

Dear GRAD STUDENT NAME,

This is Alexis Knaub. I have emailed you regarding my social networks study survey (LINK), and according to my records, you have not completed it. I'm writing today not only as reminder but also to clarify some concerns I have heard regarding the study.

- The physics department (chair, faculty, staff, students) has no access to my data. The people who can see my raw data are my advisor who is a member of the School of Education, another faculty member in the School of Education, a faculty member in psychology, and the IRB; if you are not familiar with the IRB, their job is to ensure that studies involving people are safe in all senses as well as privacy is protected. I don't anticipate any of those people needing or wanting to see the raw data, especially with the name attached. As per my agreement with the IRB, I must remove the names and email addresses from my data as soon as I schedule interviews for the study; additionally, to further describe the level of privacy ensured, I can't even reveal who has and has not taken the survey to anyone but the three faculty members listed above and the IRB. I take privacy very seriously, not only out of concern for your welfare but also because violating my IRB agreement would severely damage/jeopardize my career.

- Related to privacy, while I am collecting personal information, the data will be statistically analyzed and reported. In other words, your information would be a part of a much bigger set. I will make sure that your privacy is protected by assigning you as pseudonym and With interviews, if you choose to participate in an interview and are selected, I will exclude obvious details that would be linked to you.

- If you are interested in who I am, here's my LinkedIn profile: http://www.linkedin.com/in/alexisknaub .

- I plan closing the survey by October 31st. If that is an issue for you, please let me know.

- Lastly, there have been questions regarding the purpose of this study. This is my dissertation research, and my plans are not only to use this research in my dissertation but also write some articles. You are welcome to attend my dissertation defense when it occurs, and I'd be happy to write a note to you when it is scheduled.

- As an aside, having everyone or as many people as possible participate in this study is important, because the data will be much more compelling and statistically powerful.

Thank you so much for reading this email. Again, please let me know if you have any questions or concerns or if you would like another copy of the informed consent that I had originally sent.

-Alexis Knaub

6.1.4 Final email sent by me

Dear GRAD STUDENT NAME,

My name is Alexis Knaub, a doctoral student in the School of Education at Boston University. You have received 3 emails from me regarding my study.

As a reminder, my study is on the social networks within the physics department. I'm looking for participants to take a survey asking about the different connections in your personal network. The survey will take approximately 20-30 minutes and at the end, you will receive $10 in cash as a token of my gratitude. Attached to this email is the informed consent form, outlining confidentiality policies. The link to the survey is here: LINK . I plan on closing the survey on 31 October 2013.

Please email me at avknaub@bu.edu to discuss any questions/concerns.

Thank you so much for cooperation!

-Alexis Knaub avknaub@bu.edu

6.2 Interview Recruitment Letters

Dear NAME,

Thank you once again for participating in my survey. I have selected you to participate in the interview portion of my study.

The interview will consist of questions regarding your interactions within the department. Interviews take approximately 15-20 minutes, and you will receive $10 as a token my gratitude at the end of this interview.

If you are interested in being interviewed, please let me know ASAP so we can schedule Please email me with any questions or concerns you may have.

-Alexis Knaub avknaub@bu.edu

6.3 Network Purpose Post-hoc Games-Howell Test Results from section 4.2.4

In the following tables are the pairs analyzed from the post-hoc Games-Howell tests for various network purposes. The Welch tests and results are discussed in section 4.2.4.

			95% Confidence Interval	
	Purpose	Paired Purpose	Lower Bound	Upper Bound
In-ties	Career	Going On***	-7.36	-3.13
		In Social***	-7.34	-2.97
		Out Social***	-3.57	-0.560
	Crisis	Procedural**	0.200	2.75
		Going On***	-6.15	-1.59
		In Social***	-6.12	-1.44
	Procedural	Crisis*	0.200	2.75
		In Social***	-7.37	-3.14
		Out Social***	-3.55	-0.77
	Going On	Career***	3.13	7.36
		Crisis***	1.59	6.15
		Procedural***	3.30	7.39
		Research***	2.35	6.67
		Out Social***	0.840	5.52
	Research	Going On***	-6.67	-2.35
		In Social***	-6.64	-2.19
	In Social	Career***	2.97	7.34
		Crisis***	1.44	6.12
		Procedural***	3.14	7.36
		Research***	2.19	6.64
		Out Social**	0.690	5.49
	Out Social	Career***	0.560	3.57
		Procedural***	0.770	3.55
		Going On***	2.19	6.64
		In Social**	-5.49	-0.690

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

	Purpose	Paired Purpose	95% Confidence Interval Lower Bound	Upper Bound
Out-ties	Career	Crisis*	-4.82	-0.650
		Going On***	-13.2	-6.13
		Research**	-4.61	-0.460
		In Social***	-13.6	-5.22
		Out Social***	-7.66	-2.25
	Crisis	Career**	0.65	4.82
		Going On***	-10.7	-3.11
		In Social***	-11.1	-2.25
	Procedural	Going On***	-12.2	-5.12
		In Social***	-12.6	-4.21
		Out Social***	-6.64	-1.25
	Going On	Career***	6.13	13.2
		Crisis***	3.11	10.7
		Procedural***	5.12	12.2
		Research***	3.31	10.9
		Out Social*	0.54	5.43
	Research	Career**	0.46	4.61
		Going On***	-10.9	-3.31
		In Social***	-11.3	-2.45
	In Social	Career***	5.22	13.6
		Crisis***	2.25	11.1
		Procedural***	4.21	12.6
		Research***	2.45	11.3
	Out Social	Career***	2.25	7.66
		Procedural***	1.25	6.64
		Going On*	-8.84	-0.54
Weighted In-ties	Career	Going On***	-25.1	-11.6
		In Social***	-24.6	-10.7
		Out Social***	-12.2	-3.22
	Crisis	Going On***	-24.5	-10.8
		In Social***	-24.6	-10.7
		Out Social***	-11.6	-2.35
	Procedural	Going On***	-25.6	-12.3
		Research**	-5.61	-0.466
		In Social***	-25.1	-11.4
		Out Social**	-12.7	-3.97
	Going On	Career***	11.6	25.1
		Crisis***	10.8	24.5
		Procedural***	12.3	25.6
		Research***	9.02	22.8
		Out Social**	2.96	18.3

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

	Purpose	Paired Purpose	95% Confidence Interval	
			Lower Bound	Upper Bound
Weighted In-ties	Research	Procedural**	0.466	5.61
		Going On***	-22.8	-9.02
		In Social***	-22.4	-8.16
		Out Social*	-10.0	-0.534
	In Social	Career***	10.7	24.6
		Crisis***	9.93	24.0
		Procedural***	11.4	25.1
		Research***	8.16	22.4
		Out Social**	2.12	17.8
	Out Social	Career***	3.22	12.2
		Crisis***	2.35	11.6
		Procedural***	3.97	12.7
		Going On**	-18.3	-2.96
		Research*	0.534	10.0
		In Social**	-45.9	-20.1
Weighted Out-ties	Career	Going On***	-45.9	-20.1
		Research**	-14.4	-1.87
		In Social***	-45.3	-16.6
		Out Social***	-22.4	-5.17
	Crisis	Going On***	-43.6	-17.8
		In Social***	-43.0	-14.3
		Out Social***	-22.4	-5.17
	Procedural	Going On***	-44.3	-18.9
		Research*	-12.7	-0.838
		In Social***	-43.7	-15.3
		Out Social***	-23.0	-6.34
	Going On	Career***	20.1	45.9
		Crisis***	17.8	43.6
		Procedural***	18.7	44.3
		Research***	11.2	38.5
		Out Social*	2.21	31.6

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

	Purpose	Paired Purpose	95% Confidence Interval Lower Bound	Upper Bound
Weighted Out-ties	Research	Career*	1.87	14.4
		Procedural*	0.838	12.7
		Going On***	-38.5	-11.2
		In Social***	-37.8	-7.76
	In Social***	Career	16.6	45.3
		Crisis***	14.3	43.0
		Procedural***	15.3	43.7
		Research***	7.76	37.8
	Out Social***	Career	7.48	24.7
		Crisis***	5.17	22.4
		Procedural***	6.34	23.0
		Going On*	-31.6	-2.21
Degree Centrality	Career	Crisis***	-6.86	-1.36
		Going On***	-19.8	-10.0
		Research**	-5.80	-0.740
		In Social***	-20.3	-8.86
		Going On***	-10.4	-3.65
	Crisis	Career***	1.36	6.86
		Procedural**	0.580	5.82
		Going On***	-16.0	-5.62
		In Social***	-16.4	-5.59
	Procedural	Crisis**	-5.83	-0.580
		Going On***	-18.8	-9.19
		In Social***	-19.3	-8.01
		Out Social***	-9.38	-2.84
	Going On	Career***	10.0	19.8
		Crisis***	5.61	16.0
		Procedural***	9.19	18.8
		Research***	6.55	16.7
		Out Social**	2.37	13.4
	Research	Career**	0.744	5.80
		Going On***	-16.7	-6.55
		In Social***	-17.2	-5.41
		Out Social*	-7.43	-0.06

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

	Purpose	Paired Purpose	95% Confidence Interval	
			Lower Bound	Upper Bound
Degree Centrality	In Social	Career***	8.86	20.3
		Crisis***	4.49	16.4
		Procedural***	8.01	19.3
		Research***	5.41	*17.2
		Out Social**	1.30	13.8
	Out Social	Career***	3.65	10.4
		Procedural***	2.84	9.38
		Going On***	-13.4	-2.37
		Research*	0.06	7.43
		In Social**	-13.8	-1.30
Betwenness Centrality	Crisis	Procedural**	0.005	*0.033
	Procedural	Courses***	-0.435	-0.334
		Crisis**	-0.033	-0.005
		Going On***	-0.027	-0.006
		Research*	-0.043	-0.001
		In Social**	-0.028	-0.005
		Research*	-0.043	-0.001
		In Social**	-0.028	-0.005
		Out Social**	-0.031	-0.003
	Going On	Career*	0.00	0.024
		Procedural***	0.005	0.027
	Research	Procedural*	0.001	0.043
	In Social	Procedural**	0.005	0.028

* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$

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Education

Smith College, A.B. in Physics May 2006

DePaul University, M.S. in Physics Aug. 2010
Masters Thesis Topic: Fluid Mechanics
Committee: W.R. Matson (advisor), Jesus Pando, and Gabriella Gonzalez-Aviles

Boston University, Ed.D. in Science Education Jan. 2015
Doctoral Dissertation Title: Missed Connections: A Case Study of the Social Networks of Physics Graduate Students in a Single Department *Committee*: Bennett Goldberg (advisor), Deborah Belle, David K. Campbell, Laura Jiménez

Social Science Research Experience

Postdoctoral Research Associate Nov. 2014 through Present
P.I.: Charles Henderson, Western Michigan University
Working on multiple physics/STEM education research projects, including research on North Carolina State University's Student-Centered Activities for Large Enrollment Undergraduate Physics (SCALE-UP).

Graduate Assistant on STEM Education Initiatives Jan. 2014 to Oct. 2014
Supervisor: Bennett Goldberg, Boston University
Multifunctional role entailing education research and website development to support STEM educational Boston University. Analyzed data and created reports on STEM graduate student teacher training for administrative and faculty audiences.

- Advised graduate students on the development of teaching assistant mentoring program and a small scale educational research project on gender.
- Collaborated on STEM education website development, including writing website copy and highlighting STEM innovation through video.

Graduate Research Assistant Sept. 2010 through Oct. 2014

Advisor: Bennett Goldberg, Boston University

Worked on projects involving the Learning Assistant Program and research on the social networks of physics doctoral students. Experience with pilot studies, IRB applications, qualitative data, and quantitative data.

- Collected data via surveys, interviews, and focus groups.
- Analyzed quantitative data via statistics (descriptive, inferential, and regression) and social network attributes.

Teaching and Education Work Experience

Instructor for Science Ed. Pre-practicum Sept. 2013 through May 2014

Boston University

Taught course for undergraduate STEM majors who were contemplating careers as high school science educators. Course involved students working in high schools.

- Revitalized curriculum, readings, and assignments to engage students through more relevant and accessible readings.
- Supervised undergraduates and teachers to ensure satisfactory experiences.

Program Manager for GK-12 program May 2011 through Aug. 2013

Boston University

Supervised graduate student fellows and partner teachers in an NSF-funded program where graduate students assisted high school teachers in high needs, Boston-area public schools. Other tasks include working on the annual report, program evaluation, and recruitment and hiring teachers and fellows.

- Devised and implemented year-round professional development for fellows and teachers, including: summer training to educate graduate student fellows on pedagogy and foster strong teacher-fellow partnerships, monthly gatherings to develop a learning community, and written observations of graduate fellows.
- Guided two experienced graduate fellows in the creation of their own professional development models that they delivered to the course.

Teaching Assistant for STEM Ed. courses Jan. 2011 through Dec. 2013
Boston University
Worked as a teaching assistant for undergraduate STEM learning assistant (LA) and M.A.T. science methods courses. Responsibilities included facilitating small group discussion and grading work.

- Participated in meetings with both education and science faculty to provide feedback on the LA program.
- Implemented WordPress website to streamline application process and advertise program to both prospective LAs and faculty. Responsibilities included photography, videography, and training faculty on how to use WordPress.

Adjunct Instructor Oct. 2009 through May 2010
Ben Franklin Institute of Technology
Taught lectures and laboratory sections for algebra-based physics, conceptual physics, and algebraic math. Tutored students individually on these topics.

- Revitalized course by structuring classes to encourage group work and designing homework assignments to demonstrate the relevancy of math and physics as well as to strengthen writing skills.
- Served as a committee member for a students BA thesis.

Teaching Assistant Sept. 2007 through Aug. 2009
DePaul University
Taught labs, graded written reports, and tutored in office hours both physics and non-physics majors with material in introductory physics, electronics, and modern physics.

- Supervised other graduate teaching assistants in laboratory sections. Responsibilities included organizing lab setups and clarifying instructions to teaching assistants, as well as giving optional feedback on teaching skills.
- Developed new grading rubrics and grading schedules for the introductory labs.

Computer skills

Operating systems: Windows 95 - 8, Mac OS8 - X, Unix
Software (General): Microsoft Office, iWork, iLife, WordPress, Drupal, Adobe Creative Suite, Qualtrics, Survey Monkey
Statistical/Scientific software: SPSS, novice Matlab, LoggerPro, novice R, LaTeX, Mathematica

Scholarships, Awards, and Fellowships

Scholarship Recipient of Gates Millennium Scholars Program, May 2002 - Aug. 2014

Glenn Fellowship at Boston University, Sept. 2010 - May 2014

Gates Millennium Scholars Travel Grant to the National Conference on Race and Ethnicity (NCORE), 2013

Gates Millennium Scholars Travel Grant to Institute on Teaching and Mentoring, 2012

Southwest Travel Grant to the APIASF Higher Education Summit, 2010

Teaching Assistantship at DePaul University, Sept. 2007 - Aug. 2009

Sigma Xi, 2006

Professional Associations

American Physical Society

Leadership

Northeast Regional Advisor, Gates Millennium Scholars Alumni Advisory Association: Apr. 2014 through Oct. 2014

Asian and Pacific Islander Scholarship Fund (APIASF) Boston-area Regional Representative Chair: Sept. 2012 through Feb. 2013

Member-At-Large for American Physical Society (APS) Forum on Graduate Student Affairs (FGSA): Jan. 2013 through Dec. 2014

Chair, FGSA Travel Award Committee: Jan. 2014 through Dec. 2014

Graduate Student Liaison for the Committee on the Status of Women in Physics (CSWP): Feb. 2013 to Present

Program Manager to Boston University Physics Teaching Fellow Mentoring Program: August 2013 to May 2014

Service

Gates Millennium Scholars Mentor: January 2012 to Present

Gates Millennium Scholars East Coast Conference Volunteer: September 2011, 2013

Boston University School of Education Equity, Diversity, and Inclusion Committee Member: Sept. 2013 through May 2014

APIASF scholarship reader: Winters 2012 through 2014

Smith College Physics Alum website creator and developer: June 2012 through Present

Graduate Representative, Physics Tenure Committee, DePaul University: Dec. 2008