Preparing and Progressing: A Narrative Study of Optics and Photonics Graduate Students' Identity-Trajectory

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ABSTRACT

Identity development, through time, of graduate students is a topic understudied in most disciplines, and completely unstudied in optics and photonics. As a physical science and engineering discipline with blossoming scientific value, optics and photonics is growing a small number of graduate programs. With this growth, a more in depth and detailed understanding of the exposure, recruitment, development and enrollment experiences of those students are needed. Identity-trajectory offers a promising theoretical framework to understand academic and professional development of professionals through time and has been shown to be reliable in many social science and humanities disciplines. The narrative methodology is emerging in use and acceptance within the engineering education research community. The provoking combination of a growing discipline, a theoretical framework with little prior application in physical science and engineering, with a creative methodology were intentionally selected for this study.

A semi-structured interview protocol was developed to prompt participants through a reflective description of their academic and professional development. Twenty-five current and recent graduate students from nine degree granting optics and photonics graduate programs participated in the study. In addition to participating in the interview, averaging about forty-five minutes, participants submitted a curriculum vita in advance of the interview. Both the interview and the vita provide the primary data used in this study. Interview transcripts were coded with the theory of identity-trajectory's three strands: intellectual development, institutional influence and network.

The findings are grouped into pre-graduate training and graduate development experiences. Considering pre-graduate training, research experience as an undergraduate facilitates future decisions and access to graduate education. For graduate students, the structural experience within the graduate program, specifically related to research, facilitate progress through the program and beyond. The graduate program experience generally prepares students for academic research, but not the broader career pathways that students seek and eventually follow. All of these findings center on the laboratory, as the conduit for developing undergraduates to graduate students, and graduate students to professionals; the experience within the laboratory frames identity-trajectory throughout undergraduate and graduate experiences. These findings were used to provide strategies for departments, faculty and students in these fields, but are applicable in similarly structured disciplines.

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Romans 8:28

Being called is a blessing. Thank you to my family: Daddy, Mommy, Jessica, and Whitney for supporting me, praying for me, being there and listening for all of these years of school. Daddy and Mommy, the way you raised me prepared me to reach for my highest heights. I'm glad and humbled to give you this recognition on paper that could never adequately capture what you have given me. To my extended family, I thank you for your many years of love and support. I love you all.

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CHAPTER 1: INTRODUCTION

Optics and photonics as a discipline is rapidly becoming one of the most valuable assets to technology development although many people have never heard of it. Technological developments in optics have led directly to innovations in medicine, telecommunication, computing devices, and equipment for scientific research. In the United States, there are 14 institutions granting associate's, bachelor's, master's, and/or doctorate degrees in photonics. Optics and photonics programs are situated within their institutions in various ways. Common sites for optics and photonics research and training in academia include departments of physics, electrical engineering, and materials science; however, the number of optics departments and research centers is increasing. Graduate students migrate into the field of optics in many different ways and through various interdisciplinary pathways. This study aims to understand professional identity development of graduate students in photonics-related departments through the three strands of identity-trajectory: intellectual, institutional, and network.

1.1 Need for this Research

Graduate student identity is a well-studied area of research but there is little work focused on engineering graduate students and none on photonics graduate students. Identity is an important aspect of many studies of STEM student retention, particularly at the undergraduate level. Formal training in optics usually does not coalesce until the graduate level, and that is the focus of this study. As members of a growing field within engineering, photonics faculty and program administrators will benefit from understanding the identity development of their graduate students, including these students' prior experiences that have contributed to their decision to enroll. The professional identity of an individual changes over time due to influences of past experiences, current aspirations, and future goals. Identity-trajectory theory uses three strands of identity that are not often combined in a single study: intellectual, network, and institutional (McAlpine, 2010). Lenses that are intellectual (individual contributions), network-based (connection to the academic field), and institutional (responsibilities and resources) contribute in varying ways to an individual's professional identity construction. Identity-trajectory as a framework in this study will provide insight into the early experiences that lead to students' selection of photonics, the influence of social-professional networks, and how their graduate institutions impact their future goals.

1.2 Purpose of the Study

The purpose of this study is to describe the identity-trajectory of graduate students in photonics-related graduate programs. Photonics graduate students come from multiple disciplinary backgrounds, which may or may not have included formal training in the field prior to entering their graduate programs. Understanding how students negotiate and construct their professional identity in this (interdisciplinary) environment provides insight for photonics programs in course sequencing, unconsidered pathways to the field for recruiting purposes, and professional development of graduate students.

1.3 Research Question

The central question in this study is:

How do photonics graduate students construct their professional identity?

Graduate school is one of the most formative professional periods for PhDs and should be, to the extent possible, intentionally designed to foster the future success of graduates. The study aims to answer three sub-questions that contribute to better understanding career trajectories of photonics graduate students.

The sub-questions are:

How do past intellectual experiences contribute to the professional identity-trajectory of photonics graduate students?

How do networks and relationships influence the professional identity-trajectory of photonics graduate students?

How do institutional factors support or constrain photonics graduate students' professional identity-trajectory?

The outcomes of this research may influence pedagogical practices and policies of these graduate programs to promote student success in ways that the program administrators may not have been able to uncover on their own. This research also contributes to identity-trajectory literature, especially in the context of graduate education. McAlpine and Lucas's 2011 research focused on social science graduate students. Although there is also recent work including biological science students by McAlpine (2012), there has not been any identity-trajectory research published to date on engineering or physical science graduate students. This research contributes to the body of knowledge of graduate education in engineering and physical sciences, as well as identity-trajectory.

1.4 Overview of Methods

This study is an analysis of narratives of 25 optics and photonics graduate students in

PhD-granting programs. The study also includes a set of pilot interviews with department heads of departments of optics and photonics. Participants were purposefully selected to represent variation in institution, years in program, undergraduate background, work experience, gender, and nationality (Leydens, 2008; McAlpine, 2011). Two data sources were used for this study: interviews and curriculum vitae. Interviews were conducted with each of the participants to explore their identity-trajectory linking through their past, present, and future experiences. The findings focus on experiences, networks, and institutional factors and roles that contribute to how students saw themselves as professionals at the time of the interviews and their expected future careers. Curriculum vitae represent the students' intellectual identity throughout their programs (McAlpine, 2010). These interviews and curriculum vitaes were analyzed through open and axial coding methods to identify themes across the participants.

1.5 Limitations

One of the notable limitations of this study is that it focused on departments and PhD programs with optics or photonics in their titles. The relatively small number of specific degree-granting photonics and optics departments are at the forefront of the emerging field as its own disciplinary home. In a study on student and faculty interdisciplinary identities, McNair et al. argue that "traditionally the source of power is academic disciplines" (2011, p. 378); in the case of optics, the powerful departments are physics and electrical engineering. There is a substantially broader population in these departments of graduate students who affiliate with optics and photonics and those who intentionally develop their careers in this area could have been interesting participants; however, they were not included to reasonably limit the scope of this research.

1.6 Overview of Remaining Chapters

The remaining 5 chapters of this dissertation include (1) the literature review, overview, and theoretical framework; (2) methodology; (3) pre-graduate experiences; (4) graduate development; and (5) conclusion. Chapter 2 summarizes pilot research on photonics programs that contributed to the development of the study and reviews the literature relevant to the theoretical framework of identity-trajectory. Both the theory itself and its application in other studies of graduate students are reviewed. Chapter 3 describes in detail the methods developed and applied to this identity-trajectory study of optics graduate students. Chapter 4 presents findings on the pre-graduate training experiences of optics and photonics graduate students. These narratives demonstrate some of the most influential factors for preparing graduate students through the strands of intellectual, network, and institutional influences. Chapter 5 describes the graduate training and development of these students and the ways in which the three strands become a part of their development. Chapter 6 discusses the implications and conclusions of this research study.

CHAPTER 2: LITERATURE REVIEW, OVERVIEW AND THEORETICAL FRAMEWORK

The theme of "identity" has been a very useful concept in understanding both the educational process and the development of students. In engineering education, many scholars use identity theories to understand major selections, career choices, and student interpretation of classroom experiences. As such, investigating and elucidating the identity development of graduate students in photonics programs is the primary goal of this research. Since it is well known that the programmatic and personnel strengths of a given educational institution can impact a student's professional development, degree-granting optics and photonics programs are reviewed in this chapter based on existing publications, pilot research collected through a web search, interviews with department chairpersons, as well as results from a student survey. Studies of academic pathways seek to understand how students arrive at their chosen area of study, but also attempt to clarify how they formulate their post-graduate plans. At a high level these pathway studies explain how different types and large numbers of students move through the university educational process. On a more micro scale, these studies look at the pathways of individual students—typically their pre-college preparation and experiences—to make generalizations about how students should be prepared and taught. Identity-trajectory is a method to evaluate identity through time; in other words, how is the identity of a student influenced and changed over time with respect to their intellectual experiences, networks, and institutions? Situated in the student pathways work in engineering education and identity, this study employs the theory of identity-trajectory to understand the development of photonics graduate students. This particular chapter provides the practical and theoretical background for this study and has two distinct sections. First is a contextual understanding of optics and photonics based on the pilot study (Sections 2.1 and 2.2, from Thomas & McNair, 2011); second is a review of identity-trajectory literature, which provides the theoretical framework for this study (Sections 2.3, 2.4, and 2.5).

2.1 Historical Development of Degree-granting Optics and Photonics Programs

With its largely industrial and/or applied focus, optical engineering has existed as a specialty within various academic departments, including electrical engineering, physics, materials science, and others for over 70 years. However, for most of that period only a few degree-granting programs existed in the United States. The earliest program in optics and photonics in the U.S. was established at the University of Rochester in 1929. The program that would become the Institute of Optics was founded with a corporate grant from Eastman Kodak and Bausch & Lomb, and sought to train students in the design of optical instruments (Stroud, 2004; University of Rochester, 2011). Corporate interest in training students to design both consumer and research-related products eventually led to a second degree-granting optics program in 1962 at the University of Arizona—some 33 years later.

In the last 30 years, however, 9 additional degree-granting programs in optical engineering or optics and photonics have been established. There are now a variety of optics and photonics-focused programs in this country. Of the 14 programs currently available, 9 offer Doctor of Philosophy degrees, 11 offer Master's degrees, 7 grant Bachelor of Science, and 2 grant Associate's degrees. Scholars have yet to fully document the development of these educational optics programs, which is unfortunate since such an endeavor would yield valuable insights into the emergence of this interdisciplinary field. Moreover, there are few publications about optics and photonics programs, either a meta-analysis of several programs or a comprehensive study of a specific program. In 1980, Gaskill published survey results of an overview of optics, physics and electrical engineering programs. In this early publication he pointed out the limited number of educational programs in these three areas, resulting in a shortage of students trained to meet growing industry needs. In 1988, Rose-Hulman faculty member Brij Khorana published a short piece about the Center for Applied Optics Studies and the new bachelor and master programs at the institution. A 1991 invited paper (Thompson) overviewed the historical development of the optics program at the University of Rochester, which served as a forerunner to Stroud's 2004 publication. Thompson included artifacts such as newspaper clippings and meeting minutes in his manuscript detailing in a historical format the early years of Rochester's program. The 1996 publication by Dimmock, Ahmad and Kowel. reviewed the establishment of a Master's program in electrical engineering with a focus on optics and photonics at the University of Alabama Huntsville. That concentration would later result in a full degree program in optics and photonics at the institution. In 2003, University of Arizona faculty (Reagan) published a paper on the accreditation process of their bachelor's degree program in optical sciences and engineering. The overview discussed program objectives, curriculum layout, and the role of the assessment committee. Apart from these primary reviews, many of the other publications on optics and photonics education have tended to focus on lab courses and interventions within physics or electrical engineering departments (Andrawis, 1998; Barat 1998; Cheville & Bunting, 2009; Crone, 2007; Mead & Bennett, 2009; Sheikh & Rushdi, 2009).

2.1.1 Graduate Programs

A specially commissioned series of essays, "A Jewel in the Crown" (2004), reviewed the first 40 years of disciplinary optics education in the United States. This was an interesting set of essays; however, the decades that followed the first 40 years were far more influential. As noted earlier, Rochester's first competitor, the University of Arizona, did not come on the scene until the 1960s, after which ten additional departments or degree-granting programs would follow. Table 1 lists the chronological emergence of departments and degree programs with a focus on optics, with the greatest spike in the 1980s. In fact, programs that were founded in this decade include the first Associate's degree program, as well as one of the first Bachelor's degree programs. During interviews I conducted, several department chairs stated that many of the graduate programs available today rarely have the opportunity recruit students whose undergraduate background is in optics; most of them emerge from physics and electrical engineering programs. However, with the establishment of more undergraduate optics degree programs, formally trained students will likely populate graduate programs in optics. Of the 14 institutions reviewed, 11 offer a Master's degree or higher, with the most overlap in Master's degree offerings. Only 4 of the programs offer all degrees (Bachelor's, Master's, and Ph.D. degrees), and only 2 offer both Bachelor's and Master's degrees. The newest program, an Associate's degree at the College of Lake County established in 2011, will soon offer a program to allow students to transfer and earn a bachelor's degree as well (College of Lake County, 2011).

> Similar to other science and engineering disciplines, optics programs require a solid background in the physical sciences and mathematics. All of the graduate programs reviewed require an undergraduate major in science or engineering. The curriculum structure of the undergraduate optics programs is similar to that of other science and engineering programs. In interviews with department chairs, one reason consistently offered for the limited number of Bachelor-level programs in optics is that a very large amount of coursework would be required to prepare students to enter the optics workforce (Thomas & McNair, 2011).

Table 1. Degree-granting institutions in optics, founding date, and degrees offered

Institution and Program Type	Date Established	Degrees Offered
University of Rochester - Independent college	1929	BS*, MS, PhD
University of Arizona - Independent college	1964	BS, MS, PhD
Air Force Institute of Technology - Separate department in engineering department	1970s	MS, PhD
Rose-Hulman Institute of Technology - Physics and optics department	1980	BS, MS
University of Dayton - Electrical engineering and optics department	1983**	MS, PhD
University of New Mexico - Program in electrical engineering and physics	1983	MS, PhD
University of Central Florida - Independent college	1985	BS*, MS, PhD
City University of New York - Queensborough - Electronics engineering department with optics degree program	1986	AS
University of Alabama - Huntsville - Electrical engineering department	1992	BS, MS, PhD
University of California - Davis - Interdisciplinary engineering department	2001	BS
University of North Carolina- Charlotte - Separate department in college of engineering	2002	MS, PhD
Norfolk State University - Program in engineering department	2003	BS, MS
Delaware State University - Degree granting research center	2010**	MS, PhD
College of Lake County - Separate department	2011	AS

* - Program is in development as of 2011
** - The exact founding date of this program was unclear based on the information available. This is the best estimate, but details to support the date are unavailable.

Nonetheless, according to interviews with department leaders, programs are indeed growing in size and number. The University of Central Florida plans to bring undergraduate degree programs online by 2015. In fall 2011, the University of Rochester started their undergraduate program in optics and as noted above, and a new Associate degree program was started at The College of Lake County.

Most of these programs are being launched in response to industry demand for technical talent in optics and photonics with at least an Associate's or Bachelor's degree. Despite the fact that some interviewees wondered if these programs provided adequate training in photonics, graduates with a B.S. or a AA in optics tend to be highly recruited for industry positions and many bachelor level students go on to graduate school. Based on information available online and gathered from department chairs, there are approximately 600 students from Associate's level through Ph.D. in the 14 optics and photonics departments in the U.S. (Thomas & McNair, 2011). However, the majority of the students, approximately two-thirds, are pursing graduate degrees. In terms of faculty involvement, there are currently approximately 250 faculty members in the 14 programs—but many hold joint appointments in other departments in their institutions. Their professional training and expertise varies; however, the majority of them have earned doctorates in electrical engineering, followed by physics and photonics. Far fewer are from related disciplines such as materials science and engineering, mathematics, and other physical sciences. Some that have actually earned doctorates in optics tend to migrate to other optics programs, and work with collaborators, advisors, and committee members throughout their careers.

2.1.2 Undergraduate Programs

There are five undergraduate ABET-accredited optical engineering programs in the U.S., with the first achieving accreditation in 1998, and the remaining between 2002 and 2006 (ABET, 2011). The program at the University of Central Florida accepted its first class to begin in fall 2013 (The College of Optics and Photonics, 2013). The University of Rochester welcomed its first undergraduate optics class in Fall 2011. Both are expected to pursue ABET accreditation upon graduation of their first undergraduate class. Currently, the only ABET-accredited optical engineering technology program is located at CUNY-Queensborough, which was accredited in 1995 after nearly 20 years of training students in optical engineering. Due to the relatively unfamiliar territory of optics education, SPIE, an international society for optics and photonics (founded in 1955 as the Society of Photographic Instrumentation Engineers) joined ABET to add professional perspective on accrediting these departments (ABET News, 2011; Thomas & McNair, 2011). While there are conflicting opinions as to why optics degree programs seem to be slow growing, interviews with department heads cited the specialized nature of the field.

2.1.3 Curriculum Content

There are definite focus areas in curriculum and content for all of the optics programs in the U.S. A web search of departmental program offerings and personal interviews served as the primary data sources for determining areas of specialty, which tended to vary among the larger departments due to the fact that they are able to offer training and research in a full breadth of photonics research. In general, the following three “powerhouse” departments, University of Rochester, University of Arizona and the University of Central Florida, teach and do research in all areas of optics, and also are the largest among those surveyed. Of the 14 remaining departments, optical science, optical communication, and optoelectronics are core components of the curriculum. It should be noted that while other departments do not have all course offerings, only two of the remaining institutions, The University of Dayton (2011) and The University of California at Davis (2011), show consistent coursework and research in biophotonics and imaging. Within these areas of specialty there is definitely a range between science and engineering, as well as links to other disciplines.

The most widely represented specialty is optical science, which is closely related to physics. Optical science, which tends to focus on electromagnetic studies, geometric optics, and quantum optics, is primarily concerned with exploring and understanding the natural behavior of light. At the other end of the spectrum is optical engineering, which is focused on system design using optics knowledge toward applications. Engineering research and technology topics including fiber optic communications, optoelectronic devices, lasers, and imaging studies are also applied areas of concentration. Graduates from these programs often become electrical engineers or engineers representing other disciplines that may use these technologies in their work. Biophotonics, spectroscopy, and nanooptics tend to lie in the middle of optical science and engineering, with overlap in other disciplines, such as biology, chemistry, and materials science (Thomas & McNair, 2011).

2.1.4 Career Opportunities in Optics and Photonics

Students at any level who choose to purse degrees in optics and photonics have an excellent career outlook. Nearly all of the departmental websites advertise optics as an extremely promising career choice for students. The University of California at Davis (2011) offers the most comprehensive list of alumni opportunities following graduation. Their most recent literature listed 42 undergraduate degree students, 15 of whom attended graduate school. The remaining went into industry as engineers and consultants. The University of Arizona (2011) provides a list of the types of opportunities that graduates can expect to enjoy, including joining the optics industry, becoming researchers or inventors, or joining other major corporations that are branching into the area of optics/photonics. Even at the Associate degree level, job placement is advertised as being fairly secure, with salaries as high as $55,000 (College of Lake County 2011). Department heads who were interviewed for this study confirmed the expansive career opportunities for graduates. Several mentioned that companies looking to hire students for internships and co-ops frequently contact their programs. One department chair of an undergraduate program asserted that students at the Bachelor level are just as competitive, if not more so, than their traditional engineering counterparts. At the graduate level, students often have dissertation projects supported by industry and go on to work for those companies once they earn an advanced degree. According to interviews, most Ph.D. recipients who wish to eventually join academia will typically work in industry for several years. In fact, one department chair indicated that most academic job searches in the optics field will not seriously consider candidates who do not have at least 10 years of industrial research experience. Opportunities are also lucrative in small-start up companies for Master's and Ph.D. graduates.

2.2 Pilot Study Survey Results

Given the lack of scholarly research available about photonics graduate students, a traditional literature review was not very fruitful in this area. This section, therefore, will review the pilot data that was collected to support this study and which was subsequently used to design the research questions. The early phases of this work included data collection on all known photonics programs (through a web search), interviews with nine program leaders, and a survey of 85 current graduate students from five institutions (carried out in Spring, 2011). Selected survey questions are discussed in this section, which relate to demographics, specialty areas, and pathways to the field. Thus, the pilot data provides a basic understanding of the students, their backgrounds, and how they selected their field of study.

A total of 87 individuals (both students) responded to the survey (Appendix 1). Forty-seven respondents indicated their gender, of which approximately 62% were male. Forty-eight provided both age and race information. The age group 23-29 represented the largest proportion of respondents at 66%. Reported race data indicated that 10% were Asian and Pacific Islander, 12% were Black/African American, 67% were White/non-Hispanic, and the remaining 10% preferred not to indicate their race. Specializations within optics was also included as a survey question. As shown in Figure 1, the most frequently selected specializations were imaging, optical systems, and biomedical optics.

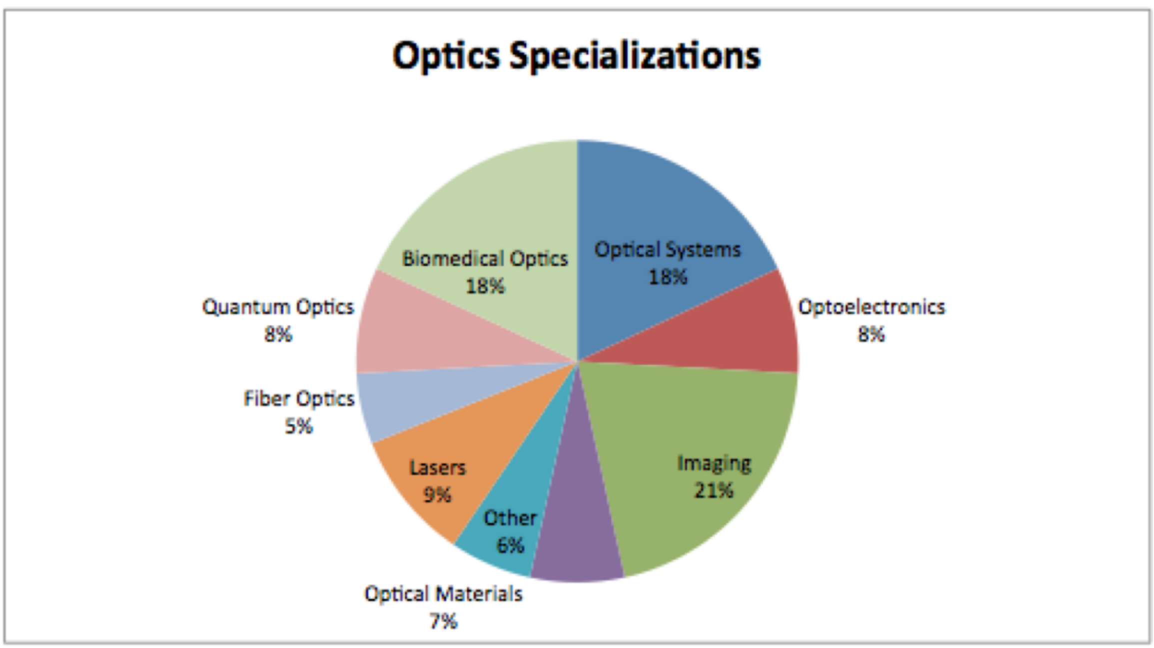

Figure 1. Optics specializations among graduate students responding to pilot survey

Another survey question asked respondents to identify their home college or university. A total of 49 responses indicated that 22 were enrolled at the University of Arizona, 14 at the University of Rochester, and 4 at the University of California at Davis. This indicates that at the time of data collection, the survey had only been forwarded to students by three of the seven departments that had originally been asked to participate. 76% of respondents were currently enrolled in Ph.D. programs, and 88% indicated that they would seek a doctoral level degree.

The original intent was to explore interdisciplinarity in optics and photonics and identify the various pathways to the discipline. As with many surveys, more questions were identified and there were limitations in achieving sufficient depth within the data. The pilot data led me to focus the study only on graduate students, and especially on their identity development within their programs. The transition to the optics/photonics field clearly occurs at the graduate level, but that process—especially for inward migrants to these disciplines—is not well understood. The findings from the survey data raised the question of how and when one changes identity while transitioning from one discipline to another.

2.2.1 Interdisciplinary Thinking and Behavior

Several questions in the survey were included to determine interdisciplinary practices and behavior. Student coursework was one area of interdisciplinary practice, with 40% of respondents indicating that they had taken less than 10% of their courses in optics related topics, and 42% indicating that over two-thirds of their completed coursework was not optics related. Approximately 64% of respondents had completed less than 10% of their coursework in electrical engineering, which is an interesting finding since they were mostly students of optics and photonics, but had done relatively little subject-related coursework.

One indicator for student interdisciplinary practice is recognizing the relationships between optics and other courses (Hermerén, 1985). Of the 59 responses to this question, all but one at least sometimes observed a relationship between optics and other courses (Figure 2).

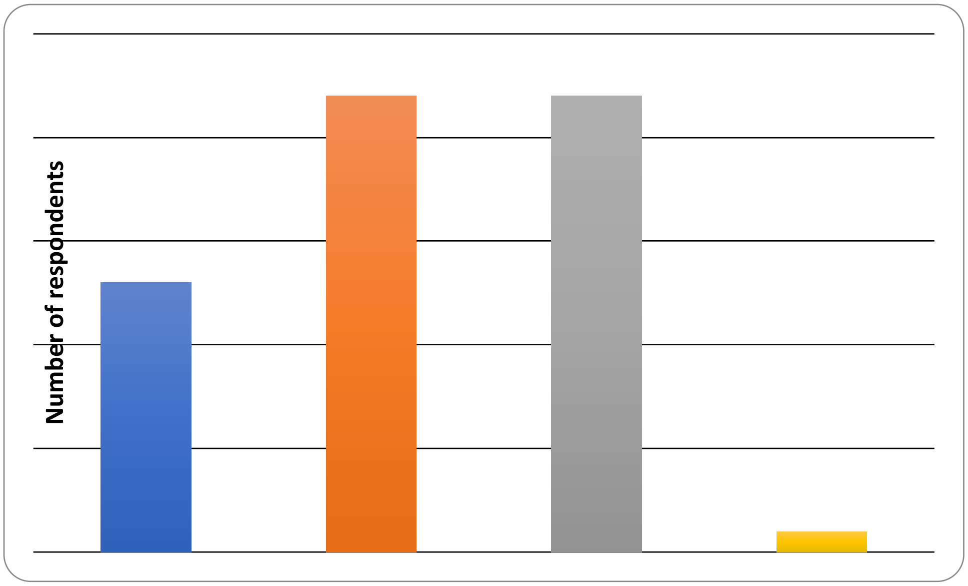

Figure 2: Graduate student participants' recognition of the relationship between optics and other scientific disciplines

Also associated with course selection and interdisciplinary practice is students' motivation for taking courses outside their home department. Students rated college requirement, interesting topics, preparation for graduate school, and a minor or specialization highest among reasons to take courses outside their home department.

2.2.2 Pathways to Degree-granting Optics and Photonics Programs

As shown in Table 2, among a list that included interesting coursework, internship opportunities, engaging instructors, and scholarship opportunities, "interest in optical technology" was cited as the most important motivating factor for students choosing to pursue optics. The coursework in optics itself was moderately important to the 50 respondents who answered this question. Several questions were developed to solicit student motivation for selecting optics, but this review will focus on one of the qualitative questions asked of respondents. To code this open-ended item, the list of codes was intentionally broad to describe all of the factors that they felt were important. The results indicated that the codes were sufficient since no responses fell outside the code list. Forty responses were provided for this question.

Table 2. Pilot survey: Number of qualitative responses for encouraging factors to pursue optics for graduate students

Factor	Number of Responses
Modern Science/Technology	13
Curiosity and Interest	12
Past Educational Experience	10
Internship/Career Opportunities	7
Interdisciplinary Features/ Broad	7
Faculty/Teacher	3
Scholarship/Funding	3

Also important to this study is identifying discouraging factors that hinder or prevent students from pursuing an advanced degree in photonics. Respondents were asked via an open-ended question to describe discouraging factors that impeded them from pursuing optics as a field of study. The most frequently selected reasons among the 37 respondents were the challenging coursework, limited opportunities to major, limited awareness of optics, and other career-related factors. Some of the "other" responses were related to personal life issues (Table 3). Many respondents expressed concern about the availability of jobs upon graduation due to the small size of the field.

Table 3. Pilot survey: Number of qualitative responses for discouraging factors to pursue optics for graduate students

Factor	Number of Responses
Coursework	13
Little Known Field/ Limited Awareness	10
Few Opportunities to Major	7
Other	5
Other Career Options	4

Respondents were asked if they had switched majors during their academic career, and if so, from what area and why. Only 18 respondents indicated that they had switched majors, and of those 18, 16 provided reasons for the change. The most frequently mentioned reason for switching to optics was linked to having been introduced to optics either in other coursework or lab experiences, identified in 10 responses to the question. All of those responses came from current graduate students in optics departments. Five responses were associated with not liking their prior major, which was usually listed as physics or other engineering discipline. Common themes also emerged about the small nature of the field, and people serving as ambassadors to encourage students to come to the discipline.

Students indicated some general career goals, and understanding those goals was also captured in the survey questions. An open coding approach was used to identify the specific factors that were most important to participants. The qualitative question related to student career goals was “quantitized” into the codes in Table 4. Both deductive and inductive evaluation approaches were used (Strauss 2008). The selected codes could apply to more than one of the 40 responses, so there were more codes than responses. For example, a participant’s response could be coded as having goals in optics research, and as well as having a goal to work in a corporate/industry environment.

Table 4. Pilot survey: Number of qualitative responses for graduate student career goals

Career Goal Categories	Number of Responses
Application related	27
Optics	24
Engineering/Physics	18
Corporate/Industry	15
Professorship/Academia	9
Other	3

The information garnered about optics education in the pilot study led me to reconsider the research questions and overall study design. Initially I sought to examine the student experience and views of interdisciplinarity based on the type of department that students selected for their graduate programs. However, the qualitative questions within the pilot study reinforced the need for greater depth. In other words, in order to achieve a more complete understanding of the graduate student experience in optics/photonics programs, a department-based investigation based on online surveys would not accomplish this goal.

2.3 Identity-Trajectory Overview

There are several theoretical frameworks that could be used to understand preparing for and navigating graduate school from the student's lived perspective. Identity-trajectory offers a framework that accommodates the dynamic day-to-day experience with consideration for intellectual, institutional, and network influences. For this study, I considered several alternate theories, yet chose identity-trajectory for its holistic perspective. The alternative theories include: goal orientation, activity theory, affinity identity, self-authorship, and social cognitive career theory. Each of these theories are useful, but would likely result in additional limitations of this study.

Goal orientation, essentially self-regulated learning, is a perspective within motivation theory. Pintrich (2003) examines goal orientation as “the reasons and purposes for approaching, and engaging in achievement tasks” (p. 676). Many studies utilizing goal orientation as a framework are strictly quantitative in nature and rely on intent on the part of the participant. As there has been limited work published about photonics students, this framework would only provide limited insight. Activity theory is used to define “the various components of a system through which cognition is situated” (Barab, 2002, p. 171). Examining the subject, object, tools, rules, community, production, and division of labor to produce a goal limits the unit of analysis to the system, not the individual. Activity theory, does however contribute to identity-trajectory’s institutional strand. Another framework that could be used for this study is affinity identity. Within Gee’s (2000) identity framework affinity identity focuses on “allegiance to, access to, and participation in specific practices” (p. 105). Affinity identity has been used as a framework in interdisciplinary contexts (McNair et, al 2011) and disciplinary spaces (Bartholomew, Darrah, Ell, & Saunders, 2011). The challenge with applying affinity identity to this study is the required assumption of intent on the part of the participant. The findings in chapter 4 indicate that students’ intent on research careers, specifically in photonics, is limited in the early stages. Each of these theories would be suitable for a study of this nature, but have limitations that can be overcome with identity-trajectory. It is also important to note that these frameworks in some ways contribute to and undergird identity-trajectory.

Agency, the actions taken to achieve a goal, is a contributing theory to the intellectual strand of identity-trajectory. The focus on individual behavior may be disconcerting for some when considering identity. The cognitive precursors to agency would direct a researcher to consider self-authorship. The concept of self-authorship—originated by Kegan (1994) and developed into a theoretical framework by Baxter Magolda (1998, 1999, 2001, 2004) and Baxter Magolda & King (2004)—is on the surface similar to agency and thus is worthy of address. Baxter Magolda defined self-authorship as "a way of understanding the process that people use to make meaning of experiences" (Baxter Magolda, 1998, p. 143). Like identity-trajectory, self-authorship has three dimensions, and these dimensions can work in sequential or cyclic nature, similar to the interwoven strands of identity-trajectory. Sattler et al. (2012) described the "potential for movement from a socialized mind (one defined by an external definition) to a self-authoring mind (one defined by an internal definition)" (p. 3). This process is achieved through the dimensions of cognitive, intrapersonal, and interpersonal—which are similar to the strands of identity-trajectory. The cognitive and intrapersonal dimensions are related to the intellectual strand of identity-trajectory. One strand of self-authorship, "relationships," corresponds to the network strand of identity-trajectory. Also, as with identity-trajectory, self-authorship is used to understand educational development and career decisions (Baxter Magolda, 1999; Creamer & Laughlin, 2005; Sattler, Turns, & Mobrand, 2012). The self-determined definition of identity provided by self-authorship, along with its reflective nature, is more similar to psychological views of agency, in that there is little focus on social structures and external factors.

Despite many similarities between self-authorship and agency, there are also clear differences between these two theories. Self-authorship is principally a cognitive theory; it relies on individual reflection of self (Creamer & Laughlin, 2005) and the development of internal definitions of beliefs, self, and relationships (Sattler, Turns, & Mobrand, 2012). Self-authorship is an empowering framework because it allows for definition of self, using individual beliefs based on societal definitions and values. In contrast, agency, in the context of this and similar aforementioned studies, requires external considerations for the development of identity.

According to Baxter Magolda's 1998 definition of agency as "the ability to collect, interpret, and analyze information and reflect on one's own beliefs in order to form judgments" (p. 143), self-authorship could be the cognitive precursor to action, which is agency. Accordingly, this study does not seek to understand the process of meaning making as its primary goal, but instead examines the actions that result from meaning making intentions. While self-authorship can result in action, that theory's focus does not match the focus of my research or the use of agency within identity-trajectory theory. Focusing attention on a small aspect of holistic development of identity has potential to exclude important influences. The explanation of identity-trajectory in this chapter, provides a framework to view these small parts in a combined way.

Together, the three strands of identity-trajectory may seem similar to other more commonly applied frameworks. One such analogous theory to identity-trajectory is social cognitive career theory. However, social cognitive career theory and identity-trajectory are different in that the latter interweaves both individual cognitive processes and actions, while at the same time recognizing that existing social systems can have an influence as well. This is not to say that social cognitive career theory does not take into account the impact of social systems. Developed by Lent, Brown and Hackett (1994), this social cognitive theory is based on Bandura (1986), who used individual thought and action with social systems to explain behavior. Social cognitive career theory depends on three primary constructs: self-efficacy, outcome expectations, and goals (Lent et al.). Lent and coworkers specifically discussed agency in ways similar to the description discussed earlier in this paper. The vocational context is taken into account in social cognitive career theory (which, of course, remains a fundamentally a cognitive theory)—making it similar to the intellectual strand of identity-trajectory. At the core, social cognitive theory expects that "people act on their judgments of what they can do as well as on their beliefs about the likely effects of various actions" (Bandura p. 231). This is important because it is extremely similar to the intellectual strand of identity-trajectory, which focuses on actions. Self-efficacy, outcome expectations, and goals can definitely be affected by social systems. Social cognitive career theory does not, unfortunately, try to explain those social systems. Identity-trajectory, through its network and institutional strands, allows us to theorize and explain how other actors and social structures can influence and impact the individual.

Identity-trajectory is a recently developed theoretical framework that has been used to frame the career development process of academics (McAlpine, Amundsen, & Jazvac-Martek, 2010). The authors explained that "Trajectory emerges through and is embodied in cumulative day to day experiences of varied and complex intentions, actions and interactions with others that may include setbacks as well as unexpected detours and opportunities" (p. 129). Their study suggested "a framework of three distinct, but interrelated strands to examine identity-trajectory through time—both to look back and reflect on the myriad of complex activities and interactions of an individual's trajectory as well as imagine forward" (p. 129). Specifically, they proposed the following three strands of identity-trajectory: intellectual, network, and institution. McAlpine and coworkers explained that the three strands "develop asynchronously through time" (p. 139) and together contribute to the long-term professional identity development of the individual. In order to elucidate the concept of identity-trajectory, I will first provide a brief overview of the three strands. I will then discuss the theoretical underpinnings of identity-trajectory in Section 2.4, after which I will review the research published using this framework in Section 2.5. Accordingly, the following brief introduction will provide basic context to explore the theoretical underpinnings of this framework, followed by examples from the research conducted by McAlpine et al.

2.3.1 Intellectual Strand

According to McAlpine et al. (2010), the intellectual strand represents "the contribution an individual has made and is making to a chosen intellectual field through scholarship" (p. 139). Essentially, the intellectual strand is about learning new information, concepts, etc. and demonstrating an understanding of that material through hands-on skills or generated products. Typically, the intellectual strand results in artifacts such as journal articles and presentations in academic venues. The intellectual strand is developed in the classroom, through research, in the lab, as well as through less formal avenues of inquiry. Also included within the intellectual strand are personal traits, desires, and goals. Because all of these are defined by the individual—e.g., they emerge as a result of a person's actions—they are considered to be part of the intellectual strand.

2.3.2 Network Strand

Networks, defined as the relationships that contribute to and facilitate professional development, come in many forms and have the potential to significantly influence a graduate student's professional trajectory. In the academic setting, a network takes six forms: academic colleagues, practicing professionals, membership in disciplinary organizations, influence of the work of others, journals, and research collaborations (McAlpine et al., 2010). Relationships within the department, the field, and with peers all have the potential to influence the graduate education process and career choices, as well as contribute to dissertation research. These networks can also either support or limit graduate students' motivation to continue within their programs or professional arena. Also, the individual's position within disciplinary networks is a part of his or her identity-trajectory. In short, the views and considerations of those in their professional/academic circles influence graduate students' current and future opportunities and intentions.

2.3.3 Institutional Strand

The third strand, institutional, refers to the organizational context that either supports or constrains individual identity-trajectory. The institutional strand of identity-trajectory "represents each person's relationships, responsibilities and resources wherever they are physically located" (McAlpine et al., 2010, p. 143). The authors added that the institution can either nurture or constrain the other strands in identity-trajectory. This notion supports earlier work by Tinto (1987), who argued that the institution can support or negatively alter graduate student persistence. Further, Ashforth (2008) explained that in the organizational context "identification matters because it is the process by which people come to define themselves, communicate that definition to others, and use that definition to navigate their lives, work-wise or other" (p. 334) Graduate school is a significant part of the professional identification of a student; as such, the identification process is molded in part by the institution at all levels. Gee (2000) proposed four ways by which identity is manifested in an educational setting—and specifically in undergraduate and graduate education. He argued that "we are what we are primarily because of the positions we occupy in society" (p. 101). The institutional "society" that is graduate school influences who we are and become as a result of four overlapping areas: nature, institutions, relationship to others, and affinity groups—all of which influence identity development in important ways.

2.4 Theoretical Underpinnings of Identity-Trajectory

The three strands of identity-trajectory and the theoretical underpinnings described in the following section provide a robust way to understand identity. Identity-trajectory takes into account one's individual psychology, social networks, and institutional affiliations. While there are limitations in any theoretical framework, identity-trajectory was selected for this study because of the confluence of other familiar frameworks and the similar context of application (graduate education and academic professions). In McAlpine's work, she supports identity-trajectory with several theories presented in this section (McAlpine & Amundsen, 2009, McAlpine, Amundsen, & Jazvac-Martek, 2010). The four primary frameworks supporting identity-trajectory are the following: (1) discourse-identity, (2) storytelling and identity, (3) agency, and (4) activity theory.

Identity-trajectory and each of its three strands are linked to four other (and possibly more) frequently applied research frameworks. Within the following subsections the four primary underpinnings of identity trajectory will be reviewed. Discourse-identity represents the individual identity traits that are developed as a result of discourse with others; as such, discourse-identity is related to the network strand of McAlpine et al.'s (2010) theory. Storytelling and identity provides a means to build links between past present and future along a trajectory; this corresponds to the through-time aspect of identity-trajectory. Storytelling and identity are reflective, holistic methods that account for the complexities of life, and in this case, graduate school. Agency—the goals that one makes and the actions needed to progress toward them—focuses on the actions of individuals within their various formal and informal structures; agency is linked to the intellectual strand. The fourth framework that supports identity-trajectory is activity theory, which focuses on the structural bounds, rules, hierarchies and roles of an organization or institution—for this study, graduate school. Given this definition, activity theory relates to McAlpine et al.'s institutional strand. Even though each of these supporting frameworks could be independently valuable in a study—and have been used effectively in related studies—identity-trajectory is a separate theory because it combines all four aspects together. The exchange between storytelling, agency, activity theory and discourse-identity address the complex identities of academics and professionals in a unique way. In this section I will also review similar or competing epistemologies and theories to clearly elucidate the similarities and differences.

2.4.1 Discourse-Identity

Gee's (2000) "Identity as an Analytic Lens for Research in Education" provides a useful framework for identity as a theoretical underpinning and its use in educational research. Gee proposed four ways for understanding identity: discourse-identity, nature-identity, institution identity, and affinity-identity. Discourse-identity is "an individual trait recognized in the discourse/dialogue of/with 'rational' individuals" (Gee, 2000, p. 100). McAlpine and Amundsen (2009) focused their discussion on discourse-identity because discourse is more dynamic in the experience of graduate students versus the institutional-identity. In other words, the institution and its representatives impart relatively limited identity to a graduate student; in contrast, one's developed professional identity occurs and is validated via discourse with colleagues. Arguably, graduate students do not hold a notable "position in society" as Gee (p. 101) pointed out, but are identified by "individual accomplishments as they are internationally recognized by others" (p. 101) via discourse. Like identity-trajectory, Gee did not separate these topical areas, but this specific view is notably applicable in the academic setting. Carlone and Johnson (2007) proposed that whom an individual is, and is recognized to be within their academic realm, is critical in understanding their professional identity and self-description of that identity.

In graduate school more so than in undergraduate programs, students are essentially striving to become a part of a community that recognizes their intellect, contributions, and talent. This goal is primarily achieved through discourse within the department, the university and the broader academic field to which they belong. Because of this, and the limited institutional-identity, McAlpine and Amundsen (2009) focused their attention on discourse-identity. (It should be noted that while the institution is an important strand within identity-trajectory, activity theory provides the greater framework for understanding organizational influence.) Gee (2000) separated institutional-identity from discourse in several ways. Discourse-identity "is not something that some institution creates and upholds" (Gee, p. 103) that is then identified by others. Instead, the researcher focused attention on the subject—not on the institution or context in which it is recognized. Gee also explained that discursive-identity is, in fact, used by the institution to support its identity. Unlike institutional identity, discursive-identity can be subjectively viewed, which leaves some room for interpretation. Gee's example of a professor's institutional-identity provides greater clarity. An individual is a professor not just by the title granted by the university, but the rules and treatment by the organization that sustains this identity. The adjectives that may describe the professor role are based on discourse within the community and are arguably more important than the title alone. Gee (2000) explained discourse-identity as "ways of being 'certain kinds of people'" (pg. 109). In the context of identity-trajectory this means being a member of a chosen profession (e.g., a graduate student or academic). By focusing on being a certain kind of person, identity-trajectory works best with groups of similarly discoursed people within their space of operation.

Even though discourse-identity is typically applied to the individual, similar discourse-identities can be grouped into thematic areas to understand types of people and their experiences within a group. Similar to initial studies of identity-trajectory, this later research focuses on women and their identity development within and surrounding the academy. Carlone and Johnson (2007), for example, provided a valuable example for understanding the notion of discourse-identity among diverse women in science careers. Specifically, the authors developed thematic discourse-identities of ethnically diverse women in science careers: research scientist, altruistic scientist and disrupted scientist. This represents a powerful tool because it allows for comparisons with a group and the types of experiences that they share while also highlighting differences. While each of their thematic identities is different, discourse identity provided different ways to understand the similar experiences of diverse research participants. In this study I chose not to use the concept of thematic identity in order to maintain consistency with other identity-trajectory work; nonetheless, the thematic experiences of participants can provide similar value.

A notable aspect of the theoretical underpinnings of identity-trajectory is discourse-identity. This framework characteristic allows for individuality in understanding identity in the context that a person operates, and focuses on their contributions to their professional landscape. For graduate students and other academics, discourse-identity is extremely important. Even though the institution grants some identity recognition, that recognition is limited in scope and depth due to the fact that the opinions of external "others" are typically needed to advance one's academic career. Developing an identity within the context of department, disciplinary, and topical discourse is of critical importance. This specific area provides recognition for an important feature of identity-trajectory that can influence the intellectual and network strands.

2.4.2 Storytelling and Identity

Identity-trajectory in part relies on a narrative methodology, which also supports the theory of identity ***as*** narratives. This construct provides a different view of identity than is traditionally used in education. However, identity-trajectory provides specific avenues for understanding identity through time, as a process, and in relation to others and different spaces (Juzwik, 2006). McAlpine and Amundsen (2009) explained the importance of the narrative in relation to the identity of an individual. In contrast, Sfard and Prusak (2005) argued for the notion of stories or narratives ***as*** identities. The distinction is important as to not reduce narratives to only a method to construct or describe. This approach is what Sfard and Prusack referred to an "***is***" identity. McAlpine and Amundsen adopted Sfard and Prusack's approach that "identity is a perfect candidate for the role of 'the missing link' in the researchers' story of the complex dialectic between learning and its sociocultural context" (p. 6). In this study, narrative ***as*** identity is used because of its ability to connect the individual, their learning, and their context. This is a critical piece for understanding identity-trajectory and some of the other related sub theories. The approach is empowering to the individual because the speaker owns the narrative and identity. They are self-identified but influenced by discursive identities granted to an individual.

Narrative identity has two sub-themes that are important to identity-trajectory: the actual identity and designated identity. "Actual identities are usually told in present tense and are formulated as factual assertions" (Sfard & Prusack, 2005, p. 16). This is essentially how we describe and understand our current state. For example, *I am a graduate student*, or *I have a master's degree* are actual identities that are fact based and true. The "designated identities are stories believed to have the potential to become a part of one's actual identity" (Sfard & Prusack,

p. 16) and include goals, hopes, dreams or future identities. Example phrases indicative of designated identities would be: *I want to become a faculty member,* or *I would like to become a great writer.* One's future identity is essential because it directs current actions. For example, if a graduate student (let's call him "Alec") were to say, *I want to become a faculty member,* some of the actions that may become a part of his narrative include completing milestone examinations, producing a successful dissertation, and publishing journal articles along the way. Sfard and Prusack also described the significance of critical stories—namely, "those core elements, which, if changed, would make one feel as if one's whole identity changed" (p. 17). Critical stories often arise within narratives discussing the actual identity and designated identity. So, Alec, our graduate student example, had already attained a master's degree but had plans to become a faculty member and great writer. He would have several critical stories along these identities, both positive and negative. Critical stories could include the experience of submitting conference and journal papers, completing coursework, or attending a conference that influenced his goals. Critical stories can also take a negative tone if they lead a person to question his or her core identity. For example, if Alec failed a milestone exam due to poor writing, he may begin to rethink his actual identity as a graduate student and/or develop a negative self-image that undermines his professional plans. In short, this critical story could dissuade or negatively influence his future identity as a faculty member. The way the individual experiences these critical stories and communicates them is its own narrative ***as*** identity; the encapsulation and potential isolation of discursive perspectives are their own lived reality and can be treated as such. While narrative ***as*** identity is an emerging framework itself, in practice the concept is not difficult to understand.

Narrative ***as*** identity is not without its critics. Some assert that it has limitations as a viable theory, and its value and definition in practice may vary across different disciplines. For example, Juzwik (2006) had this to say about narrative *as* identity:

> The tradition through which one approaches, defines, and analyzes narrative (and story) will affect what can be understood about identity and consequently, about learning. Toward the goal of clarity, sociocultural researchers who use Sfard and Prusak's identity-as-story framework ought to identify the particular tradition(s) of narrative study inspiring and informing their work. (p. 18).

Eliot and Turns (2011) adopted the identity *as* narrative approach in their study of engineering students' professional identity as understood through portfolios. Their approach focused on one's designated identity while at the same time eliciting the individually identified traits of the designated professional identity. This study is a related example within engineering education that uses the theory, in part, to support their theoretical framework and focus on professional development for the individual. "The first-person self-told identities are likely to have the most immediate impact upon our actions" (Sfard & Prusack, 2005, p.12). For the researcher, once the self-told identity is understood, the actions, or agency, of an individual can then be explained.

2.4.3 Agency

Agency can be a challenging concept to define and understand. Taylor (1977) defined agency according to elements of evaluation of desires, self-reflection, and the actions that result. Almost three decades later, Edwards (2005) modified Taylor's definition as described agency as "a capacity to identify the goals at which one is directing one's action and to evaluate whether one had been successful" (p. 169). From an emancipatory standpoint, agency is "the capacity to act within, as well as up against social structures" (Jensen, 2011, p. 66). Based on one's particular personal, educational, and professional background, the concept of agency can be interpreted differently—specifically, considering whether the individual or others (relationships, social context, etc.) has the most influence on individual actions. There is a notable epistemic debate within sociology and psychology about individual agency. The parallel views of these fields divide agency into two separate and contradictory categories: (1) the sociology viewpoint that the "normative structures of societies [serve] as an explanation for behavior patterns" (Cote & Levine, 2002, p. 10), and (2) the psychology viewpoint that is based on internal actions within social structures that have limited influence on behavior (Cote & Levine, 2002). Some believe that the sociological perspective does not provide fair decision-making for the individual. Moreover, the narrow focus on individual action has been critiqued as "unnecessary or misleading" (Cote & Levine, p.10, 2002) when seeking to understand agency in sociology. Psychology ascribes accountability and responsibility to the individual, with little consideration for the social structures in which an individual operates. These parallel traditions for understanding agency can be limiting for research that seeks to clarify how both the personal and the sociological spaces of individuals influence behavior.

There are researchers who accept the divergence between the sociological and psychological views of agency and argue for perspectives that value both. As Macedo (as quoted in Freire, 1970) noted: "Some strands of critical pedagogy engage in an overdose of experiential celebration that offers a reductionist view of identity and experience, removed from the problematic of power, agency, and history" (p. 17). Archer (2000) also described the epistemological tension of these competing views of agency:

> Too often we are presented with reductionist accounts which can either make all that we are the gift of society or, conversely, which claim that all society is can be derived from

who we are. Instead, both humanity and society have their own *sui generis* properties and powers, which makes their interplay the central issue of social theory for all time. (p. 17).

Barton (2010) also discussed individual agency and described social structures in the following way:

> [as a] dialectic, which, embedded in a practice theory framework, emphasizes the recursive loop involving actions and social structures. Such a stance holds that one's actions within a given field are enabled or constrained by the social structures available there, which themselves are recreated (or reinforced) by the actions one has taken. (p. 191).

The aforementioned researchers provide sound examples of understanding agency through both individual action and social structures, which is similar to identity-trajectory.

The intersecting approach to agency, accounting for both the individual and their social context, provides what many researchers find to be a helpful way to understand the complexities of agency. Within identity-trajectory, this intersecting approach accounts for individual action and the social structural bounds (McAlpine, Turner, & Amundsen, 2011). Jazvac-Marten et al. (2011) defined agency as representing "desire, capacity and actions to influence activities and individuals with whom we interact" (p.22). This view allows for recognition of the institutional roles, responsibilities, and rules that academics work within, while simultaneously crediting the individual for their self-directed actions. The three strands of identity-trajectory examine identity through a broad lens that includes institution, networks, and intellectual influences. Identity-trajectory also accounts for power and relationships to others in unique way. McAlpine and Åkerlind (2010) included several chapters that describe the complex identity development of academics, including graduate students—individuals at the beginning of their academic professional pathway. Other researchers who use agency to explore the early career development of academics provided a similar stance as McAlpine and Åkerlind. For example, Matheison (2011) and Archer (2000) presented example studies with the same juxtaposition of agency and the individual and his/her context. In fact, Matheison describes it this way: "Our position is that the agency of new academics is articulated in relation to the structural opportunities and constraints in a given context" (p. 245). Delanty (2008) described universities as "pressured environments in a state of constant change in response to powerful, competing external factors, making it difficult to develop a stable sense of self as an academic" (in Matheison, p. 245).

Graduate students are not exempt from this environment. Although they have a limited tenure, their experiences can be compared to faculty and career academics since the structure, and in some cases their career pathways, are shared. The similar context and consideration for graduate education to be part of the professional identity development of some future academics allows for reasonable consideration of the intersecting view of agency. When agency is viewed in these complex ways, it could warrant an entire separate study. There are intricacies within agency as its own theory, not to mention how it contributes to identity-trajectory. Nonetheless, prior work—as well as the current study—have found it to be meaningful in understanding identity.

2.4.4 Activity Theory

Activity theory is useful for defining "the various components of a system through which cognition is situated" (Barab & Plucker, 2002). It utilizes a system involving subject, object, tools, rules, community, production and division of labor to produce a goal (Jonassen, 1999). Activity theory focuses on the production of an object and "the purposeful actions that are realized through conscious intentions" (Jonassen, p. 65). The units of analysis for activity theory is the action itself, as well as the components of the system understood through discourse and artifacts (Vygotsky, 1978). These artifacts are the evidence produced by discourse, often developed from the learning process (Vygotsky, 1978). Activity theory is often used to understand the sociocultural nature of a system (Latour, 2005), but again, this theory is limited to the objects of that system and how those objects influence the outcomes and activity of the group, institution, or organization. Activity theory can also be used to understand how different organizations come together for the same activity (Stuart, 2012) in order to design learning experiences (Jonassen, 1999) and create a dynamic work environment (Leydens, 2008). The aim is to understand the system, the people that are a part of it, and the resulting products of the activity within a given institutional culture. Activity theory is a well-established theoretical framework that helps to ground identity-trajectory.

As with most activities, systems, and organizations, graduate programs and their larger academic settings have roles, rules, responsibilities and hierarchies that are maintained for the overall advancement of the institution. As noted earlier, within that context the unit of analysis according to activity theory is the organization, not necessarily the individuals that make up the organization. The activity—in this case advanced academic training and dissertation research—has a major influence on the students and those involved. Because the institution is essentially shaping the individual professionally, it is an important influencing factor and ought to be understood. The institution is not, however, the focus of this study. In order to understand the individual identity, understanding the structure, rules, roles and responsibilities that influence professional development is essential. Activity theory fits into identity-trajectory's institutional strand. Understanding the role of the individual within his/her organization, as well as the organization's influence on the individual, can create a more complete picture of identity that considers notable influential factors.

2.4.5 Discussion of Theoretical Background of Identity-Trajectory

The supporting theories of identity-trajectory, discourse identity, storytelling as identity, agency, and activity theory have been overviewed and explained for their use and relevance within identity-trajectory. Each individual theory provides its own empirical rationale and could be utilized to answer similar or sub questions of this study. While the individual frameworks are powerful on their own, when they are combined into identity-trajectory they provide detail, allow adequate flexibility, and help elucidate the complexities of identity developed through time. As a theory, identity-trajectory relies on each of these theories to support the three strands of intellectual, institutional, and network. They also provide adequate overlap that can naturally occur in complex professional lives. Of course, as with any theory, identity-trajectory has its limitations. However, taking into account its sub theories, the limitations of each offset each other when several options are considered. Together, discourse identity, storytelling as identity, agency, and activity theory, identity-trajectory can fill some of the individual voids.

Identity-trajectory, to my knowledge, has not been applied to engineering education, but its theoretical underpinnings have been. Therefore, there may be opportunities to add additional frameworks to explain and support identity-trajectory. As mentioned in discussion of several of the frameworks, some scholars have expressed dissatisfaction with the limitations of relying on a single theory, making an intersection of several related theories highly useful. It should also be noted that to date, identity-trajectory has not been specifically addressed in engineering education research. This investigation, therefore, represents a unique application of the the framework in a different context, since identity-trajectory is typically associated with the social sciences and humanities. The findings of this study in some instances are similar, but in others are very different than research using the same framework with a different population of graduate students—those in optics/photonics.

2.5 Identity-trajectory Literature

As discussed in the introduction to this chapter, identity-trajectory is a recently developed framework with relatively few publications that describe and utilize it. In fact, the bulk of the research published to date is by the theory's primary author, Lynn McAlpine, and her colleagues. Although the theoretical underpinnings and basic structure of the theory are described in prior sections of this paper, it is still important to paint a complete picture with the research and findings produced from studies that have utilized this theory.

McAlpine and colleagues, primarily, Amundsen, and Jazvac-Martek, are the primary authors of identity-trajectory literature. The various publications by McAlpine and colleagues describe identity-trajectory framework in a somewhat piecemeal fashion, tending to focus on a specific portion of identity-trajectory or one of its sub-themes. By considering them together, a bigger picture of the concept of identity-trajectory can be understood. Within this section I will review the primary publications by McAlpine and her colleagues that have informed this study and summarize the findings of their research. While the context and subject population are largely different from my study, use of the same framework and similar instruments provides an opportunity to compare and contrast findings across disciplinary lines.

McAlpine, Amundsen, & Jazvac-Martek's 2011 publication is a study of graduate students and early career faculty (pre-tenure) within two Canadian education departments. This study is one of the first publications where the authors use their data to develop identity-trajectory. It is important to note that all the participants in the study intended to stay in academia. After providing the context of graduate education and academic tenure in Canada, the authors introduced the four thematic areas that led them to identity-trajectory: (1) opaque expectations (2) personal intention and emotion, (3) academic and personal connection, and (4) past-present-future perspective. Opaqueness of expectations was experienced both by faculty and graduate students, and involved two common criteria: determining the value of one's work, and setting expectations for one's self. The second theme, personal intention and emotion, tended to involve relationships within one's academic settings. In other words, faculty and graduate students' expression of their personal intentions were often mitigated by their "place" in the department hierarchy. Becoming a valued member of the field was important for all of the participants, and they realized that establishing oneself professionally, in part, requires the acceptance and respect of others. Positive interactions with others about one's work and goals, especially those of higher rank, resulted in feelings of validation and acceptance. Negative interactions regarding one's work and goals often resulted in discouragement and frustration. These emotional responses were influenced by the academic social structure. The third theme, academic and personal connection, is very similar to the second. Because personal and professional goals are linked to emotional responses as we engage with our professional network, identity as an academic and individual begin to mesh. The authors described it this way:

> Our identities and interactions are learned through and embodied in our intentions, thinking, actions and interactions with others over time. Such actions and interaction are directed to being recognized and feeling recognized as *the kind of person each is seeking to be(come)*. (McAlpine, Amundsen & Jazvac-Martek, 2010, p. 134)

The authors acknowledged that while participants may or may not have discussed their personal lives in detail, their academic professional lives were inevitably intertwined with, and sometimes dictated by, their personal lives. Finally, past-present-future links were found as a notable theme in many of the participant's logs and interviews. Participants independently linked past experiences and their current state and status with their future goals. Whether it was the graduate student who sought to obtain a faculty position or a new faculty member developing and furthering his trajectory in the department and field, these future goals were informed by both past and present.

These four themes—opaque expectations, personal intention and emotion, academic and personal connection, and past-present-future intention—led the authors to develop identity-trajectory. The theory accounts for complexities and influences where one of the single strands or supporting theories may not be applicable. The authors also argue that the theory has practical applications for a number of reasons. First, it can be used to reflect and better understand the individual experience. The theory can relate seemingly isolated occurrences to outcomes, both positive and negative. There are, however, limitations that the authors acknowledge. Large-scale influences and perceptions of 'normality' can have a greater influence than one can recognize. McAlpine and colleagues also point out the "taken-for-granted" that they note were "difficult for such individuals in our research, having less power, to challenge" (McAlpine, Amundsen & Jazvac-Martek, 2010, p. 148). Moreover, the authors admitted that the "academia power differential" often clouded the participants' ability to view the entire picture dispassionately. This concept, in fact, can be seen in the way that much of the research is presented. The participants came across as persons with limited ability to change the structural and macro expectations that dictated how they achieved the academic identity that they were pursuing. In reviewing the work by McAlpine and coworkers, one could easily oversimplify it and dismiss it as subjective. Nonetheless, those interested in improving the graduate development experience can use these findings to enhance their understanding of an inherently complex process.

Research that uses identity-trajectory can be useful for many constituencies that have a stake in the development of future academics, including graduate students, faculty at all levels (i.e., tenured and untenured), and department chairs. First, the authors point out that participants (but especially graduate students) can gain from understanding the differences in these various academic experiences. There is also the emphasis on the regular tasks of being a researcher and the ways in which day-to-day life can impact future plans. Finally, McAlpine and colleagues (McAlpine, Amundsen & Jazvac-Martek, 2010) point out the emotional and power differentials that come into play. She suggested that these young researchers and academics may benefit from observing how senior faculty develop “equilibrium and resilience given the many dips and turns that occur” (p. 149). Identity-trajectory provides the opportunity to reflect on and explain their experiences. For tenured faculty, McAlpine et al. suggested that they could shed light on opaque expectations based on their own knowledge and experience within the department and discipline, especially for junior faculty. Implications for administrators are discussed in two ways: one, for those developing initiatives to support graduate students, and two, for new faculty and department leaders overseeing graduate programs. For those responsible for developing programmatic support for graduate students and junior faculty, McAlpine and colleagues suggested examining these two groups as more similar in nature, and using the findings of research involving these cohorts to inform program development that capitalizes on the three strands. Identifying constructive ways by which intellectual development is facilitated, networks are formed, and important institutional influences can make a difference in department planning are important goals for such studies. Essentially, for department leaders “the notion of identity-trajectory can meaningfully inform policies and practices” (McAlpine, Amundsen & Jazvac-Martek, 2010, p. 150). Through efforts as simple as clarifying opaque expectations and facilitating network and intellectual opportunities, positive results can be achieved with minimal effort.

There are some publications that give a full view of identity-trajectory and present findings within this framework. McAlpine (2012) identified some of the constructs that lead to the three strands: agency, personal, past experiences, opportunity structures, and horizons for action. Opportunity structures are defined as “what is understood or known to be the available career opportunities at any point and time” (p. 39). In most cases, opportunity structures are opportunities facilitated by institutions that become available to graduate students, particularly when they begin their post-doctoral career. Horizons for action, which are defined as “the options for action seen as personally viable at any particular time” (p. 39) refer to the personal considerations associated with career decisions. Often cited horizons for action include consideration for family, desire to live in a certain place, salary expectations, or many other factors that could be important to the individual.

McAlpine (2012) presented the story of one participant (Sam) to illustrate how the strands identity-trajectory (networking, intellectual, and institutional) influence the identity development of a graduate student. Sam’s negotiations and demonstration of agency are explained in the context of his past experiences and personal life. Sam discussed sacrificing his friendships to spend more time working on his research, which he accepted as the natural cost of furthering his academic career. These all influenced his academic identity, which he favored over some of his personal life balance needs. When considering his life after graduation, Sam appeared aware of the various work opportunities available to him (opportunity structures), along with his position in a potentially competitive job market. His main concern, however, was personal: to be in geographic proximity of his partner (horizon for action). With knowledge of these thematic backgrounds, understanding the three strands and their interrelationships can become clearer.

Several logs from Sam are discussed within the text that expose him to new opportunity structures, allow him to realistically consider horizons for action, impact his intellectual development, and provide him access to new networks that may shape his career. McAlpine (2012) discussed implications for identity-trajectory based on the theory's strands as illustrated by Sam's story. Some of her suggestions include exposing students to a broad range of opportunity structures and the skills and networks necessary to capitalize on them. Second, reinforcing the importance of networks, and developing a "strategic reading," which can be a networking tool. Strategic reading is essentially identifying works, by author, that specifically relate to the researcher's broader goals. Within the intellectual strand, McAlpine suggested learning experiences focused on disciplinary norms and epistemology. She also focused on the writing process becoming a more transparent experience. With respect to the institution, her discussion focused on enhancing agency through the department by enabling and supporting students to "act independently of the supervisor" (p. 45) and increase availability and awareness of university-based resources. The evidence and discussion provided by McAlpine in this study point to how the strands become evident, as well as how they interweave and inform each other.

McAlpine and her colleagues examined and re-examined research studies to provide further evidence to support the overall framework of identity-trajectory. In McAlpine and Amundsen's 2009 article, "Identity and Agency: Pleasures and Collegiality among the Challenges of the Doctoral Journey," they review three studies involving graduate students in different settings to reassess "agency expressed both by students about themselves and through the appraisals of others" (p.112). The first study described students involved in a graduate school committee with faculty and other university administrators. The second just included graduate students from one institution's Department of English discussing their perceptions. The third study reviewed meetings between graduate students and their major advisors. Using these three studies, the authors sought to evaluate agency in two ways: identity-as-action, and with discourse related to action and purpose. They found two ways in which agency was re-indentified in the three studies: within the proximal community (dissertation committee, research groups, etc.), and within the larger academic community. There are three challenges through which students either positively or negatively enacted agency. First, the "difference...between individual and collective values" (p. 114). Students also enacted agency in challenges with the aforementioned "opaque expectations" and institutional structures that can constrain student agency. On the positive end, agency was demonstrated around "having a say" and making a contribution, which the authors asserted was "essential to one's motivation to continue the PhD despite difficulties" (p. 115). McAlpine and Amundsen also found that collective identity and agency "provided an important sense of belonging, and of shared agency" (p. 122). Collective identity and agency, along with individual identity and agency, was found to be important to the "pleasure" of being a doctoral student.

Individual identity and agency was validated in these studies by participation in a graduate student/faculty committee in which the student members were able to make contributions. These goals were also achieved when a student's faculty supervisor validated the individual's contributions to the field. Collective agency supports the individual's sense of belonging. This is often brought about by "attempting to bring about change in one of the communities to which they belonged" (p. 122) and practicing collaborative work, which many will be expected to do beyond graduate school. These opportunities to express agency within a group provided a practice space for collaborative work and leadership in the graduate student's own development (McAlpine & Asghar, 2009). In these two example papers, agency can be either individual or collective (or both), and thus within the intellectual strand or the network strand of identity-trajectory. The individual agency (intellectual) and collective agency (network) both facilitate the doctoral program process. They provide mechanisms to overcome challenges and provide sources of positive affirmation that can support continued progression through the program.

Earlier the policies, structures, and ways of academia were mentioned as challenges for doctoral students and early career faculty to address. The accepted cultural norms of the academy are often reproduced with little thought as to why things must be a certain way or how they can be improved. These are often the questions students have at the beginning of their academic enculturation. In McAlpine and Amundsen's 2011 article, "Challenging the Taken-for-Granted," they explore two assumptions within the social science context. The first is that the advisor is the most important support for the graduate student; the second is that "the [hardest] work of the dissertation is 'writing it up'" (p.685). Their study method included individual student logs in a longitudinal study, recorded discussions between students and their major advisors, and conducted interviews and focus groups. Based on participant logs that included various forms of writing for different audiences, McAlpine and Amundsen challenged the concept that the hardest part of the dissertation is writing it. They also find that writing, followed by engaging with other authors, helps to develop the intellectual and network strands. Iterating between reading and writing is also a part of the graduate development and dissertation process. The researchers used findings related to writing for different audiences, reading the work of others to inform one's own writing, and vacillating between reading and writing as a "powerful, embedded integration of reading, thinking, writing and learning is best represented as a developmental process over time" (p. 690). They indicated that the various stages of writing, reading, and feedback (not necessarily in a sequential order) represent one of the more formidable challenges of graduate school. In contrast, writing the dissertation represents a small fraction of the research process.

The second major finding from McAlpine and Amundsen (2012) is related to the advisor as the primary support for the graduate student. Their study did find the supervisor to be important, but they also discussed and referenced family members and friends as significant support people. Participants also referenced peers and other faculty as those who supported them in their doctoral programs. They pointed out the importance of the advisor as the "academic gatekeeper," which reinforces the concept of the advisor being considered the most important person for student success. Exchanges with major advisors were, however, directive in nature "providing information related to successful completion of the dissertation or other institutional requirements" (p. 686). Meeting academic requirements is, of course, important. But as the authors documented, participants in the study found different kinds of support in their network. Student relationships and feedback from other faculty and those within their discipline "demonstrated collaboration, belonging and affirmation.... and established potential networks for students' academic futures" (p. 686). Participants saw their peers as "collegial and motivational" and family "as facilitative [and]...emotionally supportive" (p. 687). The additional supports provide some explanation for the students' success, but the majority of the participants in their study (60%) relied on personal agency most frequently in discussing their progress. McAlpine and Amundsen also noted that those who sought guidance did so among all of the supportive relationships. Of course, the major advisor is critical to matriculation through the graduate program, but not in isolation. The additional support provided by other academics, peer graduate students, and family and friends was also shown to be critical.

This is just some of the research that McAlpine and her colleagues have published from their investigations of the identity-trajectory of graduate students and early career faculty. Although quite novel, this theory has underpinnings based on more widely adopted theories. As such it provides a means to explain the limitations between individual theories while also accounting for complexities. While more of an overview in nature, this introduction to the research and further discussion throughout this dissertation explain how the theory works, which is supported by evidence from the present study.

2.6 Summary

The pilot study I conducted provided some basic quantifiable data about the educational landscape of disciplinary optics and photonics in the United States. Some of the qualitative findings from the pilot study—particularly interviews with department chairs and qualitative survey responses from graduate students—drew my attention to the educational pathways of these students. Identity-trajectory and its three strands (intellectual, network, and institutional) are used to frame and understand the professional identity development of graduate students. The theory is based on other frameworks, which when considered as a complementary whole, provide strong explanatory power for elucidating the complex experience of graduate education. Some of the other studies using identity-trajectory have been useful for participants to better understand their own experiences, for departments to consider the holistic graduate program, and for administrators to improve academic climate for greater success.

CHAPTER 3: METHODOLOGY

3.1 Purpose of the Study

This analysis of narratives seeks to uncover the intellectual, network, and institutional influences on professional identity-trajectory of graduate students in photonics graduate programs through the method of "restorying." My worldview in this study is interpretivism to "develop subjective meanings" of these students' experiences (Creswell, 2007, p. 20). Through the theoretical lens of identity-trajectory, I examine themes related to the intellectual portion of an individual's identity, the institutional influence, and the impact of networks in participants' graduate experiences. Restorying is a research methodology that repeats the essence of a lived experience in a chronological format. The primary data sources are interviews and curriculum vitae for each participant. The pilot phase of data collection in this study includes a historical and organizational overview that provides a context for the graduate experience in optics and photonics. A preliminary survey was used to identify major themes in terms of background and disciplinary exposure of students at all levels in photonics programs and adds further depth and background for this study; this was presented in Chapter 2.

Graduate students enrolled in degree-granting optics and photonics programs were selected as participants in this study. The total group of participants was as representative as possible of the demographics of the nationwide photonics graduate student population and at varying stages in their graduate career through a stratified purposeful sampling approach. Table 8 shows the overview of research questions, data and data analysis.

Table 5. Findings, research questions, data, and analysis

Findings Chapters	Research Questions	Data Source/Collection	Data Analysis
Preparing Graduate Students: Reflective Identity-Trajectories	How do photonics graduate students construct their professional identity-trajectory through time? What are the important intellectual, institutional, and network experiences that influence and prepare eventual graduate students before entering graduate school?	Interviews Curriculum Vitae	Latent thematic analysis Open coding Restoried experiences Timelines
Developing Successful Graduate Students: Findings Supporting Identity-Trajectory in Graduate School	How do photonics graduate students construct their professional identity through their time in graduate school? What are the important intellectual, institutional, and network experiences that influence graduate students' professional intentions?	Interviews Curriculum vitae	Latent thematic analysis Open coding Restoried experiences Timelines

3.2 Research Questions

The central question in this study is:

How do photonics graduate students construct their professional identity?

The sub-questions are:

How do past <u>intellectual experiences</u> contribute to the professional identity-trajectory of photonics graduate students?

What networks and relationships are most important to influencing the professional identity-trajectory of photonics graduate students?

How do institutional factors support or constrain photonics graduate students' professional identity-trajectory?

Based on the theoretical framework of identity trajectory by McAlpine (2010), these three strands were explored for currently enrolled graduate students in photonics programs. These three sub-questions are of importance because they have been unexplored in photonics, and explored very little in physical sciences and engineering. These four questions also contribute to the body of knowledge of identity construction of engineering and science students (in general) and graduate students.

3.3 Narrative Research and Restorying

The narrative tradition is rooted in humanities and social sciences and "begins with the experiences as expressed in lived and told stories of individuals" (Creswell, 2007, p. 54). Czarniwska (2004) describes this research further "as a spoken or written text giving an account of an event/action or series of events/actions, chronologically connected" (p. 17). This approach generally uses small numbers of a purposefully selected sample to understand the story of the individual. Studies that use narrative analysis may also fall into different categories. Analysis of narratives uses "paradigm thinking to create descriptions of themes that hold across stories or taxonomies of types of stories" (Polkinghorne, 1995, p. 12). There are several analysis approaches that can be used; however, for this study I used the holistic-content analysis approach. Lieblich , Tuval-Mashiach, and Zilber, (1998) define holistic-content analysis as a method that uses "the complete life story of an individual and focuses on the content presented by it" and "analyzes the meaning in light of content that emerges from the rest of the narrative" (p. 13). Narrative research presentation is done in the process of restorying. "Restorying is the process of reorganizing the stories into some general type of framework. This framework may consist of gathering stories, analyzing them for key elements of the story (e.g. time, place, plot, and scene) and then rewriting the stories to place them within a chronological sequence" (Creswell, 2007, p. 56). "By restorying, the researcher provides a causal link among ideas" (Ollerenshaw & Creswell, 2000, p. 332). In this study, data about graduate student experiences are collected through interviews and CVs, and then analyzed for individuality and compared for similar features. This process leads to the categories of findings in this study related to pre-graduate training and the graduate development experience.

This study also focuses on the lived experiences of graduate students in photonics that are given in a spoken form. The analysis of narratives approach used in this study creates descriptions of these stories related to the theory of identity-trajectory. The holistic-content approach makes meaning of the participants' experiences by looking at their whole story as it relates to their career development. These stories of several graduate students are gathered for this study and rewritten in chronological sequence using the theory of identity-trajectory as the causal link among events in the individual's story. This analysis approach is more traditional with open and axial coding methods (Creswell, 2007).

3.4 Procedure

In this study I used a qualitative research method and strategy to explore the research questions. This section describes the collection, analysis procedures, organization, and presentation of data from interviews and curriculum vitae. I also describe my experience with the discipline of optics and photonics and its influence on my analysis of the study data.

3.4.1 Qualitative research approach

The focus of this narrative study is to explore the experiences of graduate students in optics and photonics PhD programs to understand the influence of intellectual, network, and institutional forces on their professional identity-trajectory. I analyzed the interviews with open and axial coding methods (Creswell, 2007). I then "restoried" the participant interviews and curriculum vitae through the theoretical lens of identity-trajectory.

The sampling strategy in this study is purposeful sampling. Patton (2006) defines purposeful sampling as useful when "cases for study (e.g., people, organizations, communities, cultures, events, critical incidences) are selected because they are 'information rich' and illuminative, that is, they offer useful manifestations of the phenomenon, not empirical generalizations from a sample to a population" (p. 40). Through a semi-structured interview I asked participants to discuss past experiences, current status, and future intentions as it relates to their careers in photonics. I analyzed these narratives through the lens of identity-trajectory using a holistic-content analysis approach resulting in a restoried portrayal of the participants' experiences (Patton 2006; Ollerenshaw & Creswell, 2002; Lieblich et al., 1998).

This research study focuses on the lived experiences of graduate students. In studies with similar aims, bracketing is used to re-present that experience with as few preconceived notions and biases of the researcher as possible (Moustakas, 1994). Bracketing is a part of phenomenological studies, and I chose to adopt this portion of the method in my study. Creswell (2007) describes bracketing as a deliberate step—"to fully describe how participants view the phenomenon, researchers must bracket out, as much as possible, their own experiences" (p. 61).

My personal experience with optics education is based on having earned a master's degree in optical engineering as well as a bachelor's degree in physics. My own academic background is similar to that of my study participants. Throughout the study I kept note of my own personal reactions and reflections while listening to and understanding participants' experiences. A reflexive approach balances my "own perspective and voice, as well as the perspective and voices of those one interviews and those to whom one reports" (Patton, 2006, p. 65). Throughout this study I used Patton's "Reflexive Questions: Triangulated Inquiry" to reach empathetic neutrality. As a graduate student myself, studying graduate students in a field that I was a part of can be a comparative and personally engaging experience. Many of the challenges, stressors, rewards, and victories of graduate school are similar regardless of program. At this stage in my own career, however, I feel distanced enough from photonics to balance my own experience with that of my participants and praxis as a researcher to "own [my] own perspective and by taking seriously the responsibility to communicate authentically the perspectives of those [I] encounter" (Patton, 2006, pg. 65).

3.4.2 Participants and Recruitment

Degree-granting optics and photonics programs were identified as a source for potential participants in this study. Listservs for student contact, Web sites, and recommendations from department heads were used to gather a diverse sampling of students to recruit participants. Twenty-five volunteers who were currently or recently enrolled in optics and photonics programs participated in the study. Of those participants seven were women, and ten were international students. A vast majority of photonics graduate students come from physics and electrical engineering backgrounds, with some from other sciences and engineering (Chapter 2). A few also earned their undergraduate degrees at the same or other photonics programs. These differences in background lead to the common experience of enrolling in optics and photonics programs and a justification to purposefully select participants with varying academic backgrounds. The participants' undergraduate majors are not as diverse as the possibilities for those in photonics graduate programs but are representative of the majority.

Early phases of this research included interviews with department chairs to learn about program establishment and structure. These interviews also aimed to begin building a relationship with program leaders and gaining support for the project. All of the department heads were very receptive and interested in supporting future work, especially because results of this research would be shared with them to enhance recruiting and program development. These program level efforts to build rapport resulted in a high number of survey respondents who volunteered to be interviewed.

A recruitment e-mail was sent to each participating program chair to be distributed among graduate students to identify potential participants. The brief e-mail introduces the research project and requested interested participants to submit a CV via e-mail. I used the curriculum vitae to gain a basic understanding of the participants' background and select a variety of students for the study. Document analysis was completed on all interviews using codes similar to those used to analyze the interviews.

Interview candidates received background information on the study in the initial recruitment e-mail. The interviews were conducted via video chat sessions on platforms such as Skype, FaceTime, and Google Hangout. These platforms allowed for face-to-face interaction. At the beginning of each interview, I asked each participant if he or she had any questions or concerns and answered those before reading the consent. After the consent was accepted the recording began. I used a semi-structured protocol (Table 10). Table 9 includes the pseudonyms for the participants' name and university. Sex and nationality were not asked of participants, but were determined based on discussion in their interview or my own interpretation. (This was not asked of participants initially but became relevant in data interpretation for the experiences of some populations.)

Table 6. Study participants

Name	University	Sex	Nationality/Ethnicity
Brian	Southwest State	Male	Chinese
Will	Southwest State	Male	Indian
Lenny	Northern University	Male	Italian
Robert	Eastern University	Male	American
Cliff	Midwest Tech	Male	American
Anna	Northern University	Female	Italian
Brooke	Northern University	Female	American
Wayne	Northern University	Male	American
Earl	Northern University	Male	Indian
Mark	ACME University	Male	Iranian
Barry	Laser University	Male	American
Glenn	ACME University	Male	American
Ashley	Laser University	Female	Latina
Kimberly	Laser University	Female	American
Eric	Laser University	Male	American
George	Southwest State	Male	American
Wendy	Southern College	Female	American
Terry	Heartland University	Female	American
Daniel	Heartland University	Male	Chinese
Craig	Seashore University	Male	American
Jennifer	Southern College	Female	American
Jeff	Heartland University	Male	American
Alex	Midwest Tech	Male	American
Charles	Southwest State	Male	Indian

3.4.3 Interviews and Curriculum Vitae

Interviews are a primary data collection method for identity research and were used in this study. The semi-structured interview protocol allowed participants to explain their own experiences in a narrative style. Narratives were used because it allows the participant to own, construct, and convey an individual story in his or her own way (Creswell, 2002, 2007).

Using both the interview and CV, I examined three strands of identity-trajectory: intellectual development, institutional factors, and networks contributing to professional identity-trajectory. The intellectual strand focuses on the individual and their knowledge, skills, and ability, but in this study it expands to participants' past experiences with photonics that lead them to their current program of enrollment. The institutional structure examines how the department or program contributes to the participants' future career goals and plans. The type of department and its strategy and expectations of graduates influence how students experience the program but also how they plan to construct their professional identity. The ways in which graduate students make meaning of their experience and express it to others is an indicator of how that program impacts their trajectory development. The network strand examines the people and relationships that influence an individual's professional trajectory. Network strands are often advisers, lab members, mentors, and faculty members.

Table 10 presents the interview questions with some guiding questions and prompts as well as connections to the strands of identity-trajectory. In each interview, I posed the "interview question" first, and if the participant's answer strayed from the question at hand or I had relevant follow-up questions, the guiding questions and prompts were used. Some questions are linked to more than one strand because participants' responses relate to one or more stands. As the interviewer, I tried to allow for a free-flowing conversation and asked questions in response to the protocol and what the participant told me, as well as the information from their CV. In some instances CVs were provided moments before receiving consent, which influenced my own familiarity with their professionally presented trajectory.

The interview questions were piloted with five graduate students in various engineering departments as well as two professionals working in academia in engineering settings. The pilot interviews were useful in restructuring questions to elicit deeper and more detailed responses from participants.

Table 7. Interview protocol

Interview questions	Guiding questions/prompts	Identity-trajectory strand(s)
Could you walk me through your CV?	Is there any information *not* on your CV that might add to who you are as a professional?	Intellectual Network Institutional
When did you first consider going to graduate school?		Intellectual Network
What experiences or people introduced you to photonics?	How old were you? What parts of that experience are important to your decisions now?	Network
How did you choose to enroll at this institution?	If you considered other photonics programs what differences did you see? What was the most important part of the institution that made you come here?	Institutional
Can you comment on the availability of resources you need to pursue your current work?	Describe two important things that have facilitated your work as a doctoral student.	Institutional
Have you selected an advisor? How did you select your advisor?	Did your advisor's academic background matter to you?	Institutional Network
Are you part of a research group? Within your research group what is your primary function considering contributions, duties, and expertise?	Is everyone in your lab in the same department? Would you work with the people in your lab in the future?	Intellectual Institutional
Have there been any significant barriers to your ability to do the work expected of you as a doctoral student?		Intellectual Institutional
How has your work as a doctoral student helped you begin to establish yourself as an academic?		Intellectual Network Institutional
What are your career goals?	How have they changed? How has the program contributed to your goals changing?	Intellectual
What are some important things that we have not discussed?		

3.5 Data Analyses

The approach for analysis is concisely described as an open and axial coding process from qualitative research (Strauss, 2008) with adaptations to accommodate identity-trajectory's emphasis on individual stories. In open coding, researchers evaluate specific sections of text, label them with a short meaning, and then compare sections of text to allow for grouping under more explanatory terms. Subcategories are created as needed. Axial coding is "the process of reassembling data that were fractured during open coding" (Strauss, 2008, pg. 124). In the axial coding process, subcategories can show range and take form in different parts of the theory. The approach of open and axial coding is applicable for identity-trajectory studies. Using the three-strand theory of identity-trajectory can present a challenge because, as the researcher, I must be sensitive to how these codes braid together neatly (or less neatly), or various permutations, in individual trajectories. There are several subcategories that can arise in an individual story that contribute to one strand or the other based on the degree of influence and context. Through open coding techniques, I allow for the individual story to speak for itself and then use the axial process to make appropriate connections.

The following process was used to preserve emphasis on individual stories while maintaining integrity in the qualitative research process. Each participant's interview was analyzed individually before progressing to the next participant. Specific attention was given to each individual story without comparisons to other participants in the restorying process. The participant review process was as follows:

Participant Review Process

0. Schedule interview and receive CV from participant
1. Interview participant
2. Transcribe interview
3. Read interview
4. Open and axial coding
5. Applying code book
6. "Restorying" with identity-trajectory

In making sense and understanding interviews, CVs, and the multiple codes and sub-codes at work in a single interview, I needed a way to visually represent parts of a person's story to link aspects that became more or less important as they shared their experience over the course of the interview. Appendix G includes examples of the full analysis process through thematic coding and application of the study codes. Identity-trajectory is a longitudinal view of identity construction. A visual conception of the interweaving strands of identity trajectory and the influence over time was a challenge for me to grasp just from a coded transcript. To address this challenge, the first stage of the open coding process for this study was to write passages from the interview transcript on sticky notes and place them onto a large flip-chart sheet based on the predetermined codes. I drew connections, made notes, and moved specific interview sections as I progressed through analyzing the transcript. This process allowed me to focus on the participant's story as he or she told it and map it, literally, to strands of identity-trajectory theory and draw connections based on other aspects of their stories. In this process, a sequence of events arose and I was able to draw lines between events or label them in a time order. Developing visuals to arrange codes and interview content is a common practice in narrative analysis research (Koro-Ljungberg & Douglas, 2008). Authors indicate that developing a sound process includes clear explanation, iterating between data sources, member checking, and confirmation from fellow researchers (Patton, 2006; Strauss, 2008; Ollerenshaw & Creswell, 2002). In this study the participant CV and interview provide at least two sources of data. The pilot work discussed in Chapter 2 also provides some context from the perspective of the department head. Some participants in the study did participate in member checking by reading and commenting on the restory of their interview.

After using more abstract methods to internalize an interview I developed a traditional analysis file for each participant in Microsoft Excel applying the codes developed for the study. Each code was connected to a particular strand in identity-trajectory. Notes and subcategories were used to provide more detail to how the particular segment related to the theory. Upon completing multiple analyses and spending several hours re-reading my analyses, and in some cases listening to interview recordings again, I began to organize and restory the participant of focus in a chronological format.

Table 8. Curriculum vitae codes and definitions

Code	Definition/Characterization
Education	School, major and department of prior degrees
Professional experience	Internships or full time employment in photonics related positions
Academic experience	Research, summer program, or other academic institution based experiences related to photonics
Affiliation	Professional organizations, groups, or networks within the field

The approach is consistent with a three-dimensional narrative research approach; people and their interaction, continuity (past, present, and future), and contexts are bound together. The three-dimensional approach is holistic and “highlights the experiences and interactions of the individuals” (Ollerenshaw & Creswell, 2002, p. 343). The focus in a three-dimensional narrative is the overall experience and not a linear problem-solution approach. Although this method was used to analyze individual stories, sections relevant to the time period and theory are extracted and presented in this dissertation.

3.5.1 Strategies for Supporting Trustworthiness of the Study

Two primary strategies were employed to strengthen the trustworthiness of the findings. First, researchers trained in qualitative methods completed "code checking" with sample interview segments and the code definition. Primarily, graduate students in educational research programs supported the coding process. The added step of member checking also contributes to the dependability of this work. The restoried presentation of a participant and their timelines were shared with them for confirmation and editing of their meaning and story. Some of the restories were member-checked for accuracy and my interpretation of their experience. In some cases participants did in fact confirm or provide feedback or details about their story and timelines. Some, however, did not reply or simply confirmed that they agreed with the description (Lincoln and Guba, 1985; Leydens, Moskal, and Pavelich, 2004).

3.6 Contextualizing Methods and Identity-Trajectory

As described extensively in Chapter 2, McAlpine's three strands of identity-trajectory are: intellectual, network, and institution. She explains that the three strands "develop asynchronously through time" (p. 139) and together contribute to the long-term professional identity development of the individual. The open codes for this project were based on the prior work of McAlpine (2010, 2011, 2012), Mann (2008), Gee (2000), Pratt (2006), Ashforth (2008), Feldon (2010), Jazvac-Martek et al. (2011), and Dobrow (2005) in the context of the research problem and theory and are discussed in the following sections.

3.6.1 Intellectual Strand

The intellectual strand is "the contribution an individual has made and is making to a chosen intellectual field through scholarship" (McAlpine et al., 2010, p. 139). The intellectual strand results in artifacts such as journal articles and presentations. In this study of doctoral students there is an expectation that these are limited as the individual is just beginning to make their intellectual contribution. Considering this, I push the intellectual strand beyond the formal education experience in their department. Prior to entering graduate school students are interacting with the intellectual strands of others; McAlpine says that the less recognized artifacts are "course, curriculum, and program designs" (p. 139) with which undergraduate students interact. There are limited bachelor's degree programs in optics and photonics, and engineering and science majors may only formally learn these concepts in physics courses or a special topics optics course, so the scope of this study extends beyond traditional departments.

Students have several other formative experiences before entering graduate school that may contribute to their decision to go to graduate school as well as to their choice of area of study. In this project I use the concept of the intellectual strand but extend it beyond the students' contributions to their past experiences that will lead to future technical contribution. Intellectual experiences such as coursework and research were extremely valuable instances of intellectual development. McAlpine et al. (2010; McAlpine & Amundsen, 2011) and Walker (2001) suggest "pre-existing personal understandings [and] personally distinct past experiences of intention, affect and action influence present intentions and aspirations" (McAlpine, Amundsen, & Jazvak-Martek, 2010, p. 695). Feldon (2010) states, "there is a startling paucity of data on the skills that students have at program entry, the trajectories of skill development during their programs" and "no research examines trends and individual differences in doctoral students' developmental trajectories toward expertise within their respective disciplines" (p. 282). Because there is virtually no empirical research on photonics graduate students, and far fewer identified pathways to photonics as a discipline, these questions are also relevant for this field, not just general STEM PhD education. This lack of data across STEM and especially in photonics makes examining the intellectual strand of current graduate students an extremely important first step. Table 12 presents the codes that were connected to the intellectual strand, the applicable definitions, and frequent sub-codes.

Table 9. Codes for intellectual strand

Code	Definition	Sub codes/examples
Contributions	Individual (or group) new or novel knowledge, discoveries, work, research products	• Lab • Research • Articles/publications • Responsibilities
Past experience	Opportunities to engage in activities, work experience, courses, or exposure prior to current enrollment	• Research experience • Personal experiences • Courses
Agency	Desire, capacity, actions to influence activities and individuals with whom we interact (Jazvac-Martek et al. 2011)	• Seeking out information/ mentorship • Ownership of education and career
Horizons for action	"The option for action seen as personally viable at any particular point." (McAlpine 2012	• Desire to reside in a certain city • Interest in working in a specific industry • Moving with family or a significant other
Individual ability	Content knowledge in subject area, skills in a specific technique, competence	• Knowledge of physics theories • Experimental expertise
Personal	Personal life aspects that influence the person's career	• Family, significant other • Personal preferences • Hobbies

3.6.2. Network Strand

Professional relationships in academia take multiple forms and have the potential to have significant influence on a graduate student's professional trajectory. In the academic setting the network takes six forms: academic colleagues, practicing professionals, membership in disciplinary organizations, the work of others influencing your own, journals, and research collaborations (McAlpine, Amundsen, & Jazvac-Martek, 2010). Networks have potential to be a part of graduate students' motivation and exposure to continue their education at that level. Networks may provide access to institutions and the opportunity to make contributions to one's field or influence the next steps in a student's career.

The network strand frequently interlinks with the intellectual and institutional strands in the participants interviews, which is why I assigned similar codes to multiple strands but made distinctions in the definitions. In some instances, the people representing the institution or those who facilitate intellectual contribution are just as important. There is definite interweaving of the three strands; however, network is selected when the access, or most important part of a person's story, is hinged on another person affiliated to the field. Relationships that are related to the field are coded under the network strand; relationships unrelated to the field experience are coded under the intellectual strand in "personal." Table 13 represents the codes that relate to the network strand and the definition and sub-codes that were found to apply.

Table 10. Codes for network strand

Code	Definition	Sub codes/examples

Opportunity structure	"What is understood or known to be available career opportunities" (McAlpine 2012a)	• Individuals and others providing exposure to • Mentors
Advisor	The relational role of the advisor: support, encouragement, access to others in the field	• Introducing students to colleagues • Providing personal support
Intellectual	Networks that provide field access for an intellectual contribution	• Collaborations • Mentors
Lab	The primary group that the student works with on a regular basis.	• Peer collaborations and mentors • Program alumni career paths

3.6.3. Institutional Strand

As previously mentioned, there are several types of photonics education programs at different types of institutions with varying sizes, resources, faculty backgrounds. The institutional strand of identity-trajectory "represents each person's relationships, responsibilities and resources wherever they are physically located" (McAlpine et al., 2010, p. 143). McAlpine explains that the institution "can support or constrain" the other strands in identity-trajectory. In Tinto's (1987) theory the institution can support or negatively alter graduate student persistence. Ashforth (2008) explains that in the organizational context "identification matters because it is the process by which people come to define themselves, communicate that definition to others, and use that definition to navigate their lives, work-wise or other" (p. 334) Graduate school is a significant part of the professional identification of a student, and the identification process is molded in part by the institution at all levels. Gee (2000) overviews four ways in which identity can be viewed in schools, specifically in higher education and graduate school. He argues that "we are what we are primarily because of the positions we occupy in society" (p. 101). The "society" that is graduate school influences who we are and who we become and the multiple axes of nature, institutions, relationship to others, and affinity groups influence that identity development in important ways.

The stratification found in universities provides a high level to understand the organization (Carnegie classification, college vs. university, etc.), yet the lower levels of the institution (department, advisor, and lab) have a greater proximal influence on students. Initially, the types of universities and the program structures were used to group participants in the study. I found, however, the high-level structures have greater influence at the department level and less on the students' normal activities. The advisor and lab are the institutional structures that impact the student on a more meaningful level. The process of becoming a PhD is indeed an identification process that is heavily influenced by the institution. Within the department there are pressures for students to follow the path of their own advisor and prior program graduates. The faculty and other students affect the individual students' development and career plans in direct and indirect ways. Table 14 includes the codes, definitions and sub-codes that are representative of the institution.

Table 11. Codes for institutional strand

Code	Definition	Sub codes/examples
Opportunity structure	"What is understood or known to be available career opportunities" (McAlpine 2012)	• Future educational opportunities or careers • Mechanisms for career development
Advisor	The functional role of the advisor: research oversight, funding, etc	• Lab/equipment • Advising coursework and research effort of the student • Resources specifically attached to the advisor
Department/college/ program	Program's resources available to all students within the program	• Courses • Shared resources/cooperative lab space • Policies & exams • Funding (e.g. scholarships/teaching assistantships) • Admissions/enrollment options • Reputation
Lab	The primary space that the student and lab group work on a regular basis.	• Equipment • Dedicated buildings

3.7 Relationships Across Data

The pilot data in this study was a major contributing factor to reach the current methodology. Preliminary survey results (presented in Chapter 2) showed that achieving the specificity, the depth, and the necessary reflection to answer the research question required alternate methods. The interviews with department chairs and program leaders provided a foundation for this study and identified two important factors: recruiting challenges, even for the best programs, and need for this study. Even the most competitive programs must actively recruit students who may choose other disciplines over optics doctoral programs. The welcome reception and participation from department heads who were interested in the outcomes of the study added to the depth of the research questions. The interviews provided insight on how students entered the field of optics and photonics and the way that they negotiate their professional identity development. By parsing out the group's pre-graduate training experiences and graduate development, comparisons were made for similar themes that will be discussed in Chapters 4 and 5. Similarities arose in intellectual experiences, institutional influences, and the relevance of network access. The method and theory also allow adequate flexibility to avoid constricting the participant's voice to accommodate a tightly bound structure and research approach.

3.8 Outcomes of the Study

The outcomes of this study address different audiences. For participants, reflection on their journey is a benefit; thinking of one's own experience in a way that they have not considered before is helpful for future decision-making. Many of the participants eagerly shared their stories and commented that they had not thoroughly thought about how all the pieces in their experience came together. Some participants also indicated that they really appreciated being able to share their stories, especially if it would contribute to improving the graduate experience for others. Department administrators will benefit from the results related to recruitment, the institutional strand specifically, and students' conceptions of their current experience. Identifying the important aspects for student enrollment decisions in graduate school from a third party can be insightful for recruitment efforts. In the midst of their experiences, students often struggle to be open about discussing their experience in their department. Restorying is genuine to their experience, but de-identifies the student and department for anonymous feedback. For engineering and physical sciences broadly, this work adds to the knowledge about these graduate students and how they navigate the graduate school process. Many of the outcomes for departments will also be helpful for departments in other disciplines. For engineering education this work uses a different conception of identity not currently used in the field and contributes to the work focused on graduate students.

CHAPTER 4: PREPARING GRADUATE STUDENTS: REFLECTIVE IDENTITY-TRAJECTORIES

Understanding the preparation of graduate students in optics and photonics is critical to increasing the enrollment and success of these students in graduate programs. To investigate this preparation, other studies have relied anecdotes from students and faculty members (Naraynan, 1999; Luchini-Colbry, Steinke Wawrzynski, Mangiavanellano, & McCune, 2012) and large statistical data sets (Ethington & Smart, 1986; Hearn, 1987; Eide, Brewer, & Ehrenberg 1998; Sax, 2001; Hathaway, Nagda, & Gregerman, 2002; Zhang, 2005; Bedard & Herman, 2008). Several other studies have focused on graduate students not in engineering or physics (Golde, 1998; Austin, 2002; Perna, 2004; Hagerty, 2010). The findings in the present study, on the other hand, are based on the theory of identity-trajectory understood through a qualitative methodology and focus on the experiences of optics and photonics graduate students. The goal in mind for this portion of the study is increasing enrollment, developing equitable practices in preparation for this additional enrollment, and broadening representation in graduate programs.

This chapter describes the identity-trajectory of graduate students in photonics-related programs with specific emphasis on their pre-graduate school training. I use McAlpine's theory of identity-trajectory that examines network, intellectual, and institutional strands to theorize the narrative experiences of these graduate students. The research questions these findings are:

- **How do photonics graduate students construct their professional identity?**
- **How do past <u>intellectual experiences</u> contribute to the professional identity-trajectory of photonics graduate students?**
- **What <u>networks and relationships</u> are most important to influencing the professional trajectory of photonics graduate students?**

- **How do <u>institutional factors</u> support or constrain photonics graduate students' professional identity-trajectory?**

Readers will see that the most important aspects of identity-trajectory emphasized or centered in the laboratory. Research experiences expose students to the necessary networks and intellectual development opportunities, both facilitated by institutions, that become central to their decisions and ability to enroll in graduate school in optics and photonics. The laboratory and the experiences within are central to the preparation of eventual graduate students. Institutional efforts to develop undergraduate programs, along with intentional recruitment efforts are important for pre-college and first-year students in the decision to enter the field at the undergraduate level.

There are limited examples of pre-college exposure to optics and photonics, but departments offering bachelor's degrees can capitalize on inward migration from other STEM disciplines based on uniqueness and departmental climate factors. The research laboratory is central to identity development and trajectory in optics and photonics graduate students. Exposing and providing access to research laboratories for undergraduates can be facilitated by the institution, and as a result, provides access to meaningful intellectual development and networks.

4.1 Overview of Findings

The findings in this study, derived from interviews and CVs, were related to undergraduates and were analyzed in two thematic areas: formal institutional training and research experiences. Formal undergraduate training in optics and photonics was shared by only 5 of the participants in my study. Their degrees were all in optical sciences and/or engineering. This thematic area represents a special category of institutional influence. I will overview the experience of these 5 students and discuss important themes that contributed to their choice to pursue optics and photonics as an undergraduate and eventually as a graduate student. The second thematic area is research experience for undergraduates. Undergraduates who engaged in research were exposed to all three strands, so this thematic area is separated into the three parts. Research experiences for undergraduate students were common experiences most of my participants which they reported strongly influenced their decisions to pursue graduate study in optics. Research experiences involve each of the three identity-trajectory strands; these experiences facilitate intellectual development and network access necessary for enrollment in graduate optics and photonics programs and are embedded in the institutional framework of the degree program.

4.2 Formal Undergraduate Training

Enrollment in optics and photonics undergraduate programs does facilitate the future enrollment of graduate students in this field. Five of the 25 participants earned bachelor's degrees in optical sciences and engineering: Wayne, Eric, Wendy, Daniel, and Craig. As mentioned in chapter 2, there are (to date) 7 bachelor's programs, but these are relatively new additions. Bachelor's-level optical scientists and engineers were not strikingly different in pre-college experiences than their counterparts who joined the field as graduate students; they simply had the opportunity to earn a formal degree in optics at the undergraduate level. Of the 5, 4 expressed that their initial interests were in other engineering and science disciplines. In general, most participants did not discuss notable pre-college factors to the selection of optics and photonics, when available, versus their counterparts who completed bachelor's degrees in physics or electrical engineering. As bachelor's programs grow in enrollment and produce more graduates, their role in influencing graduate education in optics and photonics will become more prevalent. Eide et al. (1998) showed that private institutions have a positive and significant effect on graduate school attendance. Ethington and Smart (1986), Golde (1998), and Austin (2002) showed that involvement and academic integration at the undergraduate level were also extremely strong indicators for graduate student enrollment. In this study, only 2 students attended a private undergraduate institution. Involvement, as discussed by Golde (1998) and Austin (2002), did not necessarily have a focus on research, but research involvement was important in this study. This study contributes to expanding involvement and academic integration to research in science and engineering contexts.

4.2.1 Results of Formal Undergraduate Training

The 5 undergraduates of optical science and engineering programs all were recruited from high schools in the vicinity of the institution, and all selected their major right before or at the beginning of their college career. Within the group of 5 students one is female (Wendy) and one is an international student (Daniel). Wayne, Eric, and Wendy all attended Southern College for their undergraduate degrees and selected the optics program despite their original intent to major in electrical engineering. All three of them selected the major at the time of or immediately after their enrollment at Southern, citing the reputation of the school, distinction of the program, uniqueness, and career opportunities in the field as primary reasons. Students explained that the climate of the department was important for their selection and likely a contributor to their continued commitment in the field. Both Eric and Wendy specifically mentioned the introduction to the department at orientation or tours during their college selection process. This quote from Eric in part describes the overall climate, which was similar to the opinion of his Southern University colleagues with respect to their undergraduate optics program climate:

> It was a small program at the time. My graduating class was roughly 20-25 students and it was...so basically I was able to be friends with the entire optics program basically. It was the same 25 students and we worked together; there were a lot of classes specifically in optics and a lot of collaborative work and so senior year I had a senior project with a few other students in our optics program. That was a good experience of having a collaborative project and going through the steps from idea to execution. Partially probably one of the experiences that made me want to go on to graduate school instead of straight into industry.

Daniel is from China and his selection of optics was based on a slightly different enrollment system. Daniel intended to major in mathematics, but his undergraduate institution informed him at enrollment that he was accepted to the optics program. Daniel mentioned that both of his parents worked in the optics industry, which may exposed him to the discipline. Although he was the only international student with a bachelor's degree in optics, he shared the experience of being afforded the opportunity to pursue optics specifically early in his college career. Some institutional influence—being specifically recruited by the program—helped facilitate his decision and ability to pursue optics in graduate school.

Craig was recruited directly into his undergraduate optics program. Despite his enrollment in an early college high school program, Craig said he had no original intention to go to college; he actually planned to become a construction worker. The opportunity structure in the form of a scholarship facilitated his initial entry to the field of optics. A faculty member from his undergraduate institution visited his high school and gave a presentation. Although he did not know much about optics or what the academic program entailed, the scholarship opportunity made a difference in his decision to enroll in college at all.

> Dr. Johnson actually went around to start to recruit people...she actually went to my high school and she told me about the optics program they had and different scholarship programs. And she basically was saying it was free so I figured I might as well give it a shot. Went to State and figured out I liked optics and that was it. Graduated from there and I'm at Seashore University now. Considering what I was about to do, I was about to just do construction and stuff like that, it was a lot better than that, a whole lot better.

Clearly, the direct efforts of faculty, especially for this relatively new bachelor's degree program, engaged and prepared Craig for a pathway leading to graduate school in optics and photonics. Though this is the only specific example in this study of external efforts of undergraduate recruiting for optics and photonics programs, the positive results could provide a leading example for other new programs.

4.2.2 Discussion of Formal Undergraduate Training

For the small number of participants who selected optics and photonics as undergraduates it generally occurred through happenstance and external factors. In the background for this study there was little information available about the undergraduate students. Based on estimated numbers from interviews with department chairs, of the approximate 600 students in optics and photonics programs in the United States, undergraduates represent less than 15% of that population. Interviews with department heads referred to a field-wide discourse on bachelor's-level programs in optical sciences and engineering and the motivation to grow the programs in number and enrollment. In interviews with department chairs, there was similar discussion at the associate's level, because graduates are hired at comparable salaries of bachelor's-level engineers to do technician-type work. Bachelor's students who do not continue to graduate school often take traditional engineering roles in industry alongside their counterparts in the traditional engineering disciplines, according to department heads.

Selecting optics as a major was an "opt-in" opportunity for students immediately before or at the very beginning of their college enrollment. Eric was, in fact, the only student in the group of optics bachelor's degree–holders who mentioned any optics experience prior to college, which was limited to a short unit on basic optics in his high school physics class. Students who are early switchers, with no original intent to pursue optics, were engaged by opportunity structures—available opportunities—facilitated by the institution (McAlpine, 2012b). These students were able to establish a "homeland" based on social networks and engagement (Walden & Foor, 2008; Pierrakos et al., 2009). These are noteworthy because of the limited options for optics and photonics undergraduate studies. As the number of programs and enrollment grows, success in placing future graduate students may be influenced by these findings. The department climate, socialization, and engagement in optics helped retain the students in their disciplinary programs.

4.3 Research Experiences Alignment with Identity-Trajectory

Research experiences are commonly shared experience for eventual graduate students in optics and photonics. It is no surprise that research experiences in the undergraduate years are important to the development and future enrollment of these students in graduate school (Hearn, 1987; Seymour, Hunter, Laursen, & Deantoni, 2004; Hunter, Laursen, & Seymour, 2007; Karusktis, 2008; Harsh, Maltese, & Tai, 2011). Alex was the only participant of 25 who did not have direct research experience. The person who would become his graduate advisor deemed his work experience in a hospital maintaining advanced equipment relevant. Undergraduates participating in research, especially in the sciences, are beginning the academic socialization and network process. Examining these experiences in both quantitative and qualitative methods has been done with large data sets from the National Science Foundation and Howard Hughes Medical Institute (Seymour et al., 2004; Hunter et al., 2007).

In this study I found an emphasis on how research experiences inform trajectory and identity development. McAlpine (2012) describes opportunity structures as "what is understood and known to be available career opportunities" and research experiences in almost all instances represent that. The differences appear in how the students access these research experiences, the retroactive value they ascribe to their experiences, and the role those experiences play in the subsequent phases of their research careers. Further research in other fields of the physical sciences and engineering will likely yield the same findings.

4.3.1 Research Experiences and Network

Students conducting laboratory research can accelerate their academic career progress by becoming a part of the social network of their field. Network access in research occurs in different ways, either through finding the internship opportunity in the first place or the network developed as a new partner in the lab. As an undergraduate, Barry participated in research at his institution, and the experience triggered his further questioning of condensed matter physics. An advertisement for an undergraduate research was in the hallway at his college for Laser University. Though his undergraduate advisor didn't know much about the program, Barry applied for the REU and was accepted. The experience piqued his interest in research. Barry's REU advisor was a great mentor and when the time came for graduate school, Barry limited his decision to either a materials science program or photonics at Laser University with his advisor. "In fact I didn't accept the Laser University invitation until I finally got him to say if I came I could be in his group." Barry's undergraduate lab experience allowed him to develop a relationship with a mentor, who he sought as a graduate advisor. The network access and mentor enabled a new opportunity structure for Barry's academic pathway.

Undergraduate program faculty and their networks also contribute to academic socialization and network access. As a sophomore, Glenn started out as an invited observer in an optics research group in his undergraduate physics department. He formally joined the group as a researcher the following summer. Glenn indicated that his interest in research grew during his undergraduate lab experience, particularly due to the mentoring he received. Mark's network access similarly came through undergraduate research in his institution. Robert participated in several research experiences as an undergraduate, which helped him enter a master's degree. After completing his master's, he went to Eastern University to pursue a doctorate. Twenty-four participants had similar network access experiences in the lab before their doctoral degree enrollment.

Kimberly is a student whose relationships within the lab influenced her actions and decisions as a graduate student:

> In my undergrad days, I talked to a lot of graduate students and heard all kinds of horror stories of people who went on with people who were full professors and they were tenured and, you know, didn't really care about the students because they already had an established career and so their students were kind of floundering. And I heard more horror stories of professors who were just, just starting out and they really hadn't figured anything out and there was just a lot of work that had to be done in terms of setting up labs and doing this and that, which could be a great opportunity and well-respected.

Kimberly selected her initial advisor because he was in the process of earning tenure but already had a few years at the university. In Kimberly's undergraduate research experience, the mentorship and integration into the lab group informed her future graduate school decisions. She also used her lab experience to network and begin identifying what she felt was necessary for her own success in graduate school. Although the "horror stories" may have put her on alert for potential problems, she in fact switched advisors after three years in her graduate program due to low productivity.

The lab provides access to the academic and research network. The social interactions of undergraduates with graduate students, faculty, and research scientists in the lab facilitate the present research endeavor as well as future research opportunities in the same and other labs. Thiry and Laursen (2011) indicate that in the involvement in the community of practice of scientific research, intellectual support and personal and emotional support are the most important aspects of the mentored research experience. The concept is very similar to McAlpine's framing of the network strand. McAlpine (2010) proposes that the network strand begins at the master's level, based on her findings for primarily social science and humanities graduate students; however, the findings in this study suggest that in optics and photonics the network influence begins earlier than graduate enrollment.

In this study I found that access to the network of scientific research, especially in optics and photonics, was an important factor for nearly all of the participants in this study. Networks as an undergraduate informed and influenced the decision to enroll in graduate school. In this study I found that women participants, when discussing their research experiences, attributed more emphasis and value in preparation for graduate school than their male counterparts. This was, however, a very small sample, so future work should focus specifically on gender in photonics. For many, decisions to pursue graduate school and where were influenced by faculty mentors, graduate students, and postdoctoral scholars in their lab experiences as undergraduates.

4.3.2 Research Experiences and Intellectual Development

Laboratory research experiences for undergraduates provide a means to make a unique intellectual contribution and to interact with the intellectual strands of others. Students use the authentic research learning experience to inform decisions about their own future intellectual contribution.

Undergraduate research can assist students in developing skills or reaffirming their learning in the classroom. Brooke's undergraduate experiences in the lab exposed her to optics and influenced her career path. These early experiences influenced her pathway toward graduate school. "Well, working in the labs in the summers I really enjoyed the atmosphere and the people being able to work on scientific equipment and all that," Brooke said of her undergraduate research experience in optics. This intellectual development experience (primarily because it was so early in her career and short-term) and the network established in her lab were the first comments in her interview where she really talked about how her pathway started.

There are other examples of research experiences developing authentic skills for students that support their future graduate enrollment. Anna earned a telecommunications engineering degree as an undergraduate but did not get involved in research until her senior year. Based on that initial research experience she became interested in going to graduate school because of the things that she was learning in the lab. During her lab research experience she found that she wanted to pursue work in biomedical optics. Though she continued on the path she started in optical communications, she was able to redirect her existing skill set and knowledge to an area that interested her more, biomedical optics, in her master's program.

Research experiences also influenced course selections for other learning experiences. Glenn started out looking for a job during the semester and saw flyers for research positions around his department. He found a group that he was interested in that did work in optics and the faculty member invited him to begin attending group meetings. That subsequent summer Glenn began doing compensated research within the lab and began taking graduate courses in optics as an undergraduate physics major. His physics department had significant emphasis on/strength in optics and photonics, but not until he joined a research group did his practical skills and knowledge begin to develop.

Learning from the intellectual strands of others is also a means for disciplinary orientation. Comparison with peers and reading the research products of others can facilitate interest in graduate school. Wayne described why he wanted to go to graduate school this way:

> I felt like it was something I could handle—going to graduate school, with my performance relative to my peers. I was excited about new research, reading papers, and

> the idea of being able to produce work that would be interesting enough to publish papers about it.

As an undergraduate Wayne had what he described as a "crummy" part-time job in the marketing department of a company that sold scientific research equipment. His job was to determine the research areas of faculty based on their publications and then cold call them to sell equipment. His work experience gave him the opportunity to read current research and understand the current state of the field. He enjoyed the research process for the job and reading the research of others. Although he did not name specific researchers he found through this position, the involvement in the intellectual strands of others was apparent. Later in his undergraduate career he participated in laboratory research experiences that also contributed to his preparation and interest in a research-oriented career.

Research experiences for nearly all of the participants were likely a contributing factor to their acceptance and enrollment in their graduate program. Because only one participant in this study did not have formal research experience, the findings imply that research is a necessity *before* admittance and enrollment in these graduate programs. All but one participant did research in optics and photonics or very closely related fields before graduate school. An alternative explanation is that because optics is a field with few undergraduate programs to expose and recruit students, undergraduate research is one of the only ways that potential graduate students become aware that the field exists. It is expected that most, if not all, applicants to graduate programs demonstrate academic excellence, as the curriculum vitae of participants indicate, but the direct link between research experiences and intellectual ability may be an overlooked factor for graduate enrollment (Seymour et al., 2007). This finding raises additional questions worth pursuing in future work.

4.3.3 Research Experiences and the Institutional Strand

Several students in my study were introduced to optics and photonics in their courses, but their interest was further piqued through innovative teaching practices. Course design has great potential to expose undergraduates to research without necessarily becoming a part of a lab. Contributing to her foundation in photonics, Kimberly took a fiber optics course that included an open-ended project-based learning experience; she selected photonic polycrystal fibers. The course project in the fiber optics course required Kimberly to spend significant time researching and reading recently published research on her topic. In talking about her project in this class it is clear that Kimberly's project experience influenced her career planning:

> So, I had this strong interest in the way little things come together into big things, and you know how all these materials work and here we're talking about something about where you actually engineering a material to get light to do something that you want it to do. And you realize studying these things that a lot of analogs for semiconductors, and I had been studying a lot of semiconductors so I thought this would be a fantastic area to go into since it's really studying optics and photonics there's just a lot going on right now because technology has finally matured to a point where you can actually start really experimentally realizing the structures. And so I made the decision to pursue a degree in optics or at least to find a place doing research in optics so I could actually study these nanostructure materials.

Early in her academic career Kimberly had very general interests in science and engineering but eventually found her way to electrical engineering. Her career benefitted from an excellent, project-based course experience. It could be argued that since Kimberly was an outstanding student, a *summa cum laude* graduate with three minors and research exposure, that there was no way that she would not have attended graduate school. Based on this portion, and other parts of her interview, Kimberly enthusiastically lent credit to the research experience afforded her by a course within her major requirements for exposing her to critically evaluating graduate education opportunities.

Innovative program requirements, such as external research experiences, also contribute to the trajectory of eventual graduate students in optics and photonics. Terry did her graduate work at Heartland University, but as an undergraduate her relatively small, liberal arts physics program required students to complete a summer research project. She did an astrophysics project in the one experimental group at her college, but she felt the research was too “far away” and abstract. The next summer she found an internship at NASA. The application required a list of areas of interests and Terry “haphazardly threw together” a list of topic areas from her coursework. She was selected to join a research group in part because she listed optics as an area of interest and joined a group researching morphology-dependent resonances, or fiber lenses. During the research program she was able to do independent research in optics and became engrossed in the field. Based on her research experience she found her personal fit and career path and began to look for an optics program. Through the network she developed at NASA, Terry was connected to a principal investigator at Heartland who eventually became her advisor.

Research experiences do not necessarily have to be a part of the student’s home academic department or coursework; in fact the program or organization hosting student research may not directly benefit from eventual enrollment of the student. Of the 25 participants in my study, Wendy is the only one who attended the same university for undergraduate, research as an undergraduate, and graduate school. Barry is the only student who enrolled in graduate school at the institution that hosted his research experience. Although there are clear, positive relationships between undergraduate research experiences and eventual graduate school enrollment (even with students who did not intend early in their academic career to go to graduate school), these findings do warrant further study. Understanding the quality of these experiences, meaningful practices, and the mentoring experience may lead to greater understanding of how departments can influence and develop undergraduate research experiences to meet their goals.

Facilitating research experiences for undergraduates is a functional role of the department or program and faculty advisor and often also the mission of the university. The institution, in all of its parts, has a significant role in the development of future graduate students and a unique opportunity through the provision of research experiences. McAlpine's theory, in short, focuses on the institution as resources and responsibility, framed slightly differently based on perspective and stage in career (McAlpine, 2012b; McAlpine, Amundsen, & Jazvac-Martek, 2010). For graduate students, the institution is the department and its resources and structure. The institution is the department, advisor, courses, policies, and the lab. The institution also provides opportunity structures at the beginning of graduate school, throughout the graduate program, and after graduation. Crede and Borrego (2012) identify some of the resources necessary for graduate student success: mentoring, learning, professional socialization, and research, similar to the sub-codes of the institutional strand. Their study focuses on the structure and access to these resources in the lab based on group size. This study takes a step back to understand how students access the lab, and later the resources and structures within.

The institution holds the access key for future graduate students in program structure and access to such programs. Prior work has under-studied the practices for selecting undergraduate researchers and program structures, and this is an area that institutional structures can have some influence (Hathaway, Nagda, & Gregerman, 2002). Narayanan (1999, p. 363) says "common-sense guidelines to identify potentially promising undergraduates" should be used to select candidates for research experiences. This recommendation is also supported by Willison (2012), that high-achieving students are already on the path to graduate school are thus selected for mentored research experiences. This sort of conventional wisdom reinforces the idea that there are some students who “ought” to become graduate students and others who should not. Of course, ability to meet admission requirements is of utmost importance. It is part of the role of the undergraduate institution to expose and help students access diverse career opportunities. In fact, by expanding research opportunities for undergraduates who do not fit a specific model, providing the training and network access necessary, the number of potential graduate students will also increase. Selection criteria for these programs must become broader; if research experiences for undergraduates do not become more readily available in classrooms to all students, growth and diversity potential will not be reached. Willison (2012) agrees with the suggestion that research experiences in the classroom have greater reach to encourage less-than-likely graduate students. These findings suggest that departments and faculty interested in preparing future graduate students should explore the course research model to encourage all students while developing valuable skills regardless of trajectory.

Altogether, the institution provides access to intellectual development and relevant professional networks. The lab is a critical conduit for intellectual development and network access for undergraduates in physical science and engineering fields to proceed to graduate school. Because of the necessity of the lab to accelerate one’s career in research, care must be taken in its design and access granted to the lab keeping in mind that it is necessary for expansion of a physical science and engineering discipline.

In some instances undergraduate programs in teaching-focused institutions have limited research opportunities for students. Students like Alex can graduate without any authentic research experience in scientific disciplines. Though Alex’s summer work at home in a hospital and heavy-handed institutional recruiting influenced his decision to go to graduate school, some undergraduate institutions take a more proactive approach. For example, Terry was a physics major in an undergraduate program at a small institution that did not offer many of its own research experiences but required a summer research project. Terry secured an internship at NASA that was instrumental in introducing her to research and optics and photonics as a field. Terry credited her internship experience for her interest in pursuing graduate education. Some colleges and universities may have limited capacity for local research. Programs facilitating or requiring external research may provide a research exposure mechanism for undergraduate students.

The research experience falls centrally into the three strands of identity-trajectory, leading to the lab and experiences therein as the most important aspect of the identity-trajectory for graduate students in optics and photonics. From the intellectual development strand, undergraduate research experience notably contributed to intellectual development and contributions. Opportunity structures, lab members, and access to intellectual contributions are primary codes found within the data and align with the network strand. Considering the institutional strand, not only is the lab a physical structure and mechanism of the institution, but it also presents opportunity structures and access to an advisor.

4.4 Summary

This portion of the study examined the three sub-questions at the undergraduate level. In this study, I found the undergraduate research experience was important for influencing the pursuit of graduate school. I also found that formal undergraduate training, either through options to major in the discipline or creative course content, were also constructive influences on students' interest in pursuing graduate school.

Research experiences contribute to all three strands of development for eventual graduate students in optics and photonics. By joining a research lab as an undergraduate, students' research socialization process begins and provides them access to networks that expose and facilitate future opportunities. Once in the lab, students' intellectual development expands to include the state-of-the-art in their field. The institution bears the most notable role in facilitating such experiences. Considering the importance of research experiences and the influence on students' future enrollment decisions, departments offering undergraduate research experiences should be intentional about the holistic experience that the lab provides. This portion of the study aimed to identify how optics and photonics graduate students develop their professional identity over time and identify the critical intellectual, institutional, and network experiences that contribute to that development. In this study I found that the lab and research-based experiences are central to intellectual development, network access, and enculturation, and the institution has a valuable role in managing and implementing successful experiences for students.

The summer research experience is not new for faculty researchers and universities but course research experiences tend to be limited. Only providing summer research experiences—along with the necessary resources, time, and funding considerations—limits the number of students who could gain from these formative experiences. One participant, Kimberly, gained similar benefits of a summer research experience in a course research experience. By expanding research opportunities to the classroom, more students may consider graduate education options without the commitment of a full summer research experience.

A question arising from these finding is: Were these students destined to pursue graduate study, or did undergraduate research experiences influence their decision? It would seem, based on these findings, that having research experience is a strong indicator of future graduate school enrollment. Future work could focus specifically on undergraduate students engaged in research experiences and examine their pathways over time. Not every student who completes a research experience as an undergraduate will pursue graduate school, but a longitudinal study of undergraduate students in research may provide details as to how research experiences influence their future decisions. To help disentangle this "which came first" question, future work could examine admission requirements and other student data factors to broaden our understanding of graduate identity-trajectories.

CHAPTER 5. DEVELOPING SUCCESSFUL GRADUATE STUDENTS: FINDINGS SUPPORTING IDENTITY-TRAJECTORY IN GRADUATE SCHOOL

Complementing Chapter 4, which focused on undergraduate students, this chapter describes the identity-trajectory of graduate students in optics and photonics graduate programs, with specific emphasis on their training. McAlpine and Amundsen (2009) have used identity-trajectory to theorize the development of graduate students and early career academics through three strands: intellectual, network, and institution. The following central and sub research questions guided this portion of the study, with specific attention to graduate education:

How do photonics graduate students construct their professional identity?

- **How do past <u>intellectual experiences</u> contribute to the professional identity-trajectory of photonics graduate students?**
- **How <u>networks and relationships</u> influence the professional identity-trajectory of photonics graduate students?**
- **How do <u>institutional factors</u> support or constrain photonics graduate students' professional identity-trajectory?**

5.1 Overview of Findings

In this chapter I present evidence from interviews and personal CVs related to graduate students' identity-trajectory in the three strands: intellectual, networks, and institutional. It should be noted that the nature of their graduate experience was similar, regardless of the institution that the student attended. Similar features of the graduate experience include highly independent research work—even within lab groups—student perceptions of a competitive admissions process, advisor selection, and career goals at the beginning of graduate school. Networks became important for graduate students in two ways: navigating the graduate school experience and preparing for their future career. While advisors were important to student development, networks with departmental faculty were also essential for students who eventually switched advisors, a common occurrence for these participants. Relationships with other lab members, which represent another vital human network, were important for students' research project progression. All participants were asked and discussed how their lab functions. There were a range of lab group sizes, structures, and responsibilities. Students typically interacted with each either other through formal and informal discussions, even if their projects were not directly tied together. These relationships within the lab, along a broad social to professional continuum, contributed to the research progress of graduate students in important ways. Interestingly, the participants in this study generally began their graduate education with academic career intentions; however, their professional goals gradually evolved away from joining the academy. The majority of the students in my study intended to first pursue industry careers, but their preparation for industrial-type research work, as well as access to the most effective networks to facilitate that goal, were limited. Some students directed their attention to preparing for specific career opportunities without guidance from others. Activities like developing a professional network or seeking opportunities to develop transferable skills were not frequently reported among graduate students. Thus, an important finding from this study was that students' professional development needs were not adequately met for the types of industrial positions they were planning to pursue after graduation.

Finally, the program itself tends to have an important role for the development of graduate students through the laboratory and the faculty. The institutional strand focuses on the importance of the laboratory and its structure, and on departmental faculty. Both the laboratory and faculty within the department led the researcher to conclude that revising the approach to advising graduate students in these and similarly oriented disciplines might be warranted. An encouraging sign in analyzing the data was the overall similarity of graduate experiences. Participants at the different institutions shared consensus on the ranking and prestige of programs in optics and photonics. For example, there was a strong consensus among students about which optics programs were top-tier and the most competitive. Despite the diverse representation of universities, students described their graduate pathways in similar ways.

These similarities unify important features of the graduate experience and provide meaningful context for understanding the findings of this study through the theory of identity-trajectory. The three strands (intellectual, network, and institutional) came to life in the experiences of my study participants. One important study goal was to give examples of those experiences and the influence that those experiences had on graduate program progression and career development.

5.2 Intellectual

The intellectual strand consisted of two major themes for graduate students: socialization in the department and the wider institution. The graduate school transition process and their academic socialization facilitated learning opportunities for students. Early experiences in their graduate programs were important for shaping the academic pathways of individual graduate students. As students developed through the program they demonstrated greater agency, especially as senior graduate students. In many cases, they became the people that newer graduate students leaned on for advice and for guidance while in the lab. This evolution of roles is likely a natural by-product of experience, coursework and time in the program, but nonetheless was interesting to study. As students progressed through various roles and stages in their program, their individual goals were refined and their professional identity began to emerge.

5.2.1 Socialization in the Department and Field

In Chapter 2, I discussed the undergraduate majors of graduate students in optics and photonics. A total of 20 participants majored in physics or electrical engineering as undergraduates. My pilot study similarly found that photonics faculty members most often have doctorates in physics or electrical engineering. This means that although graduate students formally joined the optics/photonics field upon entering graduate school, their introduction most typically occurred in research experiences or via special topics undergraduate coursework (19 of 20 physics and electrical engineering majors). In different ways, these shorter-term experiences facilitated participants' pursuit of optics in graduate school and prepared them for admission to their programs. Participants explained that at the beginning of their graduate programs they actively sought interactions with advanced graduate students to learn more about core concepts affecting their research projects. Those who were not immediately assigned to an advisor (a rare occurrence) sought the advice of senior graduate students to help identify advisors and labs. In fact, many students explained that their socialization to graduate school was frequently facilitated by senior graduate students. Beginning the socialization process in the department and field appears to have been important for student success; in contrast, students did not cite meaningful formal activities that helped to facilitate the socialization process. In pilot interviews with department heads, they indicated that a standard one- or two-day department orientation was standard procedure. This type of program provides incoming graduate students a chance to meet faculty, other students, view labs and complete paperwork. A socialization and/or enculturation process was not an explicit goal of those programs. In my primary study graduate students did not mention department orientations as important in helping them adjust to the department culture; however, their time in the research lab was important to that process.

One student, Mark, discussed how he considered transferring because of the difficult transition he experienced during his first few months in his graduate program. He specifically cited the challenge of finding a faculty member who was doing research he was interested in and who also had funding to support him. When discussing his peer network, Mark rarely mentioned other students in his department or lab, but rather colleagues at other universities around the country. Another student, George, actually transferred institutions—in part because he never became a part of the department at Southwest State, his initial university. He had an advisor, but other than taking classes and doing a little research in the lab, he did not establish the supportive relationships that may have encouraged him to stay. George returned to his home state and switched to an electrical engineering doctoral program doing similar research; in fact, it was extremely similar to what his optics and photonics counterparts were doing in their research programs. In contrast, Mark stayed at his university but raised the idea of transferring when he talked about his current situation. George was a student who actually left his program, at least in part because he did not assimilate as well as he would have liked into the department. Thus, student retention may be partially attributed to the socialization process in graduate programs.

Many senior graduate students viewed assisting new students as a natural progression and responsibility, but they were reticent to discuss how their leadership role evolved. Jennifer was very involved in her graduate program by acting as an informal ambassador, taking on leadership roles in her lab, and contributing to her group beyond research. Despite being an advanced graduate student, she was hesitant to provide direction for newer graduate students or undergraduates because she was not sure how to take on that role responsibly. She specifically mentioned not wanting to steer another graduate student in the wrong direction. Another student, Wendy, was also hesitant and said that the challenges she was experiencing toward the end of graduate school led her to avoid a mentoring role in her lab. Wendy did, however, seek the support of peers to write her dissertation, and even to learn what a normal and constructive laboratory-based graduate experience was like. She discussed that even though her career plans did not immediately include becoming a faculty member, knowing the experiences of her peers would be personally helpful. Despite the fact that both Wendy and Jennifer indicated that they valued the help and advice of senior students when then entered the program, they themselves expressed some hesitation in taking on the expected role of an advanced graduate student. This reluctance could be based on their own experiences; both switched advisors at least twice, and dealt with some notable challenges in navigating their dissertation research process. Their own experiences may have affected their confidence in being role models for newer graduate students.

These prior examples demonstrate how limited socialization within the department can hinder progress and result in alternative career pursuits. With a positive socialization experience, however, even though students' career intentions may still change, their progress is likely to have far fewer negative interruptions. As an example, participants like Barry easily navigated their graduate programs with quick advisor selections, minimal research challenges, and the development of useful skills that continued to accelerate his career. In fact, Barry stood out among study participants as being a student whose curriculum vitae reflected involvement in local academic organizations, in addition to the expected national professional organization membership and participation. At the time I interviewed Daniel, he was nearing the completion of his first semester at Heartland University, but he discussed his socialization process in positive terms. While most of our discussion focused on three specific types of relationships, Daniel's adjustment to the new university seemed positive. For example, he talked about his relationship with his lab mate first, and then spoke about a senior graduate student in his advisor's lab who mentored him. Second, he discussed his relationships with his instructors, who helped him complete his first semester coursework. The third set of relationships that Daniel discussed were social relationships with upper level undergraduates and other graduate students. These networks helped him identify an advisor within the department, make coursework decisions, and learn about the faculty and students in the department. While only a short period of time had been spent in the program at the time of our interview, Daniel's early, positive adjustment represents a sound foundation for a constructive graduate career at Heartland.

As Crede and Borrego (2011) pointed out, the lab group structure is an important part of a graduate student's social and intellectual development, and care should be taken in designing its structure—particularly for new students. In this study I found the research lab to be central to intellectual development and network access of graduate students. Students were often immediately assigned to an advisor and as a result, a laboratory. This process implies that student success and retention are to a significant extent the responsibility of the laboratory group. In science and engineering cultures, this is the norm. As a result, laboratory groups should be planned with this responsibility for student retention and success in mind and not solely on the execution of a research objective.

5.2.2 Agency

The intellectual strand is undergirded by agency. Agency is an interesting feature of intellectual development in which each person, in describing their experience, owns their trajectory. As reviewed in Chapter 2, agency is defined as actions taken to achieve a goal. As discussed in Chapter 4, an undergraduate will not typically describe his or her pathway in a manner representing the theme of agency. Ideally, graduate students will become contributors to their fields of expertise after graduation. This requires that they eventually conduct independent research and publish their results. Graduate students can demonstrate agency in their academic development by organizing their work to achieve milestones, engaging in professional networks, and dealing with external issues that influence academic progress. Between the second and fourth years after coursework and master's degree requirements have been met, students make more decisions to take ownership of their progress. Those who experienced progress issues usually experienced them within this timeframe.

The students who took part in this study typically described their research work as very independent, regardless of the stage of their graduate career and laboratory size. The majority of them described spending hours in the lab, doing as much as they could on their own, and preparing reports or discussion points for lab meetings during which meaningful feedback could occur. Lab meetings were not just a progress marker or an arbitrary formality, but a means to gain feedback for challenges or problems. One participant, Will, seemed to demonstrate agency most clearly in talking about his work and trajectory. He took ownership of his transition to the U.S. for graduate school; in fact, he did not describe any outside guidance in this process. Will was only accepted to one program to which he applied for graduate school (Southwest State). At Southwest State, the optics program is situated between departments, so Will was a part of the physics department because all of his prior academic work was in physics. The opportunity structure within the institution made a new academic home easier to adjust to because of his academic background in physics. After two years of coursework and research, Will's advisor took a new position working in a Department of Defense lab. Since Will was not an American citizen, moving with his advisor was not an option. He calmly explained looking for and finding a new advisor at Southwest State:

> As I came here I was offered a research assistant position in a project called [title] and, uh, I was mostly doing experimental work in the lab, but they unfortunately after 2 years of working for my advisor he moved away…. To, uh, you know the *Department of Defense Lab* and, you know, being a non-American, you know, being an [nationality] citizen I couldn't follow, so, uh, anyway. So I ended up shifting my project to a different one but I didn't...uh it just adds to your experience.

After his advisor left, Will left campus without his terminal degree for a visiting scholar opportunity at Southern College and its prestigious optics program. Soon after that appointment he worked with a group that was developing a new solar energy company. After some time and experience, Will returned to Southwest State to finish his doctoral work. In each of these transitions, Will's personal decisions and actions helped him progress through the program, but he also gained additional experience in the field. That professional experience expanded his expertise beyond the traditional graduate student.

Will talked about his experience and academic pathway in ways that demonstrate agency in that he rarely mentioned the input of others. He took the responsibility for developing his career independently; he understood that he was the determining factor for his eventual professional success—not his advisor or other department faculty. How he spoke about his experiences is quite telling. Will was keen to identify how his prior knowledge in physics influenced his academic trajectory. For example, his desire to pursue experimental work, which was limited in his home country, depended on his strong foundational knowledge. His knowledge as a researcher and theorist was his main strength, which was evident throughout his interview. The following statement is possibly the best way that Will described his own agency and the ways he took advantage of opportunity structures:

> Yeah, you know, I just have enough broadening and university enrollment and I'm also, I'm more interested in simulation but I'm working in experiments and already have a grasp of how to connect the theory and the real experimental side of stuff -that may help me in the long run. So yeah that's just, uh, yeah I'm still here and this is how I work through all my experience and stuff.

Despite what could be a major hindrance in progressing through graduate school, Will turned his former advisor's career change into meaningful opportunities for himself. Among participants in this study—even those with non-traditional graduate school pathways—Will had the most diverse, yet the most relevant, optics experience. This will likely be an asset when he begins to search for full-time employment.

Other students discussed acts of agency in terms of meeting or responding to structural challenges within their program. Specifically, they mentioned milestone examinations, departmental policies, or cultural expectations that were viewed as inflexible or unaccommodating. Mark is an example of a student whose individual agency intersected with structural challenges in his program. He spoke about challenges involving research opportunities, course opportunities, and funding policies that were sufficiently detrimental for him to consider transferring institutions. Mark was admitted to two optics programs and several other physics programs. His intended path was photonics, so after some personal reflection about quality of life and career pathway issues, he enrolled at ACME University. Upon his arrival it was evident that funding to pursue the research in which he was most interested was limited. From his perspective, only one research area had adequate support and focus in the department. Mark bounced between research projects and teaching responsibilities during his tenure. Despite the structural challenges to make progress on a thesis project, he continued to piece together a project in his topic area. In our interview he mentioned considering applying to other programs, due to new program policy changes—specifically a stratified earnings system for graduate students in the department. In our interview and during subsequent conversations, Mark discussed candidly his commitment to completing his degree despite the challenges ahead of him.

In contrast, some students did not need to exhibit agency, either because they did not face notable challenges or did not need to change their behavior patterns to continue persisting through their program. By this, I mean that they did not need to change course or strategy to continue to progress. In fact, some participants seemed to have a graduate experience that was devoid of obstacles. Wendy's primary pursuit was an intellectually stimulating environment. She tried her hand at more creative pathways after completing her bachelor's degree in optical science and engineering. She wanted to "do something bigger, better and badder" in science and mathematics, which led her to graduate school. She transitioned from undergraduate to graduate student with limited barriers, especially since she had relationships in the department from her undergraduate experience. She passed all milestone exams without issue. However, Wendy depended on her own agency when she expressed feeling "misguided" on a failed research project and realized that the information she needed to develop her research was not available in her laboratory group. Despite this hurdle, she found the resources within her network. It was not until the near end of her program—in fact with less than a year left—that Wendy had to depend on herself to navigate the completion of her program.

Agency represents a very interesting topic throughout this study. Themes arose around how, which, and when students demonstrate agency in their trajectories as graduate students.

Chapter 4 indicated limited agency in students' discussion of undergraduate training and development; at times it appears that the field chooses these students and they accept the options that are made available to them. The primary mechanism for deeper engagement with the field was through research opportunities at the undergraduate level. In fact, as students progressed to grad school they talked about activities that increased their agency in the beginning of graduate school. Finding an advisor and persisting through challenging coursework were common, but these can easily be considered graduate school milestones.

While agency could be directly related to increasing independence and time in the program, in the context of graduate education agency is a nuanced theme with multiple layers to be peeled back. Worthy of further exploration is whether agency development in the graduate education setting requires intentional progress or is an unintentional process that evolves over time. At the point students' agency increases, they are generally looking toward graduation and beginning work. Within informal graduate student circles, this is the time that students reaffirm or redirect their focus to completing their program. This does raise some questions for researchers examining graduate education—but it also causes graduate students to ask questions of their own. Is the timeline for graduate programs too long, or are these students finally demonstrating the independence that doctoral education seeks to cultivate? Deconstructing the axes of agency could be a separate study on its own, but there are features to highlight in this study including collective identity, and the self-appraisal of agency that may be explored further in future work.

Agency and the narrative method have been used to improve understanding of reflective experiences and activity theory, a supporting theory of identity-trajectory (Stuart 2012). The narrative methodology enables a discussion of the multiple aspects that influence a person's experience. Edwards (2009) described how work responsibilities evolve in time and space and influence identity over time, which is also true for graduate students (McAlpine & Amundsen 2009). This study focused on the participant's self-appraisal of professional identity, which is primarily confined to the university and the relationships within it. Participants in this study rarely related themselves, in terms of agency, to the broader field of optics and photonics. As noted in the prior section, Mark was the only participant who extended his self-appraisal beyond his own department—but only after he found out that department resources were lacking. He recognized and demonstrated his ability to make contributions beyond his immediate sphere of influence. Viewed in total, a collective identity within the department was somewhat limited. The only exception was with study participants' discussions of hierarchy, which focused on time in the program. Participants defined their roles based on their stage within the program and without connections to others with whom they interacted.

This description of agency differs from McAlpine and Amundsen's (2009) findings. Their interdisciplinary study of collective agency indicated that feelings of belonging and having contributed to a group larger than themselves motivated individual agency. The group to which a student contributed included both his or her immediate program as well as the broader discipline. Examples of collective or relational agency are contributions beyond one's own department as well as sharing goals (Edwards, 2005; Lave & Wenger, 1991). McAlpine and Amundsen also discussed collective identity not just as a specific group, but also as a specific cause. The current study did not find agency defined in terms of the field or the department. Participants' agency was solely tied to the individual's quest for personal gains, exemplified by graduation, job placement, and other factors. Within the lab context, senior graduate students rarely articulated how, if, or when their projects contributed to or were part of an overall laboratory strategy. This difference from interdisciplinary studies raises questions of the natural cooperative ideals of laboratory work. If, in fact, these students did not relate their work to the overall advancement of the group, what then is the purpose of the laboratory group itself? Because the laboratory model has typically been seen as critical to the development of graduate students, these findings conflict with its global importance. Either through time or other factors, there seems to be a disassociation with the "collective good," i.e., the needs and identity of the larger group diminishes.

Self-appraisal of agency is an interesting challenge within a narrative study. This method focuses on the individual's lived experiences from his or her own perspective. At times it seemed as if there was a lack of recognition of external factors that facilitated success or overwhelming dependence on those factors.

5.3 Networks

The third strand, networks, corresponds to the connections and relationships that graduate students form within their discipline. This study showed that the networks within the department tended to center around the academic advisor. In other words, being in a specific faculty member's lab usually afforded access to that advisor's other students, researchers and sometimes even facilitated extra-university network participation. In this section I review the role of advisors in the development of student professional networks. Specifically, I focus on the selection of the advisor and the networks that facilitate future career options.

5.3.1 Advisors for Local Network Access

Faculty members are the frontline representatives of the institution, but are also critical in network access within and beyond the institution. As gatekeepers to the laboratory, faculty serve a critical role in the development of a potential or current graduate student. Accordingly, selecting an advisor should not be a casual decision for either the student or the advisor. Participants in this study were either recruited by their advisor or actively sought a specific advisor based on mutual interests. There were, however, outliers in both categories. For example, Cliff, Alex and Craig were assigned to or specifically recruited by their faculty mentors for various institutional reasons. Nonetheless, those relationships were all reported to be productive and positive. Brooke was the only student who uniquely sought out her advisor for the best personality match, and not for other factors. All remaining students indicated that they sought or were selected by their advisor based on research topics and interests. There was not much distinction in being sought or selected since those advising decisions seemed to be mutual at the onset. It should be noted that not all student-advisor relationships culminated in reasonably successful student progress; some pairs mutually agreed to end the relationship before program completion.

For most students in this study, being assigned to an advisor and thus a research project typically meant that they also joined a larger laboratory group of students. The advisors provided access to this meaningful development network, even if advisors themselves were not often present in the lab. As a gatekeeper, however, the advisor had significant responsibility to ensure that group dynamics were productive and could cooperatively ensure the success of all participants. Despite the learning potential of being a member of a dynamic research group, students rarely acknowledged the presence or absence of lab members in determining their advisors. This can likely be attributed to the fact that these students did not realize that lab members could be of critical importance to a student's research success.

Professional development is important for graduate students, and even more so as graduation approaches. Advisor selections, even when entirely mutual at the outset, are inevitably linked to the needs and structure of the network. Brooke spoke specifically about making her enrollment decision based on her advisor, as well as the lab—but she was the only participant who did so. Overall, she was happy with her progress, learning, and experiences in her graduate program. Students who were specifically recruited, like Alex and Craig, made expected progress and even overcame barriers because of the research support of their advisors. These students expressed regular and meaningful access to their research advisor that other students did not convey. For all the other participants, their advisor selection, which was based on mutual research interests, tended to leave progress to chance. Twelve participants were quite successful in progressing through their programs and did not express major challenges. Among the remaining thirteen, 11 changed advisors and/or experienced notable difficulties in their graduate programs.

5.3.2 Career Networks

Some students acknowledged that professional development opportunities offered by their programs and universities were limited. Barry mentioned, "Professional development is just non-existent. I feel like most of my peers are unprepared," so he sought professional development in his own ways. In response to my request for each student's curriculum vita, Barry provided two—one for the academic market and the other industry-oriented (although they were not markedly different from one another). During our talk he stressed that he would be seeking a variety of opportunities to ensure that he was competitive in the job market. However, he also noted that his envisioned career trajectory was influenced by his advisor's perspective. Barry's advisor was an early-career faculty member and Barry chose Photonics University because of that individual. Although Barry's career goals were notably diverse, they were also a bit more specific compared to his counterparts in the study. He was confident in his ability to be an effective leader and manager based on his strong understanding of what he called "the science of business" and technology transfer. He alone talked about the entrepreneurial features of science, as well as the obligation to affect policy with scientific knowledge. In a rich discussion about career prospects, Barry pointed out a common theme—that most faculty members tend to prepare students for a career in academia. While his most immediate steps following graduation will be in an academic research lab with an advisor from his undergraduate years, Barry demonstrated the strongest interest in pursue a wider range of opportunities in comparison to others in my study.

"Non-traditional students"—those who worked full time before or during their tenure as graduate students—tended to have a more practical grasp of the skills necessary to advance their careers. They already possessed important social capital and network knowledge as a result of their professional experience. For example, Ashley worked full time while in graduate school and her employer shared the cost for her entire graduate degree. In our discussion Ashley talked about gaps in what she already knew and needed to know at work versus what was taught at Photonics University. The primary issue was software packages and programming languages that were industry essential, but not used or taught on campus. This academia-industry disconnect in a field that has substantial links to industry is worth noting. The participants who spoke of such disconnects (e.g., Ashley, Cliff, and Barry) had prior experience or exposure that made them aware of these differences. Independently, they made efforts to ensure their own ability to compete in the industry, which were not directly identified (based on pilot interviews) by their faculty or the program course content itself.

Most students, however, did not have network connections to their desired career paths. Moreover, faculty who did have industry connections tended to use them for their own career development. In fact, at no point in the study did any participant mention their advisor or other faculty as a conduit for professional development. Independent awareness of career development needs, which was evidenced by Ashley and Eric, helped ensure secure options after graduation. For many others, however, career access was nonexistent. Photonics departments like those represented in this study may need to begin reconsidering the function and use of career services within the institution to better facilitate network access. Students whose networks are limited to academia have fewer career opportunities at the completion of their graduate programs. Those closest to the transition from graduate school to career were unsure about the specific steps they would take once they had their diploma in hand. All students were generally positive in discussing their career pathways, even if they did not know the exact trajectory they would take.

5.4 Institution

The institution was also influential for individual identity-trajectory. For graduate students in optics and photonics, the research laboratory represented a very important institutional feature for all students. By working in the lab, students were able to complete essential research that would lead to graduation. Within the lab, however, there were roles, responsibilities, rules, and context for self-definition. The role that graduate students hold in the lab and the research products they produce are a part of their professional identity—both of which highlight the importance of the lab in progressing through the graduate program. Labs provide access to intellectual development opportunities for graduate students seeking degrees in optics and photonics, as well as for undergraduates thinking of entering these graduate programs. Crede and Borrego (2012) reaffirmed the importance of the laboratory as the appropriate institutional vehicle for understanding engineering student socialization in graduate school. Indeed, the lab helped to shape the career aspirations of some of this study's participants. In the following section, I will present findings emphasizing the importance of the laboratory, focusing on its structure and the role of faculty on graduate student development. While all students mentioned the lab during our discussions, they also singled out their advisors as important representatives of the institution and organization. Considering the essential functional role of the advisor for a graduate student in providing laboratory access, facilitating progress, and overseeing program milestone requirements, the influence of advisors is also reviewed below.

5.4.1 Laboratory Structure

In STEM disciplines, the traditional laboratory within a research university is principal structure through which academic research and contributions to scholarly advances are developed and disseminated. All of the students in the study talked about joining and becoming a part of a lab early in their graduate experience. The culture of science and engineering graduate education focuses on laboratory research—a notion that was reinforced through discussions with participants about their labs. It is important to recognize that for most graduate students, access to a specific research lab is linked to an advisor and the funding to support that student's graduate education. In some instances, a student will initiate his or her graduate program without an advisor and funding. Will, for example, started as a teaching assistant and found time to do research when he could. He was the only person in my study who specifically mentioned this arrangement, but others like Jennifer and Mark did mention the challenge of balancing teaching responsibilities while conducting research.

Laboratory resources and available equipment can be a deciding factor for potential graduate students. Craig was looking for a graduate program that was not too far from home, but also a department that had a strong reputation for its experimental work. "As far as optical comm[unication] and experimental optics, it was a pretty good choice." He immediately liked the lab to the reputation of the faculty in his program: "They have a lot of well-known professors."

The lab does not necessarily have to be on campus, however. Wendy, for example, did most of her dissertation research in a company laboratory. In discussing her advising situation, Wendy mentioned her co-advisor who facilitated her access to an off-campus company research lab:

> I chose her (my co-advisor), knowing her value in the community and, uh, also the fact that it was at a company, not the university – it's a very different experience.... She (my co-advisor) saw my interest and potential to do the whole spectrum of what it takes to write a grant, do the research and get back to it. And also the same kind of experience that a company setting and developing products, with turning the grant into an actual, selling product. That's what I was interested in.

While Wendy seemed to enjoy the experience of working in an environment that was similar to where she saw herself professionally, she pointed out that the structure might not be conducive to completing a dissertation:

> (Laughs) Right now, I kind of well, my boss, the woman, she comes in the afternoons to do her work. I kind of, I do research at home half the day and then I go into the company and there's a couple little projects that I work on every now and then that have to do with real business. And if I have to do anything in there I will, normally, I kind of talk to my boss, see if there is anything going on, give her any updates if I have them and we are always ordering parts and trying something new so we'll discuss things. And then like I said we'll get to sit down and talk about the dissertation and where's the research at. It's

> very free-formed very non-structured. I hope that people with more structured formats are more successful than I have been. Maybe that would have helped me.... Well if I had a weekly meeting and had to report my progress when I was with my former advisor I wonder if it would have been more red flags going, you should have done more by now, this isn't working we need to change gears a lot sooner than when it finally happened.

Wendy is one of the students who switched advisors to increase her productivity, but here she questioned whether that decision was the best. During our discussion she explained that because she wanted to work in industry and not academia, the opportunity to train in an authentic environment was useful. Like Wendy, Jennifer was a graduate student at Southern College who also did industry research for her dissertation and to support her graduate education. Jennifer specifically mentioned appreciating the professional development opportunities that this type of research offered: "The group that I'm with has contracts with people in industry so you do typically have to work to deadlines and things like that, although grad students are never typically the point person on the project." Ashley, who attended Laser University, worked in industry full time while in graduate school, but conducted her research on campus. She emphasized two specific strengths in doing industry-oriented research for her graduate program: resources for collaboration and colleagues at work to help with challenges. Alex, who was a student at Midwest Tech, indicated the following: "I've found that I've been working with a lot of people over in the *defense agency* and I'm absolutely positive if I was interested in staying around here, I could make a couple phone calls to people that I've had experience working with that I could find a job pretty easily, without even moving." Each of these graduate students identified specific skills gained (possibly not different than their counterparts) and the professional benefits of working in either industry or customer-driven labs and projects as graduate students.

During interviews with participants, they often mentioned the relationships within their lab groups. Lab group sizes ranged from 2 students to as large as 30 students, postdoctoral fellows, and researchers. Regardless of the size of the lab group, two important themes emerged: relationships with other lab members and collaboration. Lab members were not always graduate students, which at certain stages became important for progress on a lab project. As suggested by Crede and Borrego (2012), larger groups do not necessarily facilitate graduate student progress; what is important is paying greater attention to group functioning and structure. Students—especially new students—who worked in labs somewhat independently with little interactions with their advisors reported struggling. Labs with stratified structures (e.g., the presence of students at multiple levels, postdoctoral fellows, and research associates) tended to produce natural collaboration, but this could be due in part to the support of other lab members and social networks within the lab.

In summary, research labs are central to the development of graduate students in optics and photonics—yet their structures are not well understood from the standpoint of student development (Crede & Borrego, 2012). As evidenced from this study, participating in a lab group facilitated intellectual development and provided the necessary network for conducting and completing research—both of which are deemed to be essential for completing a graduate degree and moving on to a professional setting. The important consistent finding from this study is that the culture of the laboratory and size are important. Students in collaborative labs that engaged multiple students on the same interdependent project enjoyed greater productivity and satisfaction with the lab, not to mention within their programs overall. Moreover, groups of an adequate size with stratified levels of expertise tended to train students who were more satisfied and productive in their graduate studies.

5.4.2 Advisor Roles

Faculty members provide access, primarily at the undergraduate level, to networks that will accelerate a student's academic career. As students begin graduate school, the advisor role is much more formal. Advisors have multiple roles when it comes to their graduate students: as a work supervisor, an academic colleague, and the person primarily responsible for overseeing student progress through a program. Understanding how the functional role of an advisor influences individual graduate students is a challenging undertaking. Nonetheless, in this section I will present some of the functional influences of the academic advisor on graduate students. These individual experiences represent an opportunity to expand our understanding of the interactions between the advisor and graduate student. In particular, narrative storytelling from this study's participants hopefully has produced greater transparency in discussing the essential functions of an advisor with respect to his or her graduate students.

In this study, changing advisors meant changing labs—and most of the time—changing research topics. Eleven participants in my study changed advisors at least once during their program. In contrast, a few students (e.g., Wendy) remained assigned to one advisor, but their primary source of guidance and feedback was from another committee member. At a number of points in our conversation, Wendy clarified that when she talked about her advisor she was referring to another committee member who provided feedback and guidance. Having a principal advisor does not guarantee that the advisor will be directly involved in the student's research or give the guidance that the student needs or expects. Those who changed advisors generally did so for two reasons: lack of guidance or the advisor changing career pathways. Changing advisors, as I mentioned before, was not a difficult change and did not seem to result in any negative repercussions for the student within the department—a finding that may be unique to optics/photonics. This is encouraging because of the large number of study participants who did change advisors.

Research opportunities and advisor involvement were the most important issues for students in selecting their advisors. Since these two institutional roles (generating a research project and providing guidance in said project) were perceived by students to be important, my discussion focuses on these two areas. As noted earlier, a specific research topic often guided students to specific faculty members. In general, when students sought out advisors they did so based solely on research interests. There were some students who very clearly emphasized the importance of their advisor for both research access and the lab. Charles, for example, stressed the involvement of his advisor and the laboratory as being essential for facilitating progress in his graduate program. In response to a question about the most important factors that facilitate success, Charles said:

> One is [an] advisor who can give you freedom to work and to think. He can guide you and, you know, and guide you through your endeavor to get more involved into the research. And also he'll give you help, giving you some exposure in the field – more resources, [such] as what people have done now in that field and what are the possible research areas. So that's very important. Another thing is that, to do experimental research in optics you need to have good equipment and good facility where you can design your own experiment, where you can do a lot of this is possible. So these two things are really important.

Charles's statements echoed others in this study. While there were variations based on personal experiences, the core expectations of most graduate students were essentially the same. Kimberly was a student who selected her advisor based primarily on research interests that she discovered as an undergraduate, as she indicates in the following statement:

> So it's like I said, I really fell in love with this project of the photonic crystal fibers so I started reading a lot of the papers that were out, it was part of a project and one of the people who I thought really did a lot of interesting things, his name was Dr. Randall and so I looked him up and I realized he was at Photonics University…. he had happen to just move to Photonics University and I was applying to come down here, and a couple other places, well I ended up applying to come down here because I wanted to work with his group so I applied got accepted, came to tour, went to visit him.

Although Kimberly did not get to work with Dr. Randall, the research project in her undergraduate course allowed her to explore a new area, which in part contributed to her decision to apply and eventually enroll at Laser University. Unfortunately, the advisor she ultimately selected and his lab were not successful in facilitating her progress, so she selected yet another advisor. Once again, Kimberly struggled to make the progress she wanted on her project, which she attributed to the fact that her group was small and had extremely limited access to equipment. In fact, she stated that the main collaborative activity within the group was scheduling time to complete experiments without dismantling a bench set-up for another group member. Nevertheless, Kimberly was able to take on an important role in a special research program, but she still had limited interactions with her advisor and other researchers in the lab. She also did not mention engaging with any advanced graduate students, postdoctoral scholars, or research associates. This deficit is important because people in these roles can be critical in advancing a junior graduate student's progress, especially since most of the participants in this study reported that faculty members spend little time in the lab working with their students. Participants like Robert, Brooke, and Daniel, for instance, mentioned specific relationships with lab mates that assisted their progress. Once Kimberly switched advisors and lab groups, her graduate experience improved because of her knowledge and ability to operate advanced equipment. In fact, collaborating with postdoctoral scholars, research associates and other graduate students in her new group kept her project moving forward, despite the independent nature of the research.

In five instances, advisors left the university or changed roles, leaving students without an advisor. Such transitions occurred in enough cases in this study to acknowledge that the issue of advisor departure is worth examining. While this abandonment can be a physical reality—in the case of an advisor taking a new position at another institution—it can also be intellectual, whereby the advisor either lessens or ceases to provide attention to the student and/or the project. Both possibilities are potentially detrimental to the student's progression in the program. It is worth noting, however, that in this study I did not identify any students who ended up abandoning degree programs after separating from their original advisors. George was the only student in this study who left his original university after his advisor left. In our discussion, he mentioned lack of academic support and advising contributed to his transfer, but there were also personal factors at play. Additionally, at the time of our interview, Mark candidly discussed exploring transfer options and submitting applications, although he had yet not confirmed any enrollment changes. In fact, Mark was the only student in the study who openly discussed alternative transfer and alternative options because of progress delays with an advisor and departmental dissatisfaction. In contrast, students whose advisors physically or intellectually ceased advising tended to resettle within the same department, either immediately or soon after the formal separation occurred. In the midst of an advisor change, Will left his department to pursue a visiting research position at another university. Kimberly used her networks within the department to find a new advisor. It should be noted that academic advisors most often ceased to advise international students and women. This finding merits further investigation, but exceeds the scope of the current study; nonetheless, an overview is provided in Chapter 6 as a platform for future work. However, a positive related finding is that advisor switching is normal and socially acceptable in many of the departments, as reported by students. Students did appear to be concerned with negative department implications if they changed advisors, e.g., retaliation from others or diminished reputations. While advisor changing generally happens once a student feels his or her progress or situation cannot improve, the ability to change advisors and begin building on prior work is positive.

Universities and departments put a great deal of effort into hiring new faculty, especially given the nature of the tenure process and the limited number of available academic positions. Thus, when a faculty member leaves a department it affects the program *and* its students. It is also important to note that most student-advisor interactions occurred during lab group meetings and during occasional one-on-one meetings that were usually reserved for advanced students. Thus, students tended to experience difficulties in conducting independent research in the laboratory, where there was limited access to faculty at best. Instead, research success often depended on advanced graduate students, postdoctoral scholars, and research associates—none of whom were assigned the formal role, responsibility or recognition for enabling student success. Because these roles are so important, providing training and formalizing responsibilities as it relates to other lab members is a recommendation. The sharing of mentoring and advising practices not only facilitates broader professional development for advanced lab members, but it also ensures that graduate students can be successful.

5.5 Summary

As evidenced through discussions with students, graduate programs that expand the experiences of students, increase their sense of independence and responsibility, facilitate their learning and skills, and prepare them for careers after graduation represent a graduate education model worth emulating. To reiterate, this study was designed to better understand the student perspective of navigating graduate programs in optics and photonics, with the goal of identifying their most important perceived features for student success. Not unexpectedly, I found that most students experienced their optics graduate programs in very similar ways.

Considering the theoretical framework of identity-trajectory, the intellectual development experience can be viewed through two separate lenses: socialization in the department/field and agency. As students orient themselves in the department as well as in the broader field, dependence on social networks within the laboratory seemed to be critical. In the early stages of a student's graduate program, the advisor is key for facilitating that individual's access to the lab—but rarely did there seem to be an established and well-understood hierarchy for directing students. This study also confirmed that social networks are absolutely necessary for student success—especially for graduate students in their first or second year. In fact, students who changed advisors (and therefore research labs) tended to do so because the structure needed for success was not formalized and well understood by all group members. Because of this challenge, departments and faculty advisors may need to redesign orientation information and procedures for new graduate students—especially with respect to an established lab hierarchy/structure so that students do not feel rudderless in the absence of an active faculty mentor. Moreover, when advanced lab members take on leadership and guidance roles, the department should recognize them—perhaps through formalized recognition.

The agency theme was an important one that emerged in this study. Agency became important for students, usually after they completed their master's program requirements, or as they became more senior members of the laboratory. As students approached their expected graduation date, their direct responsibility for and ownership of their progress increased. While this may be a natural progression of graduate education, findings from this study indicated that individual agency was most important—not the group agency either within the laboratory or cohort. Creating environments that value and require group progress will ensure that more students will be able to demonstrate the agency needed earlier in their graduate programs.

This study confirmed that the professional networks in which graduate students interact seem to depend primarily on their advisor. Selecting an advisor, or being chosen by one, adds a student to a research group and a lab. Even in small research groups of just two or three graduate students, working with an advisor provides an immediate professional group. Advisors are the gatekeepers to intellectual growth within the lab structure. As students progress, they rely on advisors to access professional networks for their career. Important to note, however, is that even though the students in this study developed their networks within academia through their advisors, at conferences, and other ways, the majority of them planned on joining industry after graduation. Thus, with a few exceptions, the networks of which they were members were unlikely to be highly useful in facilitating a jump to industry, even in instances where the advisor was involved in industry research.

This study made clear that access to and becoming a member of a research laboratory are essential for progress toward a terminal degree. Given that the laboratory is central to success, deliberate steps should be taken to facilitate access to the laboratory. Moreover, the roles and responsibilities of all members of the laboratory should be well defined. Along the same lines, although faculty are the main drivers of the student development process, other members of a department's research community are also key to advancing graduate student progress. While faculty receive credit for the graduation of graduate students, others who support the day-to-day progress of graduate students generally do not. Reorganizing the promotion and tenure process for faculty to best support their careers, as well as continuing to engage graduate students if and when changes in advising occur, can be helpful.

Improving the overall experiences and success of graduate students is important for every graduate program. Identifying and understanding the likely situations that graduate students will encounter allowed me to identify resources and recommendations for improving graduate programs. Although my study focused on optics and photonics, many of the findings discussed herein will apply to students in similar physical science and engineering fields. This research represents an initial look at the experiences of optics and photonics graduate students through the lens of identity-trajectory. There are rich findings and details that can be explored in greater depth to provide an enhanced understanding of the issues at play in graduate education, as well as increase the transferable value of the study. In short, these suggestions are intended to represent a starting point for improving graduate programs in optics and photonics, as well as contribute to understanding the graduate experience in other fields.

CHAPTER 6: DISCUSSION AND CONCLUSIONS

In this study, the milestones of students' educational careers were used to separate findings: pre-graduate training and graduate development. Identity-trajectory and the three strands of intellectual, institutional and network played various roles depending on the stage of development for graduate students that participated in this study. The narrative methodology of data collection and analysis, followed by qualitative presentation of evidence, focuses on the story of the individual and allows me as the researcher to understand their experience first and then identify codes related to the theory. This approach and theoretical framework resulted in extremely rich data and findings for the 25 participants. The similarities in their experiences and agreement with my interpretation of their experiences lends to the credibility of the research.

The findings presented in Chapters 4 and 5 discuss student experiences at separate phases of their academic career. For pre-graduate training (Chapter 4), parts of the institution, including faculty and programs, were found to play a critical role. At universities that offer bachelor's degrees in optics and photonics, recruiting efforts captured students who intended to select other engineering majors. Research experiences were the most important pre-graduate development experience, shared by 24 of 25 study participants, and students emphasized their influential role of research experiences in their decision to pursue optics graduate study. Their research in physics, electrical engineering and optics enabled intellectual development, network and institutional access for future study. In Chapter 5, I presented the commonalities in experiences for the graduate students in my study, especially in the way they talked about their research and career development. The intellectual development and contributions of graduate students occur in the laboratory and contribute to the professionals they will become. The networks these graduate students discuss being a part of do not necessarily align with their career goals;

although initially heavily engaged in an academic career path, many altered plans and were pursuing careers in industry. This mismatch leaves students to their own devices to determine the next steps in their career. Since the lab was found to be the most important vehicle for graduate student development, the department and individual faculty members should take care in the design of research labs. The traditional advisory structure may need to be reconsidered to improve graduate student success.

This discussion chapter will highlight the major points of the findings, provide recommendations, and conclusions based on the data in this study. When appropriate, I direct recommendations toward students, faculty, program administrators and policy institutions. The student category is inclusive of undergraduates and graduate students. Faculty is inclusive of all faculty, but when specified, those with undergraduate, research, and graduate responsibilities are noted. The program administrators group includes graduate program committees, department heads or deans, and in some cases those who have influence over the policies that affect students. The evidence based, actionable recommendations included herein can contribute to reconstructing the graduate experience to better fit the needs of students, faculty and programs.

6.1 Preparing Graduate Students (Chapter 4)

Considering pre-graduate training, there were two groups of findings: formal undergraduate training and research experiences. The findings in this study point to the various entities representing the institution to be prevalent influences on student identity-trajectory, so as a result, a majority of these recommendations are directed toward these entities. There are however, some recommendations for students, both undergraduate and graduate, as they navigate the institutional structure.

6.1.1 Conclusions from Formal Undergraduate Training

In formal undergraduate training, the institution, creating and exposing students to opportunity structures in optics and photonics, is very important for bachelor's level enrollment. When the university has a program, students interested in science and engineering can migrate into optics departments. While none of the bachelor recipients indicated that they would have left engineering altogether, all redirected their interest to optics and photonics when fully informed about the program and opportunity structures are made available. Students with bachelor's degrees in optics also credited the positive climate of their program for enabling and affirming a change of major. The institution itself facilitated the entry of students into their programs; the students did not seek the departments; the departments all made an effort to seek the students.

- ***Heads of bachelor degree programs should continue local outreach (e.g. regional high schools, involvement in campus recruiting) efforts and aim to maintain positively cultured, small departments that stand out among other engineering departments.***
- ***Departments should consider best use of opportunity structures such as scholarship opportunities, and resettlement plans for students switching into optics bachelor degree programs.***

6.1.2 Conclusions from Research Experiences

Research experiences were common in the development of eventual graduate students in optics and photonics. Many of the students participated in research in optics while majoring in physics and electrical engineering, which sparked their interest. Research experiences, either summer internships, in courses, or as program requirements enable skill development, exposure, network access, and awareness of opportunity structures for graduate education in the field. The experiences also helped ease the transition to the graduate research environment based on the enculturation that past research provided. Research experiences gave students information about who the researchers were in optics and photonics and the institutions with which they were affiliated. Interacting with the intellectual strands of established researchers provided direction for eventual graduate students in identifying graduate programs to which to apply. In this study I found a strong qualitative relationship between research experiences and graduate enrollment. Researchers interested in this particular finding should isolate focus on the undergraduate research experience to determine its longitudinal influence on pursuit of graduate education, as well as the specific influence those experiences may carry into the graduate program.

- ***Undergraduates who are at least considering the option of graduate school should pursue research opportunities as undergraduates***
- ***Graduate students who are a part of research labs with undergraduate should be aware that undergraduates consider them role models of what to expect and be aware of in graduate school***
- ***Faculty who teach undergraduates should consider the option of research as a course component or required experience to introduce all students to academic research culture***
- ***Departments in feeder disciplines, such as physics and electrical engineering, should consider implementing required research experiences for students either in coursework or summer experiences. Consideration for the academic timeline should also be taken; in order for these experiences to be effective they cannot only be required at the end of the bachelor's degree program, after postgraduate plans have been made.***

6.1.4 Summary of Conclusions – Preparing Graduate Students

Throughout this study the importance of disciplinary undergraduate training, whether formal or informal, was prevalent in students' decision making when considering optics and photonics graduate education. I found that the undergraduate years' intellectual experiences, network access, and institutional structures were important to the decisions of the graduate students to pursue graduate work in optics and photonics. Leaders in optics and photonics, whether in degree-granting programs or feeder disciplines, may consider providing and expanding these disciplinary training experiences. At this stage of disciplinary development a bachelor's degree in the field may not be entirely necessary, but deep, supplemental training either in classrooms or research experiences may be. Disciplines like optics and photonics with few or no undergraduate training programs may consider similar approaches, entwined with the current activities of students, courses, and research.

6.2 Graduate Development (Chapter 5)

The development of graduate students into highly skilled scholars and researchers by the time they reach graduation is a complex process. In this study I found the following themes for graduate student development: (1) socializing in the department and field, (2) agency, (3) networks, both advisors and career, and (4) institution, lab structure and the role of advisors. The graduate experience was similar for a majority of the study participants from highly competitive admissions processes, and a very independent and isolating research experience throughout. The absence of professional socialization, even for those transferring into the discipline, was generally absent. The networks that students are a part of are facilitated adviser selection and may develop over time, to facilitate postgraduate opportunities. The institution overall, but especially the laboratory and faculty, facilitate the development of graduate students, but also need improvement to enhance student development.

6.2.1 Conclusions from Socialization in the Department and Field

In Chapter 5, I discussed the on-boarding experience and absence of formalized on-boarding for new graduate students. Again, formalizing the on-boarding process beyond the curriculum will assist graduate students new to the field adjust with field specific information and direction. At the department level, understanding the program's position in the field and the opportunities within the program will begin the important socialization process necessary to succeed.

- ***Departments should consider developing in depth or first semester orientations to the department and field to assist new graduate students in adjusting to and navigating a new discipline (or expanding existing orientation programs).***

6.2.3 Conclusions from Agency

As noted, agency is one of the most interesting findings within the study, specifically during graduate training. Students demonstrate some levels agency in getting to graduate school; however, as they progress they do not seem to demonstrate agency until they near graduation. This finding raises questions of the intention of developing agency in the graduate process or students' realization that their ownership and independent push is required to complete the program. Collective agency has been found in other studies (McAlpine and Amundsen 2009) to influence individual agency. The independence finding mentioned in Chapter 5 may explain the limited agency of graduate students in this field. As students work alone, from the onset of their programs, there is a lack of collective identity or a high stakes affiliation with a larger group. This lack of collective identity may be a reason for limited agency of these graduate students until they have transitioned to a more advanced stage as a graduate student.

- ***Faculty leading research groups should consider developing a greater collective identity beyond the lab group's affiliation to a name or the faculty member themselves***

- ***Engage all students in collaborative research to promote shared responsibility for progress and collective identity through interrelated projects and sharing of lab successes***
- ***Departments may consider creative ways to develop cohort and department culture that engages all graduate students (Crede & Borrego, 2012).***

6.2.4 Conclusions from Network

Networks facilitate the professional socialization of graduate students, as described in Chapter 5. The network formed within the laboratory, department and field are nearly as important to graduate development as research and coursework. In this study I focused on network in two ways: the adviser as an initial gatekeeper and networks to facilitate career development. Adviser selection is one of the most important aspects of graduate student network access and all except one, in this study, select their adviser based on research areas or departmental assignment. Using the research topic as a guiding compass, students take a greater risk in making necessary progress. Eleven in this study changed advisors during the course of their program, commonly based on lack of research progress. As students progressed through their programs and began considering career options, their networks outside of the department influence their trajectory in notable ways.

- ***Potential and new graduate students should complete a full, personal assessment of their own work style and personal needs to succeed in a research and academically intense environment.***
- ***Potential and new graduate students should seek to make adviser selections based on personality, work style and compatibility – not solely based on research topics.***
- ***Departments should consider options at the beginning of the program to explore and make well-informed adviser selections after adequate time to determine their needs and get to know faculty within the program.***

6.2.5 Conclusions from Institution

There were two major influences from the institutional strand: the laboratory structure and the makeup of the faculty. Due to the prevalence of the laboratory, this topic is discussed separately in section 6.3. A finding consistent across many students was the importance of the "right" faculty advisor. Academia is a competitive environment that requires ability in research, obtaining grants, and accelerating one's own career while simultaneously preparing the next cohort of optical scientists and engineers. Several of the students in my study selected their academic advisor based on common research interests, and rarely discussed their working relationship with their advisors. The research-oriented selection strategy was primarily successful for domestic male students. The strategy, unfortunately, was not successful in the long-term for many of the other participants in this study. Switching advisors was common and socially acceptable in optics and photonics, which is a good thing for students. When pressed about the department, faculty, and peer view of switching advisors, students indicated that there was limited or no retribution as a result of the change. The reasons for switching advisors were primarily in two categories: lack of expected progress or the advisor leaving the university altogether.

Several participants mentioned the impact of their first advisor leaving the university; surprisingly none of the students included in the study actually came to their current program with their faculty adviser on a move. Many faculty advisors who left did so to pursue industry or national lab positions that either limited or would not allow for students to follow. International students especially felt the impacts of faculty migration; three specifically expressed having fewer funding opportunities available to them as their research funding, and essentially research progress, was inextricably linked to their academic advisor.

- ***Departments should develop specific safety nets for graduate students whose advisers leave the department unexpectedly.***
- ***Departments should consider reorganizing the advising structure to a more shared system so that student progress is not halted due to faculty career changes.***

6.3 Importance of the Laboratory

Throughout students' entire trajectory the laboratory is the most central feature to intellectual development, network access and socialization in the field. The laboratory is a responsibility of the department and university, and primarily the faculty advisor, in the contribution of scientific knowledge to the field and a vehicle of education. Access to the laboratory is useful at the undergraduate level. At the graduate level, successful socialization and integration into the lab facilitate progress in the program. In too many instances, progress is dependent on informal relationships in the laboratory. There is also little direct involvement and supervision by faculty, which can also present a challenge for some students. When advanced lab members are available and involved, graduate students' ability to progress is greatly improved. The problem is that these relationships are generally not formalized in any way. The personal, social connections that form either from being in the laboratory together or otherwise, tend to drive these critical progress connections. This presents two challenges: the student has to be socially accepted in order to make research progress and the advanced researcher has to have some sort of stake in the development of the novice, or simply willing. While developing collective agency is extremely helpful in facilitating individual agency, the process of that should not be a situation of "the survival of the socially fit," that has the chances to and does leave out some individuals.

There is concern that as students spend time in their programs, and essentially in the lab, their interest in research wanes, leaving them to look for other career options. This disillusionment could be a result of working alone, or just desire to move on to another stage in their career, there is something about the research experience that turns many students away over time. The laboratory is a critical aspect of student development (Crede & Borrego, 2012), but as students pursue various types of careers after completing their research degrees, creative lab environments that involve other professional skills may be needed. Students who worked in industry-oriented labs reported different experiences in professional development. Their work was more focused on achieving a target outcome, deadlines were critical, and teamwork was a regular facet of their research responsibilities. Whether these development experiences are learned within the university lab or at least encouraged as it relates to research, there is a need to develop more engaging environments.

6.4 Women Graduate Students

Although gender was not a specific focus of my study, I noticed some differences in the experiences of graduate students that are worth noting as directions for future work. In this study there were some interesting and markedly different experiences shared from women in optics and photonics programs. The way these co-researchers discussed their pathway and the most important facets of pre-graduate and graduate training were not the same as their male counterparts. In the preliminary survey women were 38% of respondents, which is an over-representation than women graduate students in the combined fields of physics, engineering science/physics, electrical engineering, and other engineering and physical science, a total of 18.9% (NSF 2011). Even a conservative estimate, (aggregate enrollment data by sex is limited in these programs, in part because the data can be extremely identifying), indicates that this study women did have an overrepresentation compared to their enrollment in these and related departments.

The women participants in this study had several similarities, despite institution, national origin and status in school. Examining their stories and the theory of identity-trajectory, I noted that intellectual experiences and potential contributions were the most important factors for their progress in their programs. Also, networks were similarly important, and more so for women versus men. The intellectual and network strands are almost never decoupled in this research; women's intellectual development was linked to their network. Each female participant mentioned and directly linked her progress and interest in the field with research experiences as undergraduates. Also, in interviews participants were also sensitive to and discussed the climate of their department, research group and advisor to women in science. While there may have been an enhanced level of comfort in discussing this with another woman, these findings are important. The American Physical Society, APS, (American Physical Society, 2011) published a report of the status and recommendations for graduate education for women in physics. The report includes findings and recommendations for undergraduate and faculty women as well (American Physical Society, 2013). Physics, a highly related field, also has severe underrepresentation of women and the findings in this study may contribute to the work done by APS to examine and support programs.

In the pre-graduate training experience, women benefitted greatly from research and innovative class experiences. They also discussed these experiences in great detail. Often the women participants established the critical networks to accelerate their educational careers in these domains. In detail, several mentioned the enculturation process in scientific enterprise at the undergraduate level as critically important in their future decision to go to graduate school.

These experiences also provided indirect advice and perspective about selecting a graduate advisor, the types of research that they would be interested in, and perspective on the ups and downs of graduate student life. Women discussed in great detail that the advice and information gathered from other graduate students helped them make advisor decisions. Women participants also were more likely to vocalize the feeling that their progress was directed, and often delayed because of experiences with an advisor. They also vocalized, more often than their male counterparts, advisor-switching due to lack of progress or abandonment in their programs. Establishing the appropriate mentoring relationship with a second advisor, or more senior member of their research lab staff, enabled students to continue to progress through the program.

Some of these brief findings give rise to research questions specifically about the experience of women students, how those experiences are different from their male counterparts, and the expectation differences of women students as they progress. There is an opportunity to expand the study to identity-trajectories of women in physical sciences and engineering. In McAlpine's early work (2010) on identity-trajectory there was a specific emphasis on early career women faculty, primarily in the social sciences, life sciences, and humanities. Contributing to that body of literature, as well as identity of women graduate students in physical sciences and humanities will be a positive future contribution of this research.

6.5 International Graduate Students

International students represented a notable portion of the participants in this study as well as the engineering and science graduate population overall. Research focusing on International students, as a unique population is growing, but there is still work to be done. In this study some features about the experience of students who come to the United States for graduate school are simply different than American students and lead to further research questions to improve the experience for this population as well.

Recent popular STEM education discussions have revolved around topics of International students and their placement in U.S. graduate engineering and science programs. In my study I interviewed 9 International students from around the world. Their experiences are not terribly dissimilar from that of domestic students, in preparing for and getting to graduate school. International students did however demonstrate greater agency in their undergraduate and early graduate careers, likely because of the necessity of their own action to get to the United States for graduate school. As they progress through their graduate programs their experiences are very similar to American students.

The challenges of graduate school are in some times more amplified for International students based on their status. These graduate students find themselves in more precarious situations throughout their graduate careers; yet accept these realities as part of their education. These students perceive a more competitive selection processes than their domestic counterparts. While admissions data and rubrics are not freely available, International students often have only one admissions offer. In many instances they struggle to differentiate themselves to friends and colleagues from their home countries, even in the same undergraduate or master's departments. One thing that I questioned in interviewing my co-researchers is if their responses were restrained in any ways because of whom they believed me to be. Their candidness however was extremely valuable. They shared personal views and experiences that they negotiated in deciding to come to the U.S. in the programs that selected them. International students tend to be abandoned by faculty advisors at higher rates than their domestic counterparts. Their financial concerns tend to be more amplified; policies restricting the type of work or fellowship funding they can receive often limit their research opportunities. Foreign-born graduate students in STEM graduate programs have been identified as a group with potential to close the gap in STEM talent in the United States. In 2012 and 2013 national legislation is being considered to provide greater access to permanent resident status to international students who complete graduate degrees in areas of national need. Instead of these graduates being forced to go home if they do not obtain a sponsored visa, options are being explored to retain the talent that they can contribute to the country. As policy considerations for International STEM graduates, the same policy considerations should be extended to graduate students as well. Future studies may explore differences in agency of International graduate students, and the institutional factors that support and constrain the progress of this particular population.

6.6 Reflection of Research Experience

One experience in this research that was possibly different than McAlpine, Jazvac-Martek and other researchers who developed identity-trajectory was the trust level gained between the participants and myself. Jazvac-Martek, Chen, and McAlpine (2011) mention fear of retribution and withdrawal from study participation for several graduate students; in this study the participants, and I, likely had the same reasonable concern. Although promised anonymity (the same was promised in this study), participants in the aforementioned study were concerned about being identified by being too honest and forthcoming with details. Throughout the interviews, I answered questions for my participants before recording, and only began recording once I read the consent statement. Those conversations reflected concerns of risk. Establishing this rapport with participants and the fact that we shared the experience of being a graduate student, likely helped my participants in being candid and forthcoming in a short interview.

In appendices C and E, the recruitment e-mails identified me with two distinct features, a graduate student completing a dissertation, and a woman. In this study I had 7 women participate, and as mentioned before, a small over-representation in optics and photonics programs. Most of the interviews were done via videoconference and participants clearly saw me to be African-American. This may have been a positive reinforcement for the 9 International students and one African-American in my study as we share an "other" status in most graduate programs. The importance of establishing a constructive relationship between the researcher and participant was reaffirmed for me in this study. In many instances, participants would describe an interesting or challenging situation that I also experienced. While I kept note of these personal reactions and impressions in field notes, involvement with my participants, I believe, made a significant difference in the richness and details offered. In some instances, participants would explain personal situations, and sometimes coping methods that are not easily shared with a stranger. Most interviews exceeded the 30 to 45 minute time frame – sometimes to the point where I had to stop the conversation because of another interview or meeting. In this study, I felt a strong obligation to each participant to be true to his or her story. Even in member checking, e-mails were responded to with enthusiasm, and many of the participants asked to see the results of the entire study. Some have even contacted me weeks or months after the study to just casually talk about progress and continue the conversation about the graduate experience.

Indentifying a newer theoretical framework and methodology in a dissertation is a challenge, but rewarding. Throughout the study, I was particularly attuned to themes of agency in graduate students and how they exercise agency in their work. I do feel that the freedom of thought and in conducting my project were helpful early in my graduate experience. The challenge is, as time progressed, that independence was perceived in ways I had not intended or anticipated. I learned to negotiate literature with the familiar experience, something that few of my participants have been able to express about their own graduate experience.

Throughout my own educational career, networks have provided exposure and facilitated my progress. I also experienced institutional influences early in my college career that positively discussed graduate education and research careers. A first lab based research experience was helpful, but I was not very engaged. Developing a constructive relationship with a faculty member as an undergraduate provided me access to educational research that excited me. The same advisor encouraged me to pursue graduate education, but only for something I really loved – he warned how difficult it would be. A friend suggested I apply to my master's program and my assigned advisor was interested in my past research in physics education. While a master's student, I was able to participate in an internship that allowed me to develop skills in educational research and solidify a new career plan for a doctorate in engineering education. My same master's advisor told me to visit two schools, one being Virginia Tech.

For me, the intellectual challenge of the graduate program and dissertation were taxing in incredibly personal ways, but creating a homeland in the field and external support obligated me to persist. At the beginning, I had no plans for my dissertation to evolve in the way it did. I wanted to be a cold, objective, outside, observer of my target population. I did not plan to become as involved with my participants and study as I did. At the same time, I did not expect, nor plan for my study and my own experience to have so many similarities. At the beginning of my graduate career, I avoided topics that were too reflective of my identity or experience - anything I would be too passionate about. Those topics were dangerous to me and I worried that as my career progressed I would be pigeonholed into one sort of research or being one kind of academic. I knew enough about optics and photonics to speak with participants comfortably technical terms, and maybe enough technical background to be heard. Even in an optical engineering master's program, my research was engineering education; I was not a part of the field, so thought this would not be too problematic. Graduate students should be cautious in taking on a study like this. The privilege of being established in the academy allows for the hard questions that this study brought forth to be asked with less associated risk.

In the process of interviewing the participants in my study, my commitment to improve engineering education was solidified. Their participation and stories changed my isolating research tasks into a charge to finish. My experience in the final stages of this process, in very unexpected ways, reconfirmed my findings, but reassured my career goals. All of the sudden, my own disillusionment, interactions with power, privilege, and the academy, forced me to deal with this research and my own experience in a different way. At very least, I move forward with a lived experience, testimony, relevant research experience, and renewed career mission. The experience has changed my career approach to be sensitive to the realities of graduate education in a different way. It has informed the way I engage and advise my students, and reshaped my career goals for a different kind of impact. While dissertations are rarely read, and are only a small intellectual contribution, I hope that small parts of this study can be used to improve the pre-graduate and graduate development experience for others.

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APPENDIX A: RECRUITMENT E-MAIL FOR DEPARTMENT HEADS

Dear ________,

My name is Lauren Thomas and I am a current PhD student in the Department of Engineering Education at Virginia Tech. My dissertation research, "*Pathways of knowing and using optics through multiple disciplines*," is exploring the development of degree-granting programs in optics, photonics and optical engineering. As part of my research, I would like to set up a 20-30 minute phone interview with you to discuss the establishment of your department, curriculum, and the faculty and students. Learning more about departments like yours will help me better understand the emergence of this interdisciplinary field and the factors that attract students and faculty.

Please contact me with times that you could be available for this brief conversation.

Best regards,
Lauren Thomas

APPENDIX B: PROTOCOL FOR DEPARTMENT HEAD INTERVIEWS

Purpose: The purpose of this interview is to obtain information on the process of establishing degree-granting programs in optics and photonics, and optical engineering at U.S. engineering schools. The intent in this document is to create an interview guide as Patton indicates is used "to ensure that the same basic lines of inquiry are pursued with each person interviewed" (Patton 2006).

To be completed by interviewer:
Date:
Name:
Position:
Department:

<u>Background</u>
When was the department founded?
ABET accreditation date (if obtained for B.S. Programs)? Accreditation for graduate programs?
Are there graduates of the program?

What were the primary motivations for establishing this department?

- Research interest of faculty
- University goal
- External funding
- Corporate interest

What factors within the college/university influenced either positively or negatively the establishment of the program?

- College/Department structure
- Curriculum format (specialty tracks, design of major core curriculum, special course offerings)
- Competition for funding
- Expertise

How were faculty recruited to the department? How did you come to chair the department?

- Networks utilized
- Schools/departments recruited from? Are any faculty in the department jointly appointed? In what other departments?
- Competition in hiring process

What was the process for designing the curriculum? How has it changed over time?

- Focus areas
- Influence of research on curriculum

- Influence of corporate/consumer needs on curriculum
- Influence of existing curriculum
- Prior optics education experience of faculty influencing curriculum

How were the first students recruited to the department?
- Students' prior knowledge of optics
- Career focus
- Emerging discipline opportunity
- Students in certain disciplines (ECE, Physics, Chem?)

What are the strengths of the department currently?
- Curriculum
- Research
- Production of graduates
- Relationships with industry

What are goals of improvement for the department?
- Changes to curriculum
- Research
- Preparation of graduates
- Recruitment of faculty
- Corporate participation

What will this program be and look like in 10 years?
- Number of students, faculty, etc.
- Labs and research activity
- Increased degree/program offerings
- Relationships with industry

APPENDIX C: RECRUITMENT E-MAIL FOR GRADUATE STUDENTS – SURVEY

This e-mail was sent to department heads or graduate program coordinators to distribute on student list serves.

Dear ________,

I hope this message reaches you well. A few weeks ago I interviewed you about the optics program at __________ and at the time we discussed an additional phase of the project which included a survey of students. If you would not mind distributing the survey link below to the students in your department I would greatly appreciate it. Please feel free to copy my on the distribution or insert my e-mail address as the "reply to" address for questions.

Optics Student Survey
https://vtengineering.qualtrics.com/SE/?SID=SV_3J18L7J5R3Qga2g

Best Regards,

Lauren D. Thomas

APPENDIX D: STUDENT SURVEY QUESTIONS

Optics Student Survey

Q23 Optics Student Survey

Q25 This study examines factors that impact how students choose to study optics. The results of this study will be used to better understand and improve optics education. Participation is completely confidential and voluntary, and you will not be required to submit any identifying information to participate. The survey should take no longer than 10 minutes to complete. By answering survey questions and submitting the survey, you are giving permission to use your data recorded in this study. The results of this study may be published in educational or engineering literature, or it may be presented in a course or at a conference, but no publication or presentation will contain information that will identify you. You must be at least 18 years of age to participate in this study. Beginning the survey is acknowledgement of the minimum age requirement. If you have any questions about this survey, please contact Lauren Thomas of the Virginia Tech Engineering Education Department at laurendt@vt.edu.

- ❍ I agree to continue with the survey.
- ❍ I do not agree to take the survey.

Q1 1. Prior to choosing your degree did you have any coursework experiences related to optics?

- ❍ No
- ❍ Yes. Please describe the class(es) ____________________

Q3 2. Prior to choosing your degree did you participate in any non-coursework activities that encouraged you to pursue optics (REU, lab/research experiences, co-ops, etc.)?

- ❍ No
- ❍ Yes. Please describe the activities. ____________________

Q6 3. What percentage of your completed coursework was in optics, photonics, and/or optical engineering? Consider undergraduate and graduate levels.

- ❍ 10% or less
- ❍ 20-30%
- ❍ 30-50%
- ❍ 50-70%
- ❍ 70% or more

Q7 4. What percentage of your completed coursework was non-optics related? Consider undergraduate and graduate levels.

- 10% or less
- 20-30%
- 30-50%
- 50-70%
- 70% or more

Q8 5. What percentage of your completed coursework was in physics? Consider undergraduate and graduate levels.

- 10% or less
- 20-30%
- 30-50%
- 50-70%
- 70% or more

Q9 6. What percentage of your completed course work was in electrical engineering?

- 10% or less
- 20-30%
- 30-50%
- 50-70%
- 70% or more

Q19 7. I take classes outside of my major department because:

The courses are required	❍	❍	❍	❍
The topics are interesting	❍	❍	❍	❍
The courses prepare me for graduate school	❍	❍	❍	❍
I need a break from my department/major	❍	❍	❍	❍
These courses are related to my minor/specialization	❍	❍	❍	❍
The ideas are related to my optics and photonics interests	❍	❍	❍	❍
I plan to use the learning material in my career	❍	❍	❍	❍
I can earn better grades in these courses	❍	❍	❍	❍
Other	❍	❍	❍	❍

Q20 8. I see relationships between my optics related courses and other courses

❍ All the time
❍ Frequently
❍ Sometimes
❍ Never

Q10 9. Select the factors that related to your decision to study optics:

Availability of the major	❍	❍	❍	❍
Interest in optics related technology	❍	❍	❍	❍
Family or friends suggested it	❍	❍	❍	❍
Teachers/Faculty	❍	❍	❍	❍
Scholarship/funding to study optics	❍	❍	❍	❍
Coursework	❍	❍	❍	❍
Other	❍	❍	❍	❍

Q24 10. I chose a career in optics because optics offers:

Unique career opportunities	❍	❍	❍	❍
Good pay opportunities	❍	❍	❍	❍
A way for me to influence future technology	❍	❍	❍	❍
Opportunities for success	❍	❍	❍	❍
A career path I really enjoy	❍	❍	❍	❍

Q11 11. What factors most encouraged you to study optics?

Q12 12. Please describe any challenges or factors that discouraged you from choosing to study optics:

Q22 13. What optics specialization are you most interested in?

- ❑ Optical systems
- ❑ Optoelectronics
- ❑ Imaging
- ❑ Optical materials
- ❑ Other ____________________
- ❑ Lasers
- ❑ Fiber Optics
- ❑ Quantum optics
- ❑ Biomedical optics

Q21 14. Please briefly describe your career goals.

Q13 15. What is your home department?

Q14 16. What college or university are you currently enrolled in?

Q15 17. What degree are you working toward?

- ❍ AS
- ❍ BS
- ❍ MS
- ❍ PhD
- ❍ Other ____________________

Q16 18. What is the highest degree that you will seek?

- ❍ Associate Level (AS, AA)
- ❍ Bachelor's level (BS, BA)
- ❍ Master's level (MS, MA, ME, MBA, etc.)
- ❍ Doctorate level/Terminal (PhD, DEng, MD, JD etc.)

Q17 19. Have you ever changed majors?

- ❍ No
- ❍ Yes, I switched from: ____________________

Q27 20. If you switched majors, why?

Q24 21. Age
- 18-23
- 23-29
- 30-40
- 40-50
- 50+

Q25 22. Sex
- Female
- Male
- Prefer not to answer

Q26 23. Race
- American Indian
- Asian & Pacific Islander
- Black & African American
- Hispanic, Latino and Spanish
- White (non-Hispanic)
- Other/prefer not to answer

Q26 This research will also include interviews and focus groups of optics students. If you would like to be interviewed or participate in a focus group please enter your name and e-mail address in the field below.

Q27 Thank you for completing our survey!

APPENDIX E: RECRUITMENT E-MAIL FOR GRADUATE STUDENTS – INTERVIEW

Recruitment E-mail for Graduate Students
Recruitment E-mail

Email #1

Subject: Invitation to Research Study About Photonics/Optics Students

Message:

Dear Graduate Students,

My name is Lauren Thomas and I am a graduate student in Engineering Education at Virginia Tech. Dr. ______ identified you as belonging to a group of graduate students who could provide valuable input for my research on optics and photonics programs.

The aim of my dissertation research is to understand how students become interested in optics/photonics and how their graduate experience influences their goals. An expected outcome is to improve graduate programs for students like you and those in your program.

I am emailing to ask you to participate in a 30-45 minute voice recorded interview about your graduate experience in optics/photonics. The interview is confidential and focuses on your individual experiences related to optics and photonics study. In order to participate in the research, please e-mail me and I will explain more about the study and the interview process.

I'll ask for a copy of your CV (current and old versions if you have them). Then, we will set up an interview via Skype, FaceTime, or Google Hangout.

I know it's not much, but in return for your participation I will send you a $20 Amazon gift card.

I hope that you choose to participate in my study!

Best Regards,
Lauren

APPENDIX F: FULL CODE BOOK

Strand	Code	Definition	Sub codes/examples	Example Segment
Intellectual	Contributions	Individual (or group) new or novel knowledge, discoveries, work, research products (McAlpine 2010)	〈 Lab 〈 Research 〈 Articles/publications 〈 Responsibilities	So I will tell you how it has help me become a good researcher. So you know my experience has been, I’ve been able to work with different projects you know, mostly related to optics and uh they haven’t restricted myself to working on a single topic, you know. I’ve done free space communication and before coming to America I worked in fiber optics and I got into polarization imaging, I worked in industry and solar technology so you know I - and I’ve taken different classes here in optics so overall I see myself, I see my next experience working in different fields of optics and you know the classes I have taken, have you know helped me to think like a good researcher, so that way. This is how I would explain how things have helped me. (Will 202-210)
Intellectual	Past experience	Opportunities to engage in activities, work experience, courses, or exposure prior to current enrollment	〈 Research experience 〈 Personal experiences 〈 Courses	In a sense I was always interested in studies, mostly sciences and uh there were opportunities in India, but I was also interested in actually in uh seeing things experimentally (Will 85-87)
Intellectual	Agency	Desire, capacity, actions to influence activities and individuals with whom we interact (Jazvac-Martek et al. 2011) The indiviudal drives their trajectory	〈 Seeking out information/ mentorship 〈 Ownership of education and career	I will answer this question being more of a theorist because an experimentalist would have a very different point of view because the resources that they need are very different from what I need. So as a theorist all I need are some good books and if I want to simulate I need a good computer but more than that I think it is the consistency of work. You have to work every day regularly. You don’t need to work long hours on a regular job and be very organized - that’s the most important thing, being very regular and organized. (Will 253-258)
Intellectual	Horizons for action	“The option for action seen as personally viable at any particular point.” (McAlpine 2012. The latent meaning here focuses on the individual's personal desire. These are less detailed and focus on a specific personal desire.	〈 Desire to reside in a certain city 〈 Interest in working in a specific industry 〈 Moving with family or a significant other	....Ok so in that way I began to know optics is really about promise or like industry. It was very promising at that time so when I began to consider like my future career or my future uh like area. I began to consider optics as my very important part of my future study or research. So I begin to prepare my graduate school tests at that time. So I was enrolled in another university in Beijing and I get to be like uh study optics and also in physics department. (Brian 33-38)
Intellectual	Individual ability	Content knowledge in subject area, skills in a specific technique, competence	〈 Knowledge of physics theories 〈 Experimental expertise	Uh you know I don’t think so, I was always interested - basically I’m a thinker you know the fact that I’m still doing theory, was very related to theory, although now I’m in the flight area now, is a is a reflection of basically my personality was. It’s just that I didn’t know I’d put my energy into science, though I was in science. The basic quality was in science you have to have a good mind to think. (Will 268-272)
Intellectual	Personal	Personal life aspects that influence the person’s career. Familial influences or knowledge of personal preferences.	〈 Family, significant other 〈 Personal preferences 〈 Hobbies	Um I also got into the University of Maryland physics program which is huge -except it’s really competitive and I realized I didn’t want that. I already had enough of that in undergrad. (Brooke 44-46)
Institutional	Opportunity structure	“What is understood or known to be available career opportunities” (McAlpine 2012). These are facilitated by an external body or group or are means to advance a person's career in a specific topic area.	〈 Future educational opportunities or careers 〈 Mechanisms for career development	I also went to the University of Arizona, the optical sciences center there to work as a visiting scholar for some time (Will57-58)
Institutional	Advisor	The functional role of the advisor: research oversight, funding, etc	〈 Lab/equipment 〈 Advising coursework and research effort of the student 〈 Resources specifically attached to the advisor	Yeah right. So I just you know talked to different professors in the department here and try to find out if someone has a project and the funding for that project. So you know I just found one who knew me because I had taken a class with him and he was you know, eager to take me. (Will 148-151)
Institutional	Department/college/ program	Program’s resources available to all students within the program	〈 Courses 〈 Shared resources/cooperative lab space 〈 Policies & exams 〈 Funding (e.g. scholarships/teaching assistantships) 〈 Admissions/enrollment options 〈 Reputation	I feel like Northern has a lot of administrative issues. I spent a lot of time trying to straighten out my paycheck and that sort of nonsense (Brooke 121-122) I got a master’s degree, it’s just my (indistinguishable) it’s loaded into my PhD program because I finished the coursework and that part can be - I got a degree for that, so I just get a degree for that. But so far I have finished my proposal defense, some of you call it a comprehensive exam so I am a PhD candidate right now. So now I am just working on my dissertation. Probably within one year, or something like that I will graduate (Brian 56-62)
Institutional	Lab	The primary space that the student and lab group work on a regular basis.	〈 Equipment 〈 Dedicated buildings	So for most of the experiment I want to do or most of the things I hope to do I think I can do. And the lasers and all the other better instruments are pretty good. I mean many things I still don’t use, and so there are other resources I never use that but I feel it’s good. (Brian 110-114)
Network	Opportunity structure	“What is understood or known to be available career opportunities” (McAlpine 2012)	〈 Individuals and others providing exposure to 〈 Mentors	I also went to the University of Arizona, the optical sciences center there to work as a visiting scholar for some time (Will 57-58)
Network	Advisor	The relational role of the advisor: support, encouragement, access to others in the field	〈 Introducing students to colleagues 〈 Providing personal support	And my choice of advisor, like my choice of Northern seemed to go the same way. I was really personality focused, I realized I would be spending more time with this person, or people than I would my own family. There was a professor who was doing, I wasn’t really sure what work he was doing because he had a small group obviously, I went and talked to him and realized I really liked talking to him and he was really excited about what he was doing (Brooke 190-203)
Network	Intellectual	Networks that provide field access for an intellectual contribution	〈 Collaborations 〈 Mentors	there was a professor at Binghamton, who was my undergraduate advisor, who was really into getting people to go to graduate school and pushing taking, helping us figure out what we were supposed to do for the physics GRE and all of that sort of thing so you know I was really interested in it and there was a professor who was really active into getting students into graduate school. (Brooke 20-24)
Network	Lab	The primary group that the student works with on a regular basis.	〈 Peer collaborations and mentors 〈 Program alumni career paths	Some of the interactions with other students is really important at Northern and was certainly important for me getting my research done because it allowed me to have lots of other sounding boards and people worked together a lot even across research groups. That was one of the more important things for getting things done. (Brooke 91-94)

APPENDIX G: BROOKE ANALYSIS

extended version

[redacted]

Google scholar page:
[redacted]

Education

Ph.D. Candidate, Optics, [redacted]

Relevant Courses: Radiation and Detectors, Geometrical Optics, Physical Optics, Instrumental Optics, Laser Systems, Nano-Optics, Quantum Mechanics, Quantum Optics, Opto-mechanics, Lens Design

Thesis submitted, [redacted]

[redacted]

B.S. Physics, [redacted]

Magna cum Laude, [redacted]

Research Experience

[redacted] **University** [redacted] [redacted] 2007-present

Advisor: Prof. [redacted]

Dissertation: Polarimetry and Beam Apodization using Stress-Engineered Optical Elements.

•Explored the mechanical and [redacted].

• Investigated unconventional polarization states and their propagation characteristics through theory, simulation and
experimental implementations.

[redacted] instrumentation, including snap-shot polarimetry and angular spectrum polarimetry.

• **Collaboration:** [redacted] identify new applications for polarization-related [redacted]

• **Collaboration:** Polarization [redacted] matrix polarimetry on highly stressed optical elements.

University of [redacted]
Undergraduate intern, [redacted]
• Constructed an optical tweezers [redacted]
• Adapted system to [redacted]

[redacted] **State University,** [redacted]
Undergraduate intern, [redacted]
• Built a system to investigate Magnesium [redacted]

Mentoring and Teaching Experience

[redacted] University [redacted]
Supervised undergraduate research intern: [redacted]
• Mentor and research guide to undergraduate intern [redacted] original optomechanical parts.

[redacted] **Optics, University** [redacted]
Teaching Assistant
[redacted] Graded homework assignments. Taught selected course subjects (polarization, coherence).
[redacted] Graded homework and laboratory

assignments.

Taught selected course subjects (basic programming definitions) and weekly laboratory sessions. [redacted]

Department of Physics, [redacted] University, [redacted] NY [redacted]

Laboratory Instructor

- Led Introductory Physics laboratory sessions.
- Taught basic experimental principles, demonstrated physical concepts and graded laboratory assessments.

[redacted]

Corps Member, [redacted]

- Taught Environmental Science in third grade classrooms and tutored [redacted]
- Coordinated and led physical service projects [redacted]

Journal Articles

[redacted] "Full Poincaré [redacted]

[redacted] "Full Poincaré [redacted]

[redacted] "Degradation of MgB2 [redacted]

Proceedings Articles

[redacted] "Star Test [redacted]

[redacted] "Full Poincaré [redacted]

[redacted], "Imprinting aberrations [redacted]

[redacted] "Pupil polarimetry [redacted]

[redacted] "Focal splitting and [redacted]

[redacted]

Skills

Language: English (native speaker), French written and oral fluency
Software (Fluent): Matlab, LaTex, Powerpoint
Software (Proficient): Code V, Nastran/Patran, Sigfit (FEM to Lens Design translation), Mathematica
Software (Some experience): Pro/E, Zemax, Labview, Excel, Photoshop
Laboratory: Free-space optical bench system construction, design and mechanical drawings of original optomechanics, polarimetry (both commercial and original systems), standard optical metrology (interferometery)

Awards and Fellowships

[redacted]
Best Student Paper [redacted]
[redacted] Student Travel Grant, [redacted]
[redacted] Outstanding Student Paper [redacted]
Dean's Fellowship, [redacted] [redacted]

Professional Activities

Student Advisory Board, Optical Engineering 2010
[redacted] SPIE Student Chapter, Outreach Co-chair
2009-2011
Council Member, OSA [redacted] House Co-Chair
2008-2010
Professional Society Member: SPIE, OSA
Reviewer for professional journals:
Journal of Optical Society of America A, JOSA B, Optics Express, Optics Letters, Applied Optics, Journal of Modern Optics


Amber
Network
horizons for action
agency
Past Experiences
institution
intellectual
opportunity structures

Strand (s)	Code	Subcategory	Line No.	Segment
Intellectual	Past Experiences	Education	7 -9	So I did my undergraduate in physics at a school that was very materials science based,
Intellectual	Past Experiences	REU	8-11	but I did a couple, I did an intern at the lab at the University at Binghamton and I also did two summer programs, the Research Experience for Undergraduates, REU, and I did one of them in um low-temperature physics so semiconductors and the second one was in optics at the University of Arkansas.
Network/Institution	Past Experiences	Lab	11-13	Then I really liked working with lasers and microscopes and all that, so then I started looking at doing optics and photonics in grad school. So I kind of just stumbled into it.
Network/Institution	Past Experiences	Lab	19-20	Well working in the labs in the summers I really enjoyed the atmosphere and the people being able to work on scientific equipment and all that
Network	Mentor		20-24	there was a professor at Binghamton, who was my undergraduate advisor, who was really into getting people to go to graduate school and pushing taking, helping us figure out what we were supposed to do for the physics GRE and all of that sort of thing so you know I was really interested in it and there was a professor who was really active into getting students into graduate school.
Intellectual	Personal experience	Family	29-31	My father was always really into science and scientific things so I spent a lot of time talking about that at home. So that is a more social support. Um other than that I kind of wandered my way and ended up here.
Network			42-44	So I applied to a few physics programs that had optics laboratories but the people at Northern are really nice and it's a very cooperative atmosphere.
Intellectual	Personal needs		44-46	Um I also got into the University of Maryland physics program which is huge -except it's really competitive and I realized I didn't want that. I already had enough of that in undergrad.
Institution	Resources		46-47	So Northern had a very good salary, or stipend I guess it's called. A very competitive stipend for the cost of living in Northern and the people were really nice.
Institution/Intellectual	Prestige & personal contribution		51-52	I mean because yeah, I only applied to places that were at the level I wanted to be at. Umm so I had already made my choice as far as academic prestige and all that.
Network	Personal needs		52-54	So when it got down to where I wanted to go after I was accepted to a few places to where I actually wanted to spend five years of my life and with people I wanted to spend five years of my life with.
Institution	Identification	Null interdisciplinarity	59-63	No it didn't really make a difference to me, no I didn't really see it being an issue there. I also applied and was accepted to the physics program at Rochester. The labs I visited were mostly the same for both programs. A lot of the professors in physics have overlapping or at least people doing optical physics type things have overlapping appointments so it didn't make that much of a difference except the people in that case even.
Institution/Network/Intellectual			73-75	Well I was in a small group so I had the resource of time of my advisor which not a lot of people have. I'm sure you're aware professors can be more scattered or less scattered or whatever.
Institution/Network/Intellectual	personal needs, individual contribution, lab		89-91	Definitely access to my professor, and having someone who was really concerned with my doing good research and having everything to do good research. That was definitely most important and um let's see.
Network/Intellectual	Lab		91-94	Some of the interactions with other students is really important at Northern and was certainly important for me getting my research done because it allowed me to have lots of other sounding boards and people worked together a lot even across research groups. That was one of the more important things for getting things done.
Intellectual	Agency	Lab	104-107	Yeah sort of did our own trajectories of research around polarization. So I was kind of the mechanical engineering, weird polarization type person. We all had our own space and we shared equipment and everything but it was all the small projects with independent research basically.
Institution	Hindrances		121-122	I feel like Northern has a lot of administrative issues. I spent a lot of time trying to straighten out my paycheck and that sort of nonsense
Intelletual/network	Loss of network	Becoming the senior graduate student	130-135	But I didn't feel like I was terribly afloat, oh um except up until the actual thesis time. You only do that at the end and you only do that once hopefully so anyone else who's already had some experience is gone immediately after so it's really hard to tell what you're supposed to do for that because you can't ask anyone else for that because they're already gone. And that was a lot more process heavy, sort of bureaucratic heavy than I was expecting so that just became a frustration at the end
Horizons for action			152-153	Partially that's geographically driven. Where I want to be is Montreal and they don't have a large - it's really a lot of microscopy and that sort of stuff.

Institution/Network/Intellectual			190-203	and professors to see what they were like. And my choice of advisor, like my choice of Northern seemed to go the same way. I was really personality focused, I realized I would be spending more time with this person, or people than I would my own family. There was a professor who was doing, I wasn't really sure what work he was doing because he had a small group obviously, I went and talked to him and realized I really liked talking to him and he was really excited about what he was doing. And so, I really went with like this guy is really cool with women, which there are one or two professors which – they aren't outwardly against women in science, but they don't know the vocabulary and so they say really awful things in that old dude way, and I just can't deal with that – I don't even want to. And this guy had a lot of female students and he was really popular with them and I met some of his current students and so I was like "Oh, let me see what you do." He had something interesting that I, something I thought was really cool, so you know I told him I might be interested and he had me talk to his grad students and such.
Network			229-231	Oh I definitely think it was the people I was around. I don't know if that was the first one or the last one. Being able to be around people who were supportive and interesting that sort of thing was definitely the most important contingent thing for me.

Brooke
Northern University
Transcript

INT: So I kind of quickly looked over your CV. The first question for you to really explain to me kind of how you got to where you are.

Brooke: Ok so where I am is optics and photonics education right? So I did my undergraduate in physics at a school that was very materials science based, but I did a couple, I did an intern at the lab at the University at Binghamton and I also did two summer programs, the Research Experience for Undergraduates, REU, and I did one of them in um low-temperature physics so semiconductors and the second one was in optics at the University of Arkansas. Then I really liked working with lasers and microscopes and all that, so then I started looking at doing optics and photonics in grad school. So I kind of just stumbled into it.

INT: Makes sense. So um, what made you first want to go to graduate school? You mentioned through those REUs in optics. Was there a specific you know experience or person that influenced you?

Brooke: Well working in the labs in the summers I really enjoyed the atmosphere and the people being able to work on scientific equipment and all that and then there was a professor at Binghamton, who was my undergraduate advisor, who was really into getting people to go to graduate school and pushing taking, helping us figure out what we were supposed to do for the physics GRE and all of that sort of thing so you know I was really interested in it and there was a professor who was really active into getting students into graduate school.

INT: Ok and do you think there is anything not on your CV that was really important to get you where you are?

Brooke: Humm. My father was always really into science and scientific things so I spent a lot of time talking about that at home. So that is a more social support. Um other than that I kind of wandered my way and ended up here.

INT: Ok so, what made you choose Northern University?

Brooke: I applied to a few schools, the other, well I'm sure you know what the optics schools are, but um I'm a very, very pale person, I'm a northern person so Arizona was out of the question just because I'd get sunburned. I've gotten sunburn in the fall in Canada

INT: Oh wow!

Brooke: So Arizona was pretty much out because of that. I did go and spend some time there and I did really like it, but it's just too hot for me. So I applied to a few physics programs that had optics laboratories but the people at Northern are really nice and it's a very cooperative atmosphere. Um I also got into the University of Maryland physics program which is huge - except it's really competitive and I realized I didn't want that. I already had enough of that in undergrad. So Northern had a very good salary, or stipend I guess it's called. A very competitive stipend for the cost of living in Northern and the people were really nice.

INT: So those were probably the bigger fit questions?

Brooke: I mean because yeah, I only applied to places that were at the level I wanted to be at. Umm so I had already made my choice as far as academic prestige and all that. So when it got down to where I wanted to go after I was accepted to a few places to where I actually wanted to spend five years of my life and with people I wanted to spend five years of my life with.

INT: Of course. So you mentioned that you also applied to some physics programs, so did it make a difference if your degree was going to be in physics or optics?

Brooke: No it didn't really make a difference to me, no I didn't really see it being an issue there. I also applied and was accepted to the physics program at Rochester. The labs I visited were mostly the same for both programs. A lot of the professors in physics have overlapping or at least people doing optical physics type things have overlapping appointments so it didn't make that much of a difference except the people in that case even.

INT: So now that you've finished, hoorah, congratulations, that's exciting.

Brooke: Thanks.

INT: What was the availability of resources for you to do your dissertation work – whether it was equipment, people, or libraries or anything, can you talk about the resources that were available to you?

Brooke: Well I was in a small group so I had the resource of time of my advisor which not a lot of people have. I'm sure you're aware professors can be more scattered or less scattered or whatever. Um I was given a computer to work on my thesis on. So I can bring with me when I left at first, I mean it belongs to the university I have to give it back, but I was able to keep a computer I could take out of the lab and do all of my latec-ing and all that fluff, do my corrections after I graduated without really being forced to give everything back immediately. I didn't go to the writing center or anything like that. As far as my availability for research I think I pretty much had access to all the equipment I needed.

INT: Ok, could you identify, maybe two of the most important things that helped you through your work?

Brooke: Through the whole process? Just the dissertation writing or the actual thesis research?

INT: Everything.

Brooke: Definitely access to my professor, and having someone who was really concerned with my doing good research and having everything to do good research. That was definitely most important and um let's see. Some of the interactions with other students is really important at Northern and was certainly important for me getting my research done because it allowed me to have lots of other sounding boards and people worked together a lot even across research groups. That was one of the more important things for getting things done.

INT: Okay, so within your research group was there a primary function that you had? Or specific duties or contributions or expertise

Brooke: Yes, we had a small group and we were only a maximum number of grad students ever was four.

INT: Oh wow

Brooke: Yeah sort of did our own trajectories of research around polarization. So I was kind of the mechanical engineering, weird polarization type person. We all had our own space and we shared equipment and everything but it was all the small projects with independent research basically.

INT: And was everyone in the same department?

Brooke: Yeah we were all optics people. In the past it wasn't always, but in the time I was there it was all optics people.

INT: Okay and do you think you will work with the people in your lab in the future? (295

Brooke: Will I work with them? I don't know about that, because we're all working in different places.

INT: So have there been any significant barriers to you doing the work that is expected of you?

Brooke: Humm…I feel like Northern has a lot of administrative issues. I spent a lot of time trying to straighten out my paycheck and that sort of nonsense, which took up time during the day, but other than that I don't think so.

INT: Okay, and like I guess as far as your matriculation like all the exams that you were expected to take you knew when they were, you were prepared, or you felt prepared and stuff like that?

Brooke: Yeah they're really good about that sort of thing and the last couple of years they've been better about really letting people know what the expectations are and such. But I didn't feel like I was terribly afloat, oh um except up until the actual thesis time. You only do that at the end and you only do that once hopefully so anyone else who's already had some experience is gone immediately after so it's really hard to tell what you're supposed to do for that because you can't ask anyone else for that because they're already gone. And that was a lot more process heavy, sort of bureaucratic heavy than I was expecting so that just became a frustration at the end. I had signatures to get and that sort of thing and in the summer that was especially difficult.

INT: Right. Okay. So what are your career goals? What are you planning on doing, I know you said you applied for a postdoc, but what do you see yourself doing immediately or further down the line?

Brooke: So um, I'm trying to do a bit more technical work, probably postdocing so I applied to a few grants and I have a lab that wants me. So um, that would be the immediate future. In transitioning more I really did free space optics and really esoteric projects, exotic polarization and stuff, so I really want to switch into something more systems based, and stick to fibers a little, I've never done anything fiber based. So after the postdoc I don't know if I really want to the academic route, I could see myself working in a company- like a medical device company, something like that.

INT: Is there any particular reason why you're interested in the medical field?

Brooke: Partially that's geographically driven. Where I want to be is Montreal and they don't have a large - it's really a lot of microscopy and that sort of stuff.

INT: How have your career goals changed throughout your time at Northern?

Brooke: I would say they haven't very much, I didn't really know what I wanted to do when I got there and I still don't know what I want to do. (laughs)

INT: I definitely understand that. I still don't know either.

Brooke: And when you get to that point people start asking too, you're supposed to know by now.

INT: They are just adding on to the pressure of the actual work you need to do right now.

Brooke: Yeah exactly. So um, Northern has not dissuaded me from academia specifically, I just was not very enthusiastic about that from the beginning. My career goal was clearly to be a grad student, I just didn't know what that was. I didn't know that's what it was called. Like I wanted to go to a place, and work in a lab, and meet new people and go to conferences. And was like oh that's grad school – okay.

INT: Yeah, it's not a bad life though.

Brooke: No, no it's not at all and I enjoyed my time there, but it's limited apparently

INT: So I guess could you comment on maybe on what alumni of your program do?

Brooke: Um, as far as I know quite a lot of alumni of the program go the government lab and industry route. I really don't know, let me think, most of the people I know don't go the postdoc route. Industry jobs seem to be pretty common, which are easier to find than say if you were a theoretical physicist or something. We're sort of an engineering program so people can get engineering jobs. I know a few people have gone to Naval Research Laboratory or Los Alamos or something.

INT: And when you were selecting your advisor, what was that process like?

Brooke: So, you mean at the institute or a process for me? I guess it's both. We do a full year of classes before looking for an advisor. You start looking for an advisor your second semester at Northern. I started looking at groups I would be interested in doing research for and talked to students and professors to see what they were like. And my choice of advisor, like my choice of Northern seemed to go the same way. I was really personality focused, I realized I would be spending more time with this person, or people than I would my own family. There was a professor who was doing, I wasn't really sure what work he was doing because he had a small group obviously, I went and talked to him and realized I really liked talking to him and he was really excited about what he was doing. And so, I really went with like this guy is really cool with women, which there are one or two professors which – they aren't outwardly against women in science, but they don't know the vocabulary and so they say really awful things in that old dude way, and I just can't deal with that – I don't even want to. And this guy had a lot of female students and he was really popular with them and I met some of his current students and so I was like "Oh, let me see what you do.'' He had something interesting that I, something I thought was really cool, so you know I told him I might be interested and he had me talk to his grad students and such.

INT: Okay, did your advisor's academic background – was that at all a factor?

Brooke: No, no it wasn't really

INT: And as far as his past students it was more so just their comfort with him and recommendation that was important?

Brooke: Um hum, um humm.

INT: Okay…I think you might have been the fastest to get through the questions. Well I guess the wrap up question is are there any important things we haven't talked about?

Brooke: Humm…hold on a second. I think I went for very non-academic reasons for doing things so, but I'm still happy in the end. I don't think it adversely affected me in any way, but I took people's personalities as opposed to their academic records or something. Because I was happy, that's what I would say at the end, because I chose to be with people I wanted to be around.

INT: If you had to identify one of three things as the most important would it be the relationships/network, the actual intellectual work and research and also your past experiences, or the institution itself and the institution is your advisor, Northern, the department, your group. Out of those three things what would you say is most important for getting you through this graduate school experience?

Brooke: Oh I definitely think it was the people I was around. I don't know if that was the first one or the last one. Being able to be around people who were supportive and interesting that sort of thing was definitely the most important contingent thing for me.

INT: Were you able to visit before you enrolled?

Brooke: Yeah.

INT: And were you able to visit the other schools you applied to?

Brooke: I did a couple visits and that's definitely what sealed the deal for me for Northern.

INT: Well that's actually everything. Did you have any questions for me?

Brooke: No, I don't think so.

Brooke
Northern University
Defended July 2012

Educational Background

Brooke recently defended her Ph.D. in optics at Northern University. At an interesting and exciting transition point in her career her possibly clearer perspective was captured for this study. Brooke grew up with a Dad who enjoyed and talked about science at home; she eventually enrolled in college in a physics program, but doesn't feel like the at home "social influence" was extremely important. During her undergrad years in a materials science based physics department Brooke was able to take advantage of three separate lab experiences: one on campus during the school year and two summer REUs, one in low-temperature physics, and one in optics. Brooke's lab experiences exposed her to the technology, equipment, and most important the people who would influence her decision to go on to graduate school and eventual completion of a PhD in optics. Upon completing her Ph.D. Brooke was not sure of the details of her next step and even said that her decisions were not very scientific, but her own clear personal needs and developing and leveraging relationships were prevalent in her pathway. Brooke's story intertwines all three parts of identity-trajectory in a very neatly packaged way.

Intellectual and Network

Brooke's undergraduate experiences in the lab gave her exposure to optics that would influence her eventual career path. These early experiences to carving out her own scientific niche along with the people involved in those experiences influenced her pathway. "Well, working in the labs in the summers I really enjoyed the atmosphere and the people being able to work on scientific equipment and all that" Brooke said of her REU experience in optics. This intellectual development experience (primarily because it was so early in her career and short term - the institution was not as important) and network with people in the lab is the first time in her interview that she really talks about how her pathway started. She also talked about an undergraduate professor who acted as a mentor and coach to help expose students to graduate school and the requirements to be accepted.

When it came time to select a graduate school Brooke's decisions were influenced by the people she would be around and collegial atmosphere that she would live and work in. Her personal awareness and positive network experience likely helped her awareness when it came time to find a program.

> "Um I also got into the University of Maryland physics program which is huge except it's really competitive and I realized I didn't want that. I already had enough of that in undergrad."

At one point in her interview Brooke even mentioned that the people she would be with were key because she would spend more time with them than her own family. Although agency is not a major theme in Brooke's story, she talks about her responsibility to direct her research within her small research group:

> "Yeah,[we] sort of did our own trajectories of research around polarization. So I was kind of the mechanical engineering, weird polarization type person. We all had our own space and we shared equipment and everything but it was all the small projects with independent research basically."

Speaking about the end of her graduate career Brooke expressed what seemed like some disappointment of not having the network of other graduate students, especially more senior students around her. As Brooke became the senior student and having recently defended the end of her graduate career was the first time that she felt that resources were lacking.

> "You only do that at the end and you only do that once, hopefully, so anyone else who's already had some experience is gone immediately after so it's really hard to tell what you're supposed to do for that because you can't ask anyone else for that because they're already gone. And that was a lot more process heavy, sort of bureaucratic heavy than I was expecting so that just became a frustration at the end."

Throughout her time she became so accustomed to cooperation and being able to seek perspective of others, that when there was no one else ahead to look to she seemed a little abandoned.

Intellectual, Network and Institution

There are a few times in which the institution (usually in the form of her advisor and the lab), network and intellectual contribution weave together almost seamlessly. Brooke's advisor and his availability and attention to her work and success came up frequently. She noted that most graduate students did not enjoy the ease of access and what seemed to be a very comfortable relationship with their advisors that Brooke enjoyed. Even others in the lab and other labs were what seemed to be mutual resources. While she rarely talks about her own intellectual contribution it is sewn into her work in the lab, with her advisor and others.

> "I started looking at groups I would be interested in doing research for and talked to students and professors to see what they were like. And my choice of advisor, like my choice of Northern seemed to go the same way. I was really personality focused, I realized I would be spending more time with this person, or people than I would my own family. There was a professor who was doing, I wasn't really sure what work he was doing because he had a small group obviously, I went and talked to him and realized I really liked talking to him and he was really excited about what he was doing. And so, I really went with like this guy is really cool with women, which there are one or two professors which – they aren't outwardly against women in science, but they don't know the vocabulary and so they say really awful things in that old

> dude way, and I just can't deal with that – I don't even want to. And this guy had a lot of female students and he was really popular with them and I met some of his current students and so I was like "Oh, let me see what you do.'' He had something interesting that I, something I thought was really cool, so you know I told him I might be interested and he had me talk to his grad students and such."

This quote from Brooke summarizing how she selected her advisor, and made sense of her trajectory really encapsulates all three strands of the theory. It's important to note that Brooke knew "the level I wanted to be at" when applying for programs, which eliminated other options (horizons for action & institutional). Self awareness, likely based on past experiences (intellectual), led her find the right people (network). Beyond the first elimination of institutions, the collegial environment became the most important to selecting a program. She mentioned she did not care much about the program differences between the optics and physics departments she considered - even within the same university (institutional). Her small lab group, positive relationships with other graduate students, and an advisor that she liked were key elements to Brooke's success in one of the highly competitive, at least from the outside, optics graduate programs.

APPENDIX H: WILL ANALYSIS

[redacted]

EDUCATION :

May 2006: MS Optical Sciences & Engineering,
ECE, [redacted]
Research area: Infrared Stokes vector Imaging & Free Space Laser Communication.

May 2001: MS Physics, [redacted]
India, major in Fiber-Optic Telecommunication.
[redacted]

May 1999: BS Physics, [redacted] India.

WORK EXPERIENCE:

Feb 2008 - Dec 2010 Optical Scientist.
[redacted] Technologies Inc. [redacted]
Responsibility: Laser cutting Solar cells, testing solar cells, building solar panels, testing solar panels.

Oct 2006-Dec 2007: Visiting Scholar, [redacted]
University [redacted]
Research Area: **Infrared Polarization Imaging.**
Motion-b[redacted]

- [redacted]
- Able to simultaneously correct both the problems using the [redacted]

[redacted]

Aug-Nov 2007: Optical Fabrication Technician,
[redacted] Corporation, [redacted]
Involved in fabrication and testing of optical components like

- Grinding and polishing of plano-convex, plano-concave, bi-convex, and bi-concave lenses.
- Polishing of torroidal lenses.

2004-2006: Research Assistant, ECE [redacted].
Research Area: **Infrared Polarization Imaging.**
[redacted]

2002-2004: Research Assistant, Center [redacted]
Research Area: **Free space laser communication.**
Demonstrated the [redacted]

- Achieved [redacted]
- Erbium-[redacted]
- Achieved a[redacted]

2001-2002: Project Associate, Physics [redacted]
[redacted] India.
Research Area: **Fiber optic pressure sensors.**
Demonstrated a novice fiber-optic pressure sensor system

- Using a fib[redacted]ch end placed in between two microbend plates.
- The property of equidistant spacing [redacted]
- [redacted]
- The work was published [redacted]

[redacted]

AREAS OF EXPERTISE Polarization Imaging, Image Processing, Fiber-Optic Communication, Free-Space Laser Communication, Fabrication and Testing of Optical Components, Solar cells.

MAJOR COURSES: Advanced Optics, Fiber-Optic Telecommunication, Physics of Semiconductor Devices, Laser Physics, Guided Wave Optics, Experimental Optics, Non Linear Optics.

PROGRAMMING SKILLS: Matlab, Fortran, Familiar with Zemax.

LANGUAGES: English, Spanish, Hindi.

PUBLICATIONS and PRESENTATIONS:

- [redacted] Motion-based [redacted]
- [redacted] Motion-based nonuniformity correction [redacted]
- [redacted] Reducing IFOV error [redacted]
- [redacted] Combatting infrared focal [redacted]
- [redacted] Modeling precision and accuracy [redacted]
- [redacted]: 2.5-Gbps amplified retro-modulator [redacted]
- [redacted] SMS fiber optic [redacted]

Will
Southwest State
August 2, 2012

INT: Great! So I got your resume and one thing that I'm really excited about with this study is really hearing people's stories and how they got into optics. And sorry if there's a lot of background noise I'm in Panera Bread because I just moved and I'm not you know at Virginia Tech right now and haven't turned on the internet at my house so it's kind of crazy.

WILL: Ok

INT: So the first thing I wanted to ask is just could you walk me through your educational background?

WILL: Yes, I had to, I had my bachelor's, you know I'm from India. Can you hear me?

INT: Yes

WILL: Yeah so, I don't think the video is that great. Do you want to do it on audio? Or because it could be easier that way?

INT: We can do that.

WILL: Ok let's do it on audio so that uh it's not something listening or talking. Ok? Yeah so - can you hear me?

INT: Yup!

WILL: Yeah so I have a bachelor's in physics from India from the lead university and then I got into master's in physics from Indian Institute of Technology in Delhi in India. And there for the first time there was uh, an emphasis on optics, mostly fiber optics and uh I did a (indistinguishable) I did the master's program. It's a 2 year program and in the final semester you had to do a project, like a thesis. And uh, you know I, I was working in the field of fiber optics so I was trying to develop a sensor based on fiber optics. And you know that's where mostly the uh, you know the motivation came to pursue higher education in optics. Uh and you know then I applied to, for a PhD programs over in the US from India so you have to you know you have to write GRE and TOEFL and all these stuff and then based on those scores you apply for different universities. So I applied for most of the optics programs in different optics departments. Optics itself is not a department so I applied to physics department because mostly because I come from physics background. Are you there? Lauren? Hello?

INT: Yes, I'm here. I just put myself on mute, but I'm listening. This is cool.

WILL: Okay. So uh and then I was accepted at Southwest State in the Optical Sciences PhD program here. And then uh you know I had the opportunity to work in different projects actually. As I came here I was offered a research assistant position in a project called free space optical communication and uh I was mostly doing experimental work in the lab, but they unfortunately after 2 years of working for my advisor he moved away

INT: Oh no!

WILL: To uh you know the Air Force base and you know being a non-American, you know being an Indian citizen I couldn't follow so uh anyway. So I ended up shifting my project to a different one but I didn't...uh it just adds to your experience and uh so I on the way I finished my master's in optics and I was working on different projects I was working on polarization imaging and then I was also, I also went to the University of Arizona, the optical sciences center there to work as a visiting scholar for some time and in between before finishing I took up a job as an optical scientist in a solar company in Tuscon, Arizona. I worked there for three years as an optical scientist. You know we were trying to build a company you know, based on solar technology

INT: Right

WILL: And uh you know these experiences helped me in in going through all these steps you know. And uh it was about time that I decided that I should stick to one project and finish up my dissertation, now I'm back at Southwest State working on a project called digital super resolution uh which tries to enhance the resolution of a camera. By collecting multiple, you know, frames of the same object

INT: ok yea you definitely have a very in depth experience in optics as far as your work experience and your school experience and its one thing I've found so far is a lot of people make a connection at different optics schools, so you know being at Arizona and you know being enrolled at SOUTHWEST STATE is pretty interesting.

WILL: Yeah you know I just have enough broadening and university enrollment and I'm also, I'm more interested in simulation but I'm working in experiments and already have a grasp of how to connect the theory and the real experimental side of stuff, that may help me in the long run. So yeah that's just uh yeah I'm still here and this is how I work through all my experience and stuff.

INT: mkay. So I want to bring you back to your undergrad years. So what made you want to go to grad school in the first place?

WILL: Uh well it's uh you know I was very, how should I say? In a sense I was always interested in studies, mostly sciences and uh there were opportunities in India, but I was also interested in actually in uh seeing things experimentally and in India to do not have so many opportunities to do experimental stuff. So after my bachelor's it was easy for me to go for a master's in physics, but after that I had to decide whether I wanted to continue doing, you know, going to grad school in India or come over here because my focus was more interest (indistinguishable) uh I thought US was more advantage uh you know experiments which you can really see how the physics is

INT: Yes, my background is in physics and then I switched to optical engineering too so. What were the main reasons that you chose to enroll at SOUTHWEST STATE? Are you there? Will?

WILL:I think I lost you for some time.

INT: Oh, ok . I think I only lost you for a little bit at the end. But I got the last part about coming to do experimental work, cause there's not a lot of opportunities in India.

WILL: Yes, um I just wanted to see the connection between what we read in books as theory and uh you know what would really be observed when doing experiments so it was one of the motivations of actually coming to the US. Because here there are enough opportunities you know labs with a good infrastructure that you can actually replicate what you study in books and try to see if you know you really see those things in the experiments and stuff .

INT: ok, so why did you choose to enroll at Southwest State?

WILL: Uh, it's just I only applied to 3 places and you know, this was the only place that you know that offered me assistantship and accepted me so that's why I was here.

INT: Ok And did you apply to other optics programs or was it

WILL: Yes I applied to the University of Central Florida the also have an optics program

INT: Mmm hm (346.2.1.120)

WILL: And I think I forgot there was one more university, Rochester you know so I didn't get into any of those universities so that's why I came here

INT: Ok so talking about your experience here at Southwest State and uh can you comment on the availability of resources to do your current work and your current research?

WILL: Yeah so most of my current research is theory and simulation and once in a while experiments. Regarding theory and simulation all you need are good books and a fast computer, which I have with me.

INT: Okay

WILL: But regarding experiments it's a very simplistic experiment which needs, all it needs is a camera on a translation station so that you can move the camera and I can easily find that in the lab here, so regarding my project the resources are here, you know to carry it on.

INT: okay and you have an advisor currently right?
WILL: Yes

INT: So when your original advisor left how did you select a new advisor?
WILL: Yeah you know for international students it is mostly because we do not get any scholarship here because most of the scholarships are for US citizens so we have to look for projects that are funded because we also have to survive.

INT: Right

WILL: Yeah right. So I just you know talked to different professors in the department here and try to find out if someone has a project and the funding for that project. So you know I just found one who knew me because I had taken a class with him and he was you know, eager to take me.

INT: Mkay, and are you a part of a research group?

WILL: Uh yeah, yeah, yeah. My advisor is Dr. Prasan, he is a physicist here and uh you know he has three students, but we all work on different projects yeah, but of course they are all connected in some way or the other. But mostly in theory and simulations most of the projects are independent projects. It's not like in an experimental project you have different you know - it's a big group who work on different (indistuinghable) very independent so my project is mostly in theory and simulations I am the leader of my project and I take advice from my adviser sometimes.

INT: Okay. So since you have been at New Mexico have there been any significant barriers to your ability to do your work and do what is expected of you as a graduate student?

WILL: Uh at Southwest State it's not - all I can say is that here the optics program, even though the strength of the optics program here, at least from my perspective since I like to see things more from the deeper understanding here -

-disconnected-

INT:

WILL: So I was telling you that here the limitation is that the group is not that big. What this school has to offer the optics community or the optics students compared to other schools, like if you go to Arizona the optics program is very big, but here is that you know the physics department is involved in everything. My understanding is mostly based on theory and I like that is available more here, but at other schools it's mostly engineering schools and they are mostly involved in the engineering aspect of the problem. So I don't know, it's a trade off. It's okay, my project has - my advisor is great you know and the theory and math of the project you know. And I have simulated and tried to see if I can experimentally demonstrate what I am proposing. But definitely this program is not that wide or big of a community.

INT: Right. That was one thing. I was interviewing Dr. Lester probably almost eight or nine months ago and it was really interesting to hear about the set up of the program there so I was really excited that you and some other people responded because I really wanted to get your take on that. So uh, what are your career goals?

WILL: Well after doing this well my you know I don't set it up as my career but I set it up as my interest that will take me someplace so I am more interested in research, more of a you know theory based research which makes me more suited in the university and NASA lab in Langley. Mostly I would go after my PhD to a postdoc for two or three years and then try to see if I can get a faculty or a national lab. I will see, other than industry though.

INT: So how has your work so far really helped establish yourself as an emerging academic and researcher really?

WILL: Well uh you know some people are basically researchers and you have to make researchers and everything else kind of flows along with it. In administration you have to do other jobs and administration and so on but mostly your baseline is good in research. So I will tell you how it has help me become a good researcher. So you know my experience has been, I've been able to work with different projects you know, mostly related to optics and uh they haven't restricted myself to working on a single topic, you know. I've done free space communication and before coming to America I worked in fiber optics and I got into polarization imaging, I worked in industry and solar technology so you know I - and I've taken different classes here in optics so overall I see myself, I see my next experience working in different fields of optics and you know the classes I have taken, have you know helped me to think like a good researcher, so that way. This is how I would explain how things have helped me.

INT: Yeah that was one thing when I was looking over your CV it just have that breadth within optics and that's one thing that I've been trying to explain - I'm in engineering education and trying to explain to people that are not in optics and don't even understand it the breadth of work that we do. You're traversing from pure science all the way to completely applied engineering.

WILL: yeah, it's more of an applied science

INT: So that's uh, really the bulk of my interview. What do you think are some important things that we haven't discussed as far as your experiences within the field and also your experiences at SOUTHWEST STATE?

WILL: Really every school has some strengths and weakness. And I think that SOUTHWEST STATE has some because I have seen some other universities and I've seen industry also. Me and a group of 15 or 20 people were trying to build a company based on solar energy so I've had some wide experiences and now I can evaluate what SOUTHWEST STATE as a school and the optics program what it provides to the students and what it is unable to provide to the students so I think one of the things is you know the people here, the professors here mostly from the physics department they are good in their work and their teaching and so on uh, but the optics program here is not that wide. It's not that big of a community so uh it's limited. We have focus on semiconductors mostly there is some there is a good focus on quantum optics and uh there's quite a few good people in the physics department. They have recently started something called a uh, the imaging track. I am from the imaging track so you know we try to work in problems where we you know uh, get images from different cameras and you know try to see if it can reduce the noise or enhance the resolution or so on which I think has really just started here recently. So I think it is moving the right direction in terms of widening the field to attract students with different interests. So I think it's a small community trying to grow itself. So yeah it's okay.

INT: What do you think are the most important things in your work as a graduate student? Like things people resources, anything.

WILL: What is the most important thing?

INT: Yeah, or maybe two or three.

WILL: I couldn't follow it completely - your question?

INT: So like if you had to name a couple things that were really important as far as your development as a graduate student and researcher what would it be?

WILL: I will answer this question being more of a theorist because an experimentalist would have a very different point of view because the resources that they need are very different from what I need. So as a theorist all I need are some good books and if I want to simulate I need a good computer but more than that I think it is the consistency of work. You have to work every day regularly. You don't need to work long hours on a regular job and be very organized - that's the most important thing, being very regular and organized. If you ask an experimentalist they will talk about all the other resources because they need a lot of money to have their system and so on. At least for my project I don't need those things. It is more of a personality trait that helps you get somewhere instead of depending on machines and stuff.

INT: Agreed. The last question I do want to ask is when you were a freshman in college what did you think you were gonna do and is what you're doing now drastically different than that?

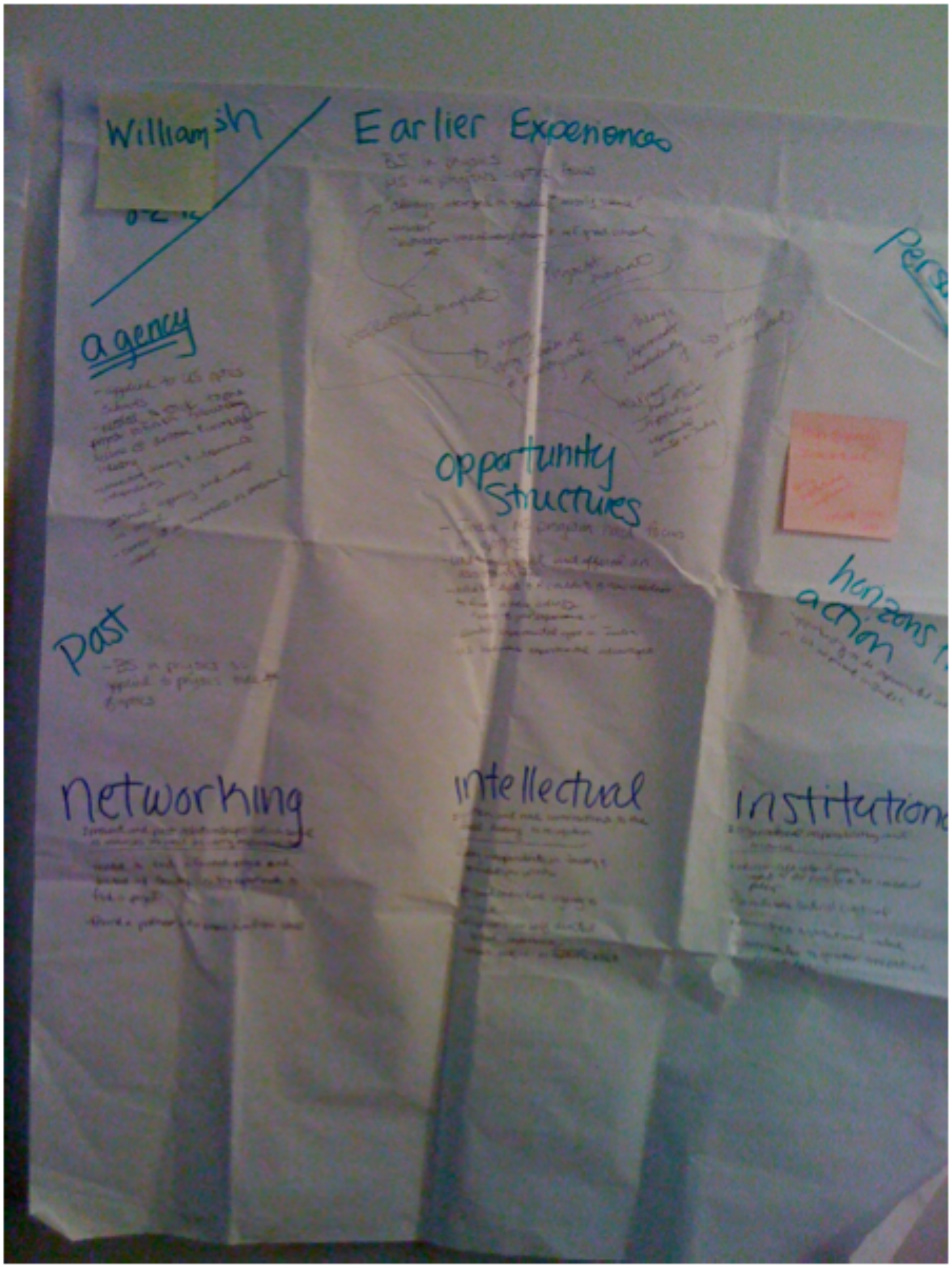
WILL: Uh you know I don't think so, I was always interested - basically I'm a thinker you know the fact that I'm still doing theory, was very related to theory, although now I'm in the flight area now, is a is a reflection of basically my personality was. It's just that I didn't know I'd put my energy into science, though I was in science. The basic quality was in science you have to have a good mind to think.

INT: Umhum

WILL: Yeah so if I look back at my freshman year in undergrad I could foresee that I might go for higher education in science or physics. And I think that motivation was always there

INT: Very cool. Well that is all the questions I have for you - do you have any questions for me?

WILL: Well no. I think I have told you my experience and you know how I ended up here and so on.


William
Earlier Experiences
agency
opportunity structures
past
networking
intellectual

Strand (s)	Code	Subcategory	Line No.	Segment
Institutional	opportunity structures		29-31	got into master's in physics from Indian Institute of Technology in Delhi in India. And there for the first time there was uh, an emphasis on optics, mostly fiber optics
Intellectual	Past		29	Yeah so I have a bachelor's in physics from India from the lead university
Intellectual	Past		33-36	know I, I was working in the field of fiber optics so I was trying to develop a sensor based on fiber optics. And you know that's where mostly the uh, you know the motivation came to pursue higher education in optics.
Intellectual	Agency		36-38	Uh and you know then I applied to, for a PhD programs over in the US from India so you have to you know you have to write GRE and TOEFL and all these stuff and then based on those scores you apply for different universities. So I applied for most of the optics programs in different optics departments
Institutional	opportunity structures	Individual agency	39-40	Optics itself is not a department so I applied to physics department because mostly because I come from physics background
Institutional		multiple project areas	46-47	And then uh you know I had the opportunity to work in different projects actually.
Network	lab		47-48	As I came here I was offered a research assistant position in a project called free space optical communication and uh I was mostly doing experimental work in the lab
Institutional	advisor		49	unfortunately after 2 years of working for my advisor he moved away
Institutional	constraints		53-54	To uh you know the Air Force base and you know being a non-American, you know being an Indian citizen I couldn't follow
Intellectual		positive construction of negative situation	54-55	So I ended up shifting my project to a different one but I didn't...uh it just adds to your experience
Institutional	opportunity structures	external	57-58	I also went to the University of Arizona, the optical sciences center there to work as a visiting scholar for some time
Network	Intellectual	Opportunity structure	58-61	in between before finishing I took up a job as an optical scientist in a solar company in Tuscon, Arizona. I worked there for three years as an optical scientist. You know we were trying to build a company you know, based on solar technology
Intellectual	lab	Individual agency	65-69	And uh you know these experiences helped me in in going through all these steps you know. And uh it was about time that I decided that I should stick to one project and finish up my dissertation, now I'm back at Southwest State working on a project called digital super resolution uh which tries to enhance the resolution of a camera. By collecting multiple, you know, frames of the same object
Intellectual	opportunity structures		76-80	Yeah you know I just have enough broadening and university enrollment and I'm also, I'm more interested in simulation but I'm working in experiments and already have a grasp of how to connect the theory and the real experimental side of stuff, that may help me in the long run. So yeah that's just uh yeah I'm still here and this is how I work through all my experience and stuff.
Intellectual	past		85-87	In a sense I was always interested in studies, mostly sciences and uh there were opportunities in India, but I was also interested in actually in uh seeing things experimentally
Intellectual	opportunity structures		87-88	in India to do not have so many opportunities to do experimental stuff.
Intellectual	Horizons for actions		90-92	, going to grad school in India or come over here because my focus was more interest (indistinguishable) uh I thought US was more advantage uh you know experiments which you can really see how the physics is
Network	lab	desired access	104-106	um I just wanted to see the connection between what we read in books as theory and uh you know what would really be observed when doing experiments so it was one of the motivations of actually coming to the US.
Intellectual	lab		106-109	Because here there are enough opportunities you know labs with a good infrastructure that you can actually replicate what you study in books and try to see if you know you really see those things in the experiments and stuff .
Institutional	enrollment options	Optics programs only	113-114	Uh, it's just I only applied to 3 places and you know, this was the only place that you know that offered me assistantship and accepted me so that's why I was here.
Institutional	lab	resources	128-130	Yeah so most of my current research is theory and simulation and once in a while experiments. Regarding theory and simulation all you need are good books and a fast computer, which I have with me.
Institutional	lab	resources	134-136	But regarding experiments it's a very simplistic experiment which needs, all it needs is a camera on a translation station so that you can move the camera and I can easily find that in the lab here, so regarding my project the resources are here, you know to carry it on.

Institutional	constraints	limited funding resources	142-144	Yeah you know for international students it is mostly because we do not get any scholarship here because most of the scholarships are for US citizens so we have to look for projects that are funded because we also have to survive
Network	advisor		148-151	Yeah right. So I just you know talked to different professors in the department here and try to find out if someone has a project and the funding for that project. So you know I just found one who knew me because I had taken a class with him and he was you know, eager to take me.
Network	advisor	lab	155-157	Uh yeah, yeah, yeah. My advisor is Dr. Prasan, he is a physicist here and uh you know he has three students, but we all work on different projects yeah, but of course they are all connected in some way or the other.
Intellectual	lab	research	157-161	But mostly in theory and simulations most of the projects are independent projects. It's not like in an experimental project you have different you know - it's a big group who work on different (indistuinghable) very independent so my project is mostly in theory and simulations I am the leader of my project and i take advice from my adviser sometimes.
Institutional	contstraints as strengths		174-177	: So I was telling you that here the limitation is that the group is not that big. What this school has to offer the optics community or the optics students compared to other schools, like if you go to Arizona the optics program is very big, but here is that you know the physics department is involved in everything
Intellectual	theory emphasis		177-180	My understanding is mostly based on theory and I like that is available more here, but at other schools it's mostly engineering schools and they are mostly involved in the engineering aspect of the problem. So I don't know, it's a trade off.
Institutional	advisor	resources	180-181	. It's okay, my project has - my advisor is great you know and the theory and math of the project you know
Intellectual	contributions		181-182	And I have simulated and tried to see if I can experimentally demonstrate what I am proposing.
Intellectual	opportunity structures		190-194	: Well after doing this well my you know I don't set it up as my career but I set it up as my interest that will take me someplace so I am more interested in research, more of a

Intellectual	lab experiences		202-210	So I will tell you how it has help me become a good researcher. So you know my experience has been, I've been able to work with different projects you know, mostly related to optics and uh they haven't restricted myself to working on a single topic, you know. I've done free space communication and before coming to America I worked in fiber optics and I got into polarization imaging, I worked in industry and solar technology so you know I - and I've taken different classes here in optics so overall I see myself, I see my next experience working in different fields of optics and you know the classes I have taken, have you know helped me to think like a good researcher, so that way. This is how I would explain how things have helped me.
Institutional	constraints	overcome with agency	224-225	Really every school has some strengths and weakness. And I think that SOUTHWEST STATE has some because I have seen some other universities and I've seen industry also.
Intellectual	opportunity structures		226-227	Me and a group of 15 or 20 people were trying to build a company based on solar energy so I've had some wide experiences and now
Institutional			227-229	I can evaluate what SOUTHWEST STATE as a school and the optics program what it provides to the students and what it is unable to provide to the students
Network	Use of other's intellectual strands		229-234	I think one of the things is you know the people here, the professors here mostly from the physics department they are good in their work and their teaching and so on uh, but the optics program here is not that wide. It's not that big of a community so uh it's limited. We have focus on semiconductors mostly there is some there is a good focus on quantum optics and uh there's quite a few good people in the physics department.
Intellectual	Agency		253-258	I will answer this question being more of a theorist because an experimentalist would have a very different point of view because the resources that they need are very different from what I need. So as a theorist all I need are some good books and if I want to simulate I need a good computer but more than that I think it is the consistency of work. You have to work every day regularly. You don't need to work long hours on a regular job and be very organized - that's the most important thing, being very regular and organized.
Institutional	lab	resources	259-261	If you ask an experimentalist they will talk about all the other resources because they need a lot of money to have their system and so on. At least for my project I don't need those things.
Intellectual	personal		261-262	. It is more of a personality trait that helps you get somewhere instead of depending on machines and stuff.

Intellectual	Individual ability		268-272	Uh you know I don't think so, I was always interested - basically I'm a thinker you know the fact that I'm still doing theory, was very related to theory, although now I'm in the flight area now, is a is a reflection of basically my personality was. It's just that I didn't know I'd put my energy into science, though I was in science. The basic quality was in science you have to have a good mind to think.

Analysis: William

Educational Background

Will is an advanced PhD candidate in his optical science and engineering program, with varied experience in academia and industry. Will earned his bachelor's and first master's degree in physics in his home country of India and says he was "always interested in studies, mostly science" in his pre and early college years. Will earned his bachelor's degree and immediately moved on to his master's degree at another university. His master's work was in fiber optics and during that time he decided that pursuing a PhD was his next step. He applied to three optics departments in the US and was accepted and funded with a research assistantship at Southwest State University with a specific advisor.

After two years of coursework and research Will's advisor took a new position working in a Department of Defense lab. Since Will is not an American citizen going with his advisor was not an option. He calmly explains looking for and finding a new advisor at Southwest State without the expected frustration that most graduate students express when major changes in their program occur. At one point in his career Will left for a visiting scholar opportunity at Southern College, another prestigious optics program. Soon after that appointment he worked with a group to grow a new solar technology company. After some time and experience, Will returned to Southwest State to finish his PhD work.

Institution and Opportunity Structures

Institutions provided access to Will's intellectual development while an undergraduate and master's student in India and through his first appointment at Southwest State in a research assistantship. The extent, however that Will describes the institution's value toward his intellectual development is limited:

> "My advisor is Dr. Prasan, he is a physicist here and uh you know he has three students, but we all work on different projects yeah, but of course they are all connected in some way or the other. But mostly in theory and simulations most of the projects are independent projects. It's not like in an experimental project you have different you know - it's a big group who work on different (indistinguishable) very independent so my project is mostly in theory and simulations I am the leader of my project and I take advice from my adviser sometimes."

Will's natural disposition toward theoretical research required little support from institutions other than the space and minimal resources to do his work. The institution however provides Will with the opportunity structures for his intellectual identity. His physics program in India provided the first opportunity structure with a physics program with emphasis on optics. When he chose to apply to Southwest State their unique program structure required that he picked a program. As a physics major Will comfortably chose to apply to the physics department's side of the optical science and engineering program.

After his advisor left Will took an opportunity as a visiting scholar at Southwest State's college of optical science and engineering. The transition between optics programs, (and other participants) continue to demonstrate the interrelationships between programs for students and faculty. A different type of institution, a start-up company, facilitated another development opportunity for Will. He does not explain how he really got involved in the company, but he did spend about three years working with the small group as an optical scientist. After time there he decided to go back to Southwest State to finish his degree.

Agency and Intellectual

Will talks about his experience in ways that demonstrate agency; he as an individual took the responsibility to develop his career. How he speaks about his experience is most important; what he says indicates how he uses his physics and optics knowledge. Throughout his interview Will almost never referenced the input of others in his pathway. His knowledge as a researcher and theorist are his main strength which is prevalent throughout his interview. These two statements are possibly the best way Will describes his own agency and capitalization of opportunity structures:

> "Yeah you know I just have enough broadening and university enrollment and I'm also, I'm more interested in simulation but I'm working in experiments and already have a grasp of how to connect the theory and the real experimental side of stuff - that may help me in the long run. So yeah that's just uh yeah I'm still here and this is how I work through all my experience and stuff. "

> "Uh you know I don't think so, I was always interested - basically I'm a thinker you know the fact that I'm still doing theory, was very related to theory, although now I'm in the flight area now, is a is a reflection of basically my personality was. It's just that I didn't know I'd put my energy into science, though I was in science. The basic quality was in science you have to have a good mind to think."

Identity-Trajectory

Throughout his story two features of the institution and intellectual strands are prevalent: opportunity structures and agency. Will's career decisions, and the way he talks about his career, focus on career opportunities that could be ahead. He also discusses his passion for theory which seems to be based on very internal, intellectual drivers. Will clearly owns his career development and takes direct responsibility for his progress. He is very sure in his intellectual ability, and has high agency which enables him to take advantage of the opportunity structures that become available to him. He also gains in knowledge and experience within those opportunities. While an end goal may not be in mind for Will, his personal agency and willingness to seek and take advantage of opportunities seems to drive him.

Throughout his progress Will talks about being in the optics program, but has a strong affiliation, and may consider himself a physicist. He mentioned the reason he wanted to come to the US was for experimentation opportunities, which he clearly takes advantage of throughout his trajectory, but at times seems dismissive of engineering focused optics departments. There may have been some personal change in priorities once more experimental opportunities were secured. Will says that access to experimental options was important for his decision , yet focuses primarily on simulation and theoretical work. There is however no doubt that Will gained valuable experiences in labs to contribute to his competitiveness and perspective.

APPENDIX I: BRIAN ANALYSIS

Resume

NAME: [redacted]
Gender: Male
Date of Birth: [redacted]
Place of Birth: [redacted] **China**
Address: [redacted]
Mobile Phone: [redacted]
E-mail: [redacted]

Education

August, 2006 – July, 2010 [redacted]
Master of Science, Optical Science & Engineering
Course work degree, no thesis
August, 2002 – July, 2005 [redacted]
Master of Science, Optics
Thesis title: Study on Refractive Index Measurement Surface Plasmon Resonance Sensor
September, 1998 – July, 2002, [redacted]
Bachelor of Science, Application Physics

Research Experience

June, 2007 – now Research assistant at [redacted]
Experimental and theoretical study of the transient electron temperature and density relaxation properties in laser induced plasma.
Study the damage threshold of thin dielectric films with femtosecond laser.
September, 2004 – June, 2006 Research assistant at Tsinghua University
Measurement of small refractive index change of air with surface plasmon resonance sensor.

Awards

August, 2006 – May, 2007 Teaching assistantship at [redacted]
June, 2007 – now Research assistantship at [redacted]

Publications

1. [redacted] "Determination of [redacted]

Interview Brian
Southwest State
August 2, 2012

Int: So I really enjoyed looking at your CV uhm, one thing that I'm really learning is that people have such diverse backgrounds. I mean my background is physics and optical engineering and I switched over to engineering education for my PhD and it's kind of cool to see the different ways that people get into the field.

So the first question is could you just walk me through your CV?

Brian: Say that again? Are you asking me some question?

Int: Yes, so could you just explain to me your educational background?
Brian: Um educational background? Let me open my CV I just send to you, so wait a second. Uh let me see. hold on. So you want to know something about my educational background?

Int: Hm hum

Brian: So I .. From college or what? I think that's easier for me. I went to college from the bottom up in 1998 I went to the University of China from there I received my bachelor degree and I think the major name should be applied optics, physics something. It's just a general physics major and in advanced education process (indistinguishable)

Int:Oh could you repeat that? It was going in and out.

Brian: (indistinguishable)

Int: Do you want to switch to voice?

Brian: Yeah let's do that. ....Ok so in that way I began to know optics is really about promise or like industry. It was very promising at that time so when I began to consider like my future career or my future uh like area. I began to consider optics as my very important part of my future study or research. So I begin to prepare my graduate school tests at that time. So I was enrolled in another university in Beijing and I get to be like uh study optics and also in physics department. So that takes me roughly three and a half. I think three years to get a masters degree there. And I worked in the lab there not as a research assistant I worked in the lab one more year until I went about to the United States. And in the graduate school there I really got to know how to do research and uh and I learned how to like model, like the research aspect. I spent a lot of my energy in doing research and uh and I so at the end of that I was considering if I would stay in China or go abroad to find another program, to explore more. At that time one of the questions which make me very interesting I noticed the United States, the researchers in the United State are very sophisticated and prudent, not only in optics but every aspect. I wanted to know the reason why they are so good at that. like at different research, or industry or any other area so I came here.

And began my explore in the United States I spent the last ten years (indistinguishable) So that is a rough history of my last ten years.

Int: Well is there anything not in your CV that might add to where you are now?

Brian: Uhm No it's uh like my, let me see yeah. On my CV I said from 2009-2010 I got a master's degree, it's just my (indistinguishable) it's loaded into my PhD program because I finished the coursework and that part can be - I got a degree for that, so I just get a degree for that. But so far I have finished my proposal defense, some of you call it a comprehensive exam so I am a PhD candidate right now. So now I am just working on my dissertation. Probably within one year, or something like that I will graduate

Int: Awesome. yeah I'm around the same time so I'm hoping to finish in a little less than a year but we'll see

Brian: it always changes

Int: Yeah it does. So when did you first consider going to graduate school? Was it um as an undergrad, instead of going to industry maybe? What made you want to go to graduate school?

Brian: Hmm I think since maybe the third year in my college and I begin to consider my future I'm going to graduate so to find a job or continue my education. So and At that time in China, more people went to work after their college and less people continue to go to graduate school. But I'm kind of like people who like to do research or kind of like interested in more like academic treatment. my future goal maybe at that time is to be more involved in science and research, maybe as academia but I wanted to have more education.

Int: Ok So where there any specific people that introduced you to optics and photonics?

Brian: I would say some people, but I didn't remember. There are some people I remember I make decision which major I want to choose I did ask several professors in my college to help make a decision. And at that time they suggested that optics is a choice, a pretty good choice. At the time i didn't know too much about optics but it looks good, and it was just a master's degree so it's good choice to know more so I choose optics

Int: So how did you choose to enroll at Southwest State?

Brian: Ah that's very - also I applied to several schools in the United States including Georgia Tech, University of Arizona and University of Central Florida. They all have a pretty good optics program. and I got a scholarship, not a scholarship, an assistantship here. so I choose to come here. I also got - I remember I got admission in university of central Florida but I didn't get an assistantship so I didn't go there.

Int: So can you comment on the availability of resources that you need to pursue your current work?

Brian: Say that again, I'm not quite understand you.

Int: So I guess um whether it is coursework, lab equipment or expertise from faculty what is the availability of resources to help you do your work?

Brian: Um I think the resources here I mean that it's general. It's pretty good because I think the program in this university has been develop more than twenty years or thirty years I don't know the exact date. So the research experiment. I mean I do experiment everyday so I'm talking more the experimental equipment. So far most of the experiment I want to do or most of the things I hope to do I think I can do. And the lasers and all the other better instruments are pretty good. I mean many things I still don't use, and so there are other resources I never use that but I feel it's good.

Int: ok what are two important things that facilitated your work as a graduate student?

Brian: Oh say that again, what's two things?

Int: Important things, or people or resources that really helped you do your work for your dissertation?

Brian: Oh uh...I think...the first one is -the first one I would say I would put the first to my faith. I don't know I mean I mean this is totally - I am a Christian and uh the faith, I think I look back to my several years I think my Christian faith is the first big element to support me and another would be my advisor. Mhhm

Int: Very good - I like that. So how did you select your advisor?

Brian: Hmm that's ah (laughs) I - before I came here I search - before I was enrolled I began to search on the internet and to look up the professors and their research background and the first year I was a teaching assisting in the summer semester, before the summer semester in the spring semester I begin to look for professors. I asked several professors and they don't have position available so I went to my present advisor his research projects, some of them my interests - like I did something related to his research. I went to talk with him and he you can work in my lab for the summer so I try and I keep in that lab, so it's not too much to talk. But I think, the big thing in my at that time probably its the funding, because at that time some professors don't have much money to support more people. But I didn't talk to my professor about the funding. He has the funding so he supported me. And I began to do research in the labs for him.

Int: Ok - are you a part of a research group?

Brian: oh yeah

Int: So within your group what's your primary function as far as contributions, duties and expertise?

Brian: um my part is, uh like to realize the ideas to do experiment, uh I don't know like, maybe you have some idea. I'm the kind of people who stays in the lab all day. (laughs)

Int:(laughs) that's good

Brian: excuse me but I have some people knock on my door - I have to check is that okay for you?

Int: Yeah that's fine.

Brian: okay go ahead

Int: okay uh let's see, I only need a second to get distracted. Is everyone in the same department in your lab?

Brian: uh well let me see. Yeah we're all in the physics department.

Int: And I guess going on into the future do you see yourself working with them or collaborating with them when you all graduate and go off to do great things?

Brian: Yeah, a lot of times, there is a little bit. My professor has some cooperation with some university in Germany so there are exchange students come to my lab almost every year. So cooperation is very often quite often because they just stay here for just one semester usually one semester so they have to know, get familiar with the lab and after they left we have to take over the things that they did. that's a lot of cooperation yea.

Int: Do you think there have been any barriers for your ability to do what is expected of you as a graduate student?
Brian: uh you mean some barriers, which that slower? a barrier to what?

Int: any barriers that would help you do the work that's expected of you. It could be in the department, university, you know personal - anything.
Brian: I still don't understand the question, let me explain to see if I understand the question. You mean something that I would if I was good at those aspects it would be better right? For my research or for my study is that true?

Int: Well yes and no - I'm kind of looking like for things like qualifying exams things were those really a hindrance as far as your progress or you know getting equipment on time or um were there specific classes that were a real challenge? Were there any things that were a barrier that negatively influenced your work?

Brian: Uh yeah let me think - uh like - I think not too much but one aspect I want to talk is uh, like kind of like my language. English is not my native tongue and uh I experience some even right now I'm still not quite there. I understand the questions but for communication American people communication style and Chinese people communication style is kind of the big thing. But I do experience language I would say communication skills I would say is one aspect of the barriers in my past years and other things Io would say. Another thing is our equipment sometimes right now it is in the status that some equipment isn't work and we send it back for repairment and it takes a while. (laughs)

INT: (laughs) yeah

Brian: And uh that really impacts the progress of my experiment
INT: (laughs) I understand completely - um let's see, what are your career goals what do you see yourself doing after you finish?

Brian: uh (laughs) I mean uh the more close to my like finishing year the more I don't know what to do (laughs)
INT: I agree

Brian: I mean uh from this past several years uh I see myself my good things, my best things and I aim to position myself, not a very good uh like researcher or productive researcher, but there are some good things that I like to do things very carefully. I like to find out the reasons very carefully. I may be I may be doing some research, but I don't think I would do some work that is very intense. I do feel overwhelmed in the past several years some time or some period of the time. So I would expect myself to do some research, but not very intense. Maybe work in the university maybe teach and not a very promising goal future maybe I would not totally be in academic area and just go to industry area and do something else, more like in the engineering aspect instead of creating new ideas, like creating new things, exploring new principles maybe that's my good thing should go. Like working to improve things like even uh I'm still trying to explore myself. This is still a very hard question to answer

INT: so I guess were there any major points at your time at Southwest State that changed your goals? Or another way to look at it when you started out in college what did you think you were going to do how did that idea change?

Brian: definitely, especially in my - once I came here, once I was involved in doing research I began to know more as a professor. My goal before I came here was to be a university professor, doing the research and since that but once I came here and got more involved in research and got more involved in the .....doing research needing research bonds and time and different thing and uh I think that my good thing and I'm not good at this aspects so I began to consider to change my career goals and it's a hard time and I have a long time I don't know what to should do when I graduate or should I graduate in a year or not. Should I continue finish my program so a lot of things go on, I guess you understand me

INT: (laughs) no I do, definitely

Brian: so finally I got the point like should I finish this or not? so a lot of struggles and I think God still wants me to finish this because he always start a thing and finish the thing. And uh he may let me do other things. I may have no idea at this point, but it is the - he is my lord so he need to know that I am very confident with my future. It must be proved a position that's just I can qualify I mean this not scientific language, but I do believe I have very good future and that's my - even I'm not quite sure what I would do after my graduation and I do have confidence and I do have several things in my will in my mind to happen

INT: I really needed to hear that myself so thank you there is a lot of uncertainty and faith involved in getting through this PhD thing.

Brian: there is the professor he is also Christian and he has a lot of students and he explained PhD as put him to death (laughs)

INT: (laughs)

Brian: So anyone in the PhD I think agree with this so

INT: so right. In wrapping up are there any things that are important that we haven't discussed

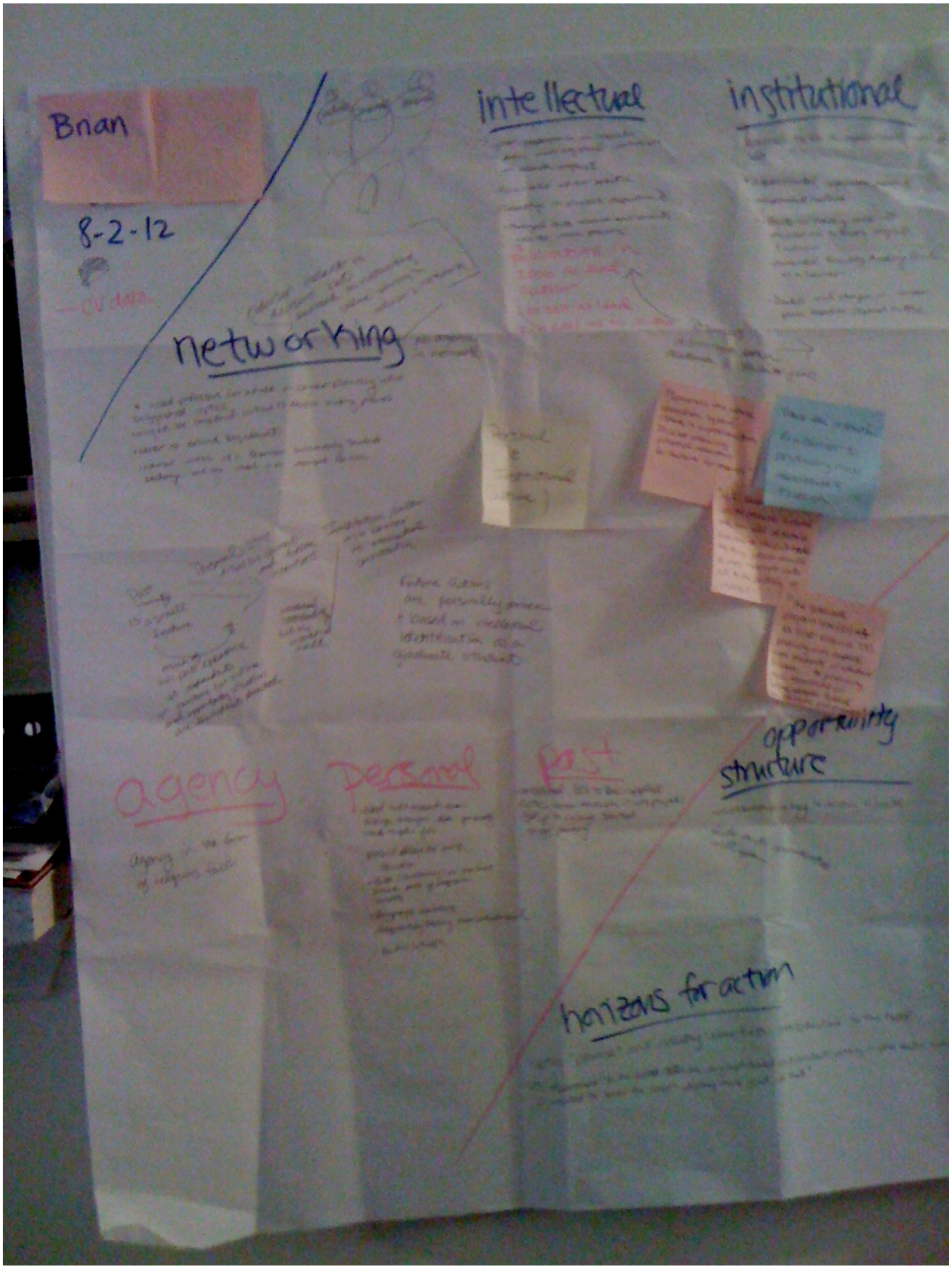
Brian: Yeah my wife is here - just one minute. Okay so I think for me I do have things like uh I mean it's kind of hard though we must agree with this. Many people went to the PhD program but they are not they should not go to that program. For me it's one of them maybe. Before I came to this program I have an expectation for my for doing research I'm not a very perfect researcher but I know a lot of thing think like how my expertise aspect so it's really hard. I know a lot of graduate students around me like meeting the general the general for many graduate program universities when graduate students enter the graduate program they are expecting to graduate immediately or as soon as possible. Somehow the whole education system there is a problem there. It is not producing potential researchers for future for research. If the student is if people like us enter into a PhD program in which people expect us to be an expert but our inner interest is not stimulated so that's very I would say that would be a very not good thing to see. I'm still experiencing that and it's not a problem of this university or this program or this discipline it's a general problem I still can't identify the problem but I'm in the reality so that's why even I even pastor even almost all my PhD study time I'm still not quite enjoying it. If that's true for many students that would be a sad result for more than education. That's I mean that's really reality.

INT: What do you think could change that?

Uh kind it's hard to turn the direction but I think uh especially nowadays in university researchers or professors put more their energy on producing research results instead of calculating more younger researchers. It's like it's like I can see these things at this time, but if I became a professor can the pressure around me from all directions push me to like put the things which should be more important but put to the position of important. I understand that it's kind of hard to turn the whole direction of education right now. It's like education kind of lose. The graduate program lose its first essence. It's producing more papers, more students, or whatever it loses it's ....to producing more researchers or future people full of hope passion and energy. We are kind of machine society. Kind of like people see this language in this way. If I don't go to my lab today, I feel pressure. I don't know if you feel this way.

INT: Absolutely

Brian: The thing I am interested research which drives me to go to lab now it's more like the pressure is bringing me. As a Christian I am trying to get out of this but tell you I got things, I tried to work it out the Lord really helped me but I told the Lord it is not my personal problem. It's kind of a mechanism of the university is running or our modern life is running and this really is bad or sad I will say


Brian
8-2-12
intellectual
institutional
networking
agency
personal
past
opportunity structure
horizons for action

Analysis: Brian

Past experiences and network

Brian is a 6th year Ph.D. candidate in a relatively small optical science and engineering program. Brian is an international graduate student who earned a master's degree in his home country of China before enrolling at his current institution. Brian's bachelor's degree is in applied physics, but he refers to it specifically as optics. As an undergraduate he did not focus on career planning until his junior year. At that time he depended on the advice of faculty at his university *(network)* to give him advice about his options. The professors he consulted with suggested that he consider the optics industry. Brian specifically refers to optics as a promise, essentially a guaranteed area of opportunity. He enrolled at another university in China in an optics program where he said he really learned about optics and was introduced to research.

His master's degree took about 3 years, and toward the end Brian was faced with the same career decisions as undergrad: unsure do you continue your education or enter the workforce? Brian was able to work in his advisor's lab doing research after he finished his degree and decided he was interested in going abroad to continue his studies. He was particularly interested in coming to the United States. He explained that researchers in academia and industry in the U.S. were "very sophisticated and prudent" in their work and he wanted to design a career in academia in that model. Brian applied to three other institutions, two with major optics programs, and one major public, engineering university.

Institution and Intellectual

He enrolled in his program primarily because of the teaching assistantship he was awarded *(institution)*. He was able to gain admission to another optics program, however funding was not offered. The teaching assistantship gave him the time and opportunity find an advisor in the department, with a one-year deadline. The time limitation motivated Brian to find an advisor with funding and an available position. He asked several professors *(little agency, networking, but situation driven)* in the department, however only one his present advisor, had an opening. Brian was eligible and comfortable with the projects in his advisor's lab based on his experience in his earlier master's program *(intellectual)*.

When discussing the program that he is a part of Brian explains that he felt the program was adequately equipped for his work, but included limited faculty funding was a barrier. While Brian remained funded throughout his time, he conceived limited funding as an issue for their program.

Brian's experiments are very independent and he works on his own with what seems like little input from his advisor. Brian mentioned his advisor's collaborators in Germany that provides an exchange vehicle for German graduate students to spend short periods of time with their local group. Brian orients new people to the lab and once they leave is responsible for finishing their projects. He does not develop his own relationships with researchers, but sees the value in the approach.

Personal/Intellectual and Institutional

Brian's personal life comes into play in discussion of his progress toward finishing his degree. His personal religious faith is his primary support for continuing in graduate school. Brian discusses his faith as the source of the career opportunities he has had, as well as personal security for his future. He speaks passionately about his future success and degree completion based on his personal faith. Brian is unsure about his next steps, even with graduation about an academic year in sight, but depends on his higher power for security which drive all of his future intentions.

He expresses that his advisor is also a critical component, however does not discuss his advisor in detail when institutional factors are discussed. Brian with raised enthusiasm, zeal and clarity (as a foreign-born student, Brian discusses his language ability and cultural differences as his primary barrier) explains how academic culture is self inhibiting in the training of graduate students. He explains that the graduate education process is a barrier to producing new researchers.

> "If I became professor can the pressure around me from all directions push me to like put things which should be more important put to the position of [not] important...The graduate program lose(s) its first essence. It's [about] producing more papers, more students or whatever. It loses...more researchers or future people full of hope, passion and energy."

The way Brian describes the graduate education experience demonstrates the gap between students' personal goals and the expectations of academia. Brian initially talks about his time in the lab with neutral to positive connotations. As he moves through his personal history and discusses his current place in his career he talks about spending time in the lab based on pressure and in very obligatory ways.

While he places significant emphasis on faith, the institution has heavily influenced Brian's imagined future. He has learned based on his graduate years that the research heavy academic setting is not his ideal. While self-doubt in research ability and contribution is verbally expressed Brian has demonstrated intellectual contributions in the form of journal articles. He has three first author papers, and two additional co-authored publications.

Identity-Trajectory

Networking is the least important strand in Brian's identity-trajectory. While network was the introductory factor for his entry to optics, Brian places almost no emphasis on people and relationships when discussing his pathway or decisions after. He does however place significant emphasis on personal, specifically spiritual, factors and the institution at greater levels of importance. The very culture of research and the attractive high level research being done in the U.S. became a two-edged sword for Brian. He was motivated and interested in coming to this country because of the research opportunities, however nearing the end of his graduate career academic culture became a major hindrance. His past intellectual experiences helped him adjust, but the dynamics of a high-stakes research culture became his undoing. Brian romantically talks about learning and research at early stages in his career, but in discussing his present stage high performance is burdensome and unappealing for future options. He expects his future actions to be driven by personal factors and based on his self identification process as a graduate student. The institution, from a cultural level have become a barrier for individual intellectual contribution.