CAREER PREPARATION FOR INTERDISCIPLINARY SCIENCE PHD STUDENTS: A CASE STUDY

by

SABRINA AMIEL KALISH GORDON
B.S. University of Central Florida, 2004
M.A. University of Central Florida, 2009

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Major Professor: Rosemarye Taylor

ABSTRACT

This case study intended to collect and analyze responses from stakeholders of the UCF Modeling and Simulation graduate program regarding the ways in which interdisciplinary (IDS) science PhD students could be prepared for diverse career paths. A mixed methodology study was executed and quantitative survey (N=96) and qualitative interview (N=10) data were collected to address three research questions. Overall, stakeholders for this case study were found to represent the three main career paths of academia, government, and industry. Survey data were utilized to gauge the level of importance that survey participants perceived for various survey scales and items. The scales that were rated with the highest means were Ethics, Teamwork, and Career Management (*M*=3.67, *SD*=.41) and Interdisciplinary Skills (*M*=3.67, *SD*=.36), while the lowest mean was reported for the Professional Science Skills scale (*M*=3.19, *SD*=.54). Interview data revealed limitations of the historically accepted apprenticeship model to include an emphasis on academia-only career preparation and a lack of standardization regarding highly individualized advisor-student relationships. And finally, survey and interview participants reported that alternative pedagogical methods to prepare IDS science PhD students for diverse career paths should include internships in each career sector, while also presenting the barriers to implementing internships regarding faculty commitments and time available to advise and help students procure such relationships. Study recommendations point to preparing IDS science PhD graduates for diverse career paths by emphasizing math, technical, communication, and interdisciplinary skills using experiential learning opportunities such as internships and an IDS project-based curriculum.

For my family: Past, present, and future.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: PROBLEM OF PRACTICE

Background of the Study

Doctor of Philosophy (PhD) studies in the U.S. and abroad have a long tradition of utilizing a pedagogical model of apprenticeship to prepare students for academic careers. Under the apprenticeship model PhD students, or apprentices, are socialized to an academic discipline by following a faculty mentor, or advisor, through activities designed to prepare them for academic careers (Billett, 2016; Noonan, Ballinger, & Black, 2007; Shuell, 1990). The apprenticeship model is implemented throughout PhD studies in the form of mentorship and faculty supervision practices. Details of these practices, such as funding and tasking, often vary based on the needs and abilities of PhD students (Ethington & Pisani, 1993; Noonan et al., 2007; Perna & Hudgins, 1996; Roaden & Worthen, 1976). The current study revisited the apprenticeship model of PhD career preparation when considering both interdisciplinary doctoral programs and the changing landscape of employment for PhD graduates. More specifically, given that the two underlying assumptions of the apprenticeship model are that it is for (a) a particular discipline or academic field and (b) an academic career, is it still relevant for use in interdisciplinary science PhD programs today?

Interdisciplinary (IDS) PhD programs pose unique opportunities and challenges for PhD students' career preparation. Uniqueness is grounded in the very goal of interdisciplinary studies, which is to generate novel conclusions that could not have been reached from the approach of a singular perspective (Newell, 2007). Interdisciplinary PhD students are to conduct groundbreaking research at the intersection of disciplines, integrating and synthesizing literature, research methods, and tools from several disciplines (Klein, 2010; Newswander & Borrego, 2009). Gardner, Jansujwicz, Hutchins, Cline, and Levesque, (2014) further identified that another challenge for IDS PhD students is finding faculty members who are qualified to mentor and socialize them to an interdisciplinary field given that few professors have (a) completed an IDS degree themselves and/or (b) intentionally socialized themselves to prepare for IDS research and supervision on their own.

The employment landscape for PhD graduates was once a direct path to academia, however it has been changing as many now pursue careers in other sectors such as industry and government in addition to academia (Ferris, Perrewé, & Buckley, 2009). The reasons for these diverse career pursuits include that (a) there are not enough positions available in academia to support the growing number of PhD graduates (Larson, Ghaffarzadegan, & Xue, 2014), (b) some PhD graduates prefer careers outside of academia (Lee, Miozzo, & Laredo, 2010; Mangematin, 2000; Roach & Sauermann, 2010; Sauermann & Roach, 2012), and (c) in some countries, industry and government actively prefer and therefore recruit PhD graduates to work in their organizations (Cyranoski, Gilbert, Ledford, Nayar, & Yahia, 2011). Given the changing career pursuits of PhD graduates, there have been calls for universities to adapt their methods of PhD student career preparation (Bethman & Longstreet, 2013; Cassuto, 2015; Golde & Gallagher, 1999; Schillebeeckx, Maricque, & Lewis, 2013). However, change in traditional universities is not always easy due to way they are structured organizationally.

Bolman and Deal’s (2013) organizational theory posits that changes are difficult for universities to make due to their organizational structure. Universities are professional bureaucracies which rely on faculty members that are highly specialized, have autonomy, and have considerable power (Bolman & Deal, 2013). Within the university structure, graduate research assistantships are one of the funding mechanisms which require faculty members to supervise students. More specifically, graduate research assistants may work on faculty members' sponsored research (Golde & Gallagher, 1999; MIT Office of Sponsored Programs, 2016; The George Washington University, 2016; Virginia Tech Grad School, 2016). While faculty supervision is often provided under funded circumstances, it is not limited to such an arrangement and can also occur decoupled from funding.

Statement of the Problem

The problem addressed in this case study is that interdisciplinary science PhD students need to be prepared for entering diverse career paths, such as industry and government, in addition to academia, however many existing mentorship practices do not take these diverse career paths into account – specifically the apprenticeship model which continues to be the method of choice.

Purpose of the Study

The purpose of this study was to collect and analyze perceptions of stakeholders, such as graduate students, professors, and professional community members, regarding the ways interdisciplinary science PhD students can be prepared for diverse career paths. Surveys and interviews with these stakeholders were conducted to collect their perceptions regarding skills that are valued by Modeling and Simulation (M&S) professionals across varying career paths. Opportunities to build upon and adapt the historic apprenticeship model were identified to prepare interdisciplinary science PhD students for diverse career paths. This case study was conducted and focused on an interdisciplinary science PhD program, the Modeling and Simulation (M&S) PhD program at a large, metropolitan, emerging research university.

Context of the Study

This case study was based on the needs and practices of interdisciplinary science PhD programs at large research universities. Emphasis is on the Modeling and Simulation (M&S) PhD program at the University of Central Florida (UCF). At UCF, the M&S program was developed as an interdisciplinary response to the human-centric needs of the larger, more technical M&S community.

A graduate report prepared by UCF Institutional Knowledge Management (2015) shows that since the M&S PhD program's conception in 2002, it was characterized by growth with its highest counts of applications, admissions, and enrollments in 2011 (University of Central Florida, 2015b). After the program's 10^{th} year, enrollment began to slow and decreased headcounts were reported in 2012. In fall 2014, the M&S PhD program was reported as having a total of 67 enrolled students with a majority who were white (49.25%), male (77.61%), and enrolled part-time (52.24%). The mean age of M&S PhD students was 39 years old. Of the full-time enrolled students in the fall 2014 semester, more than half were financially supported on graduate assistantships with a majority of research assistantships (55.26%), then teaching (2.63%) and general assistantships (2.63%) (University of Central Florida, 2015b, 2017).

Students in the M&S PhD program are encouraged to select dissertation topics that can be highly relevant and applied in diverse career paths (University of Central Florida, 2016; Wiegand, R. P., 2015). The PhD program's 2015 assessment self-study reported gainful employment for alumni as "graduates from the past 1.5 years reflect 50% in academia and 50% in industry/government" (Wiegand, R. P., 2015, p. 10). The PhD program self-study report further describes relationships with key stakeholders by maintaining an Executive Advisory

Board that "provides feedback about the content and productivity of the graduate programs within M&S in terms of the research and students produced and entering into industry or military facilities doing such work" (Wiegand, R. P., 2015, pp. 2–3). Community members are also sought as speakers in the Modeling and Simulation Seminar Series which occur on a nearly monthly basis, and adjunct instructors for relevant content areas.

As an interdisciplinary program, UCF M&S PhD students were reportedly encouraged to seek out elective courses and dissertation advisors from any department or college within the university so long as these choices were relevant to the proposed dissertation topic (Wiegand, R. P., 2015). In addition to experiencing a wide range of coursework content, UCF M&S PhD students also experienced a wide range of advising practices since advising practices are known to vary across individual faculty members and socialized norms in specific fields and departments (Gardner et al., 2014). Aside from an emphasis in human-centric simulation, the assessment self-study report was unable to pinpoint any specific, common emphasis in student research topics, advisors, or elective selection. The program also documented a data-supported need to redesign graduate mentoring [further supported by Graybill et al. (2006)] and university laboratories to better prepare PhD students, or early career scientists, for diverse career paths (Wiegand, Morrow, Gordon, & Leis, 2015).

Definition of Terms

The terms which will be used in this case study are defined as follows.

Academia: When discussing career paths, academia has historically served as the goal for attaining employment for PhD graduates (Ferris et al., 2009). This category typically includes institutions of higher education with a preference toward professorships at research universities, but may also include full-time and part-time positions at teaching universities and colleges.

Alternative-Academia (Alt-Ac). This term was first coined in a 2010 Twitter conversation between Nowviskie and Rhody (Nowviskie, 2014). It is intended to group the types of possible career paths for PhD graduates that are in addition to, or an alternative to, academia. Examples include careers in government and industry.

Andragogy. The study of how adults learn (Knowles, 1972). This concept was intended to be a more specific version within the larger umbrella term of pedagogy which is addressed below. Knowles' (1972) refined this theory as "the art and science of helping adults learn", separate from his definition of pedagogy as "the art and science of teaching children" (p. 32).

Apprenticeship. This term is used by Billett (2016) to describe both a "mode of learning and a model of education" (p. 613) in which individualized learning and experiences are used to socialize one to an occupation (Noonan et al., 2007). It is rooted in perspectives on human development and learning such as cognitive, social constructivist, genetic epistemology, and some anthropological accounts (Billett, 2016). The term has been likened to the mentoring process of protégés by faculty members in doctoral education and addresses many aspects of the mentoring process such as research skill development, research productivity, publishing collaboratively, and job placement (Ferris et al., 2009).

Career Preparation. For the purpose of this study, career preparation is the broader term which encompasses many aspects of preparing PhD students for their careers. Methods of career preparation can include advising, mentoring, and apprenticeships (Randi, 2000).

Early Career Scientist. The European Geosciences Union (2016) defines this as "an undergraduate or postgraduate (Masters/PhD) student or a scientist who has received his or her highest degree (BSc, MSc, or PhD) within the past seven years". For the purpose of this case study, this term is intended to be synonymous with science PhD students. The researcher has chosen to use this term to emphasize the long-term goal of science PhD students to be part of the larger science community rather than their short-term student-status during a PhD program.

Faculty Supervision. The relationship between a student and main advisor; universally critical for doctoral students in all academic disciplines (Lee, 2008). Related terms include advising and mentoring. Not a direct substitute for the term graduate assistantship.

Government. Another category of employment within the larger discussion of diverse career paths. Government careers often include public positions with civilian and military organizations within the U.S. Department of Defense (DoD) and other public, non-profit organizations (Sarjoughian & Zeigler, 2001).

Graduate Assistantship. A paid position that provides the opportunity for a graduate student to apprentice under a faculty advisor or staff supervisor. These positions are often paid with a stipend, tuition waiver, and health insurance, and require the graduate student to enroll full-time. Assistantships can be awarded for duties that include teaching, research, or administrative tasks (University of Central Florida, 2015a).

Industry. The third category of employment within the larger discussion of diverse career paths. This includes professionals who work for or own privately held corporations (Sarjoughian & Zeigler, 2001).

Interdisciplinary. An approach to solving a problem by integrating knowledge and research methods from two or more disciplines to arrive at a solution that could not have otherwise been reached from any singular discipline (Newell, 2007).

Laboratory. For the purpose of this study, this term refers to a university facility that is dedicated to research. University laboratories can be housed within several organizational structures such as departments, institutes, and research centers (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2006).

Mentoring. In a PhD program, career preparation is typically addressed in a one-on-one mentoring relationship between a master/mentor/professor and an apprentice/protégé/student (Ferris et al., 2009).

Pedagogy. This term is often used as an umbrella term of educational practices which includes practices for teaching and learning (Mohring, 1990).

Conceptual Framework

The conceptual framework for this study is related to the theory and practice of preparing interdisciplinary science PhD students for diverse career paths. This includes studying the skills which are preferred by stakeholders of these programs, current methods employed by universities to prepare PhD students for careers, and emerging career preparation techniques that have been proposed for diverse career path preparation. To restate from the introduction section of this study, PhD career preparation was addressed for diverse career paths, such as industry and government in addition to the academic sector based on the need to embrace the reality of an oversaturated academic job market (Larson et al., 2014), PhD student interests outside of academia (Sauermann & Roach, 2012), and industry interests in attracting elite recruits (Hesketh, 2000). The remaining concepts that will be used to frame this study are (a) interdisciplinary science PhD studies, (b) skills and competencies expected of science PhD graduates, and (c) established methods for PhD career preparation. Following is a brief overview of the literature on these topics that support further inquiry into this case study. A complete review of the literature for this study is provided in Chapter Two.

Interdisciplinary Studies

As previously defined, interdisciplinary studies are intended to generate novel solutions to problems using multiple disciplinary perspectives and methods (Borrego & Newswander, 2010; Newell, 2007). A preference for the pedagogic concept of autonomy is related to the concept of interdisciplinary studies using Dietz and Eichler's (2013) explanation that adult students are often attracted to IDS graduate programs due to the "apparent flexibility" and opportunity to "study a variety of subject material of interest to them" (p. 97). Autonomy and adult learning needs are appropriate to highlight as the case subject for this study, the UCF M&S PhD program, has a mean student age of 39 years (*SD*=10.23).

This case study is further framed by considering that IDS graduate programs are becoming increasingly popular in North America (Hibbert et al., 2014) despite little evidence-based research to support their use for teaching and learning (Spelt, Biemans, Tobi, Luning, & Mulder, 2009) and the limited ability of university organizational structures to support their boundary-crossing nature (Klein, 2010). The confusion that students, faculty, and university administration report in administering an IDS science PhD program is addressed in greater detail in Chapter Two.

Skills Expected of PhD Graduates

This case study used a list of skills and competencies that can be expected of all PhD graduates to further address the lack of evidence-based research on IDS PhD programs. A search of the literature did not yield any centralized standards for PhD programs in the U.S. There are discipline specific standards set by accrediting agencies in some specific fields such as clinical psychology and engineering, however no U.S. standards for all PhD programs overall. However, the search did identify general PhD standards within the United Kingdom. The "Irish Universities' PhD Graduate Skills Statement" describes desired outcomes that PhD students are expected to develop [Irish Universities Association (IUA), 2015]. The IUA further address the need for research and skill development during a PhD program by stating that "…advancement of knowledge through original research is the core component of PhD education, but PhD education must also facilitate additional skills development opportunities" (p. 1). IUA skill statements were grouped within the categories of research skills and awareness, ethics and social understanding, communication skills, personal effectiveness and development, team-working and leadership, career management, and entrepreneurship and innovation [Irish Universities Association (IUA), 2015]. These categories were utilized as constructs for this study. Further constructs for this study of interdisciplinary and professional scientist skills were also addressed by using learning outcome statements from reports published by the National Science Foundation (Gamse, Espinosa, & Roy, 2013) and the Burroughs Wellcome Fund and Howard Hughes Medical Institute (2006) respectively.

Established Methods for PhD Career Preparation

Apprenticeship Model

From J. Randi's (2000) entry in the *Encyclopedia of Psychology*, the concept of apprenticeship has strong ties to what was initially used for trade and vocational preparation. However, the intellectual, or cognitive apprenticeship, has also been documented as early as Greek philosopher Socrates' approach to training disciples by having them "debate philosophical issues with him" (p. 220). The concept of cognitive apprenticeship was further developed by Collins, Brown, and Newman (1986) who illustrated it as a model to identify its four main aspects of (1) modeling, (2) scaffolding, (3) coaching, and (4) fading. Noonan et al. (2007) describe apprenticeships as involving the pedagogical concept of scaffolding a student's activities by building upon their experiences and providing authentic, challenging learning opportunities. The tasks evolve over time and gradually move the student to more autonomy as confidence and skills are developed. Sociocultural aspects of apprenticeships further function to indoctrinate or enculturate a student to a discipline, or move the student "from being on the periphery of the group to becoming an insider" (Noonan et al., 2007, p. 252).

Ferris et al.'s (2009) chapter on PhD mentoring also addresses it within an apprenticeship framework in terms of the formal and informal skills needed during a mentoring relationship such as political savviness, progression, evaluation, and tracking, and redefining the relationship once the PhD student completes the program. As comprehensive and thorough as Ferris et al.'s (2009) work was, it was still built upon the premise of students being indoctrinated into a particular department or discipline, and for the main goal of pursuing careers in academia; to the exclusion of other career paths. They explicitly state that their expectations of mentored PhD protégés "…include pursuing faculty positions at the best research universities possible, upon completion of the Ph.D." (Ferris et al., 2009, p. 277).

Faculty Supervision

Faculty supervision contributes to preparing IDS PhD graduates to be marketable in diverse career paths. The context in which faculty supervision is provided for PhD students can vary depending on whether it is done within or outside of a funding agreement for the student. If a student is not funded, research supervision by a faculty member is often advisory in nature and specific to the student's dissertation progress (Zhao, Golde, & McCormick, 2007). If a student's research is funded by a faculty member, the research topic typically aligns with the faculty's research and supervision is typically done within the structure of a graduate research assistantship that is paid for by a faculty member's sponsored research funding (The George Washington University, 2016; University of Central Florida, 2015a). Within graduate research assistantships, faculty supervision includes oversight of the student's work in the research laboratory in addition to dissertation progress (Barnes & Austin, 2009; Halse & Malfroy, 2010; Ives & Rowley, 2005; A. Lee, 2008; Mainhard, van der Rijst, van Tartwijk, & Wubbels, 2009). Graduate research assistantships in the research context typically provide tuition coverage, salary, and health insurance for students (University of Central Florida, 2015a).

Supervision practices have been studied from several perspectives, including those of faculty members and their motivations for choosing (or not choosing) to mentor students. One example was Guise, Nagel, and Regensteiner's (2012) study which used educational psychology approaches to identify motivations for why faculty members agreed to mentor students. Additionally, Crosta and Packman (2005) identified that rates of faculty PhD production were distributed unequally between and within some disciplinary fields based on several variables such as gender of faculty and students and the time a faculty member was employed at the institution . These are just two examples of studies on faculty motivations to mentor. Further studies on this will be addressed in the literature review chapter. Reviewing faculty motivations to mentor is useful for understanding the power that faculty members yield regarding students, and also the ways in which they affect the larger organizational structure of higher education institutions.

In addition to addressing the skills that are needed of IDS science PhD graduates for diverse career paths, and the ways in which universities can prepare them, it is important to consider some of the major barriers to implementing them. One such explanation lies within Bolman and Deal's (2013) organizational theory as they propose viewing universities through a structural frame. This provided context for why universities, or professional bureaucracies, are slow to change and highly reliant upon faculty members. This case study sought to address some of these structural issues which are not yet designed to support science PhD students who conduct IDS research, or science IDS PhD students pursuing Alt-Ac careers.

Research Questions

The following research questions guided this case study.

1. To what extent do participants value the science, interdisciplinary, and PhD skill statements?
2. What are the perceived advantages and disadvantages of the apprenticeship model for preparing interdisciplinary science PhD students for diverse career paths?

3. What barriers and advantages do participants identify regarding the implementation of an alternate pedagogical model for interdisciplinary science PhD students?

Methodology

The case study strategy of inquiry utilized mixed methodology for the combined benefits of quantitative and qualitative data. Educational researcher J. W. Creswell's works (2009, 2013) were selected to guide this study because they are highly regarded in the field of research design and include synthesized findings from the published works of leading researchers.

The case study approach that was utilized for this study is relevant for studying an interdisciplinary topic as it draws from the disciplines of psychology, anthropology, sociology, political science, law, and medicine (Creswell, 2013). Case study strategy of inquiry is further based on the criteria of being bound by time and activity intended to "explore in depth a program, event, activity, process, or one or more individuals," using "a variety of data collection procedures over a sustained period of time" (Creswell, 2009, p. 13). The subject of this case study was the Modeling and Simulation PhD program at the University of Central Florida. This case study used multiple sources of data to include both quantitative and qualitative methods, which are further addressed in this section.

Quantitative Methodology

Quantitative methodology for this case study employed survey research as its purpose was to generalize conclusions from the sample of participants to a larger population (Creswell, 2009). In this case, the sample of survey participants was intended to provide insights to the national Modeling and Simulation community with the potential to further generalize to the larger IDS PhD population. This study included a one-time administration of a survey as a Web-based survey due to its advantages of being able to collect a large amount of data in a short time and produce quantifiable results for statistical analysis (Creswell, 2009). Utilizing a survey also had the advantage of being low cost. In this case, there was no cost for utilizing surveys since participants were not compensated and the survey software was free to the researcher. A disadvantage of Web-based surveys is that they do not allow for in-depth response probes or individualized, human-intuited probing beyond a pre-determined algorithm (Creswell, 2009). The qualitative methodology which follows was intended to address these disadvantages.

Qualitative Methodology

The qualitative methodology for this study followed Creswell's definition of a semi-structured interview involving "generally open-ended questions that are few in number and intended to elicit views and opinions from the participants" (Creswell, 2009, p. 181). The purpose of conducting interviews is to collect a richer level of detail from participants. The advantage of interview questions is that they can allow researchers to collect more in-depth data than what could be captured in a quantitative survey. A challenge with interviews, however, is that they are time-intensive to develop, conduct, and transcribe. Questions must be carefully designed to avoid subtly leading the participants to any particular response (Creswell, 2013). For this reason, the target of 10 interview participants was proposed to make data collection and analysis more manageable. The smaller number of interview participants was balanced by the larger response that was targeted by the quantitative survey for this study. These methods follow Creswell's (2009) definition of concurrent mixed methods in that both forms of data collection were intended to be complimentary and collected at the same time, not constrained by any particular sequence.

Population and Sample

The same target population was used for both the quantitative survey and the qualitative interview portions of this study. Contact e-mail addresses for the population were provided by the UCF M&S graduate program office. To allow for the largest possible population, this study utilized the program's e-mail distribution list and social media accounts which are described here in more detail. The e-mail distribution list had been accumulated by the program over the four years from 2012 to 2016. It included approximately 400 affiliated contacts such as alumni, students, administrators, faculty, industry and government leaders and partners, and community members who have requested to be included. The list was trusted to be up to date and thorough because it was regularly used by the program to advertise important program updates, events, and research seminars. To address interested members of the community who were not be included in the e-mail list, the population also included approximately 700 contacts affiliated with UCF M&S graduate program's social media accounts on Facebook (https://www.facebook.com/UCFModelingAndSimulation/) and Linked In (http://www.linkedin.com/in/ucfmodelingandsimulation). Some individuals may have overlapped as contacts on one or both social media pages and additional inclusion within the e-mail distribution list. In total, approximately 1,000 contacts were included in the population for this study.

Participants were not incentivized with any direct or monetary reward; the only anticipated benefit was indirect by helping to improve the overall M&S community. Participation in both the quantitative survey qualitative interview portions of this study relied on voluntary participation. The dissertation researcher was also the administrator for the UCF M&S

graduate program, and was given permission by the faculty program director to utilize the program's e-mail contact lists and social media accounts to recruit participants.

Quantitative Survey

The sampling goal for the quantitative survey portion of this case study was to recruit approximately 100 responses. Single stage sampling design was followed for the survey since the researcher had access to the population contacts and could sample them directly (Creswell, 2009). Anonymity for survey participation could not be guaranteed because there was an option to disclose self-identifying data at the end of the survey for those who wished to be contacted for further participation in the qualitative interview portion of the study. However, confidentiality was guaranteed for survey participants since their responses would be reported in aggregate and self-identifying data were not included in the final report.

To address quality control of participants, the survey included some questions to identify the extent of experience that participants had regarding length of time in the field of M&S. Additionally the survey was designed in Qualtrics using a function to prevent participants from taking it more than once.

Qualitative Interview

The sampling goal for the qualitative interview portion of this case study was to recruit approximately 10 participants. Creswell's (2009) purposive sampling procedures were followed for each interview to "best help the researcher understand the problem and the research question" (p. 178). The purposive interview sample was further selected to ensure even distribution across the diverse career paths addressed in this case study: academia, government, and industry.

Confidentiality was guaranteed for all interview participants as no self-identifying data were included in the final report.

Procedures

Quantitative Survey

The target population was invited to participate in the study survey by direct e-mail and by public invitation on the UCF M&S program's social media accounts. The initial e-mail recruiting message included a brief introduction, an attached informed consent form (Appendix A), and an open link to the online survey which was anonymous and not password protected. The social media recruiting messages included the same brief introduction, attached informed consent form, and link to the online survey which was anonymous and not password protected.

The informed consent form was also acknowledged a second time in the Web-based survey, presented with a yes or no option to consent prior to accessing the rest of the survey questions. The survey was developed and administered using Qualtrics software which is available for free to UCF researchers. Survey responses were not tracked. Survey content is further described within the instrumentation subsection below; the full survey is provided in Appendix C.

Qualitative Interview

Interview invitations for the qualitative portion of this study were sent individually by e-mail to request an interview which would take place in varying modes based on each participant's preference (i.e., in person, by phone, or electronically using video conferencing software) (Appendix B). Each participant received an informed consent in the original e-mail invitation. Full interview protocol, including items and prompts, is included in Appendix E.

Instrumentation

Quantitative Survey

A quantitative survey was developed by the researcher based on the *Irish Universities' PhD Graduate Skills Statement* (2015), the *Essential Competencies for Interdisciplinary Graduate Training in IGERT: Final Report* (Gamse et al., 2013) and *Making the Right Moves - A Practical Guide to Scientific Management for Postdocs and New Faculty* (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2006). The survey items were intended to identify the extent to which participants valued various PhD skills based for their professional fields and to identify some of their professional characteristics.

The survey utilized for this study was new, therefore statistical measures for reliability and validity were not yet developed and could not be reported until data were collected. However, each item listed in the survey was individually reviewed for content validity, readability, and relevance by a university researcher and 11 field experts based on best practices identified by Creswell (2009). The wording of each survey was adapted to elicit a Likert scale rating. The possible responses for each survey item included: (a) strongly agree, (b) somewhat agree, (c) somewhat disagree, (d) strongly disagree, and (e) do not know. The full survey is included in Appendix C.

Qualitative Interview

A qualitative, semi-structured interview was instrumented by developing an interview protocol for this case study. Interview items focused on exploring the research questions for this case study regarding participants' perceptions of PhD skills and mentoring experiences. The full interview protocol is included in Appendix E.

Data Collection

Quantitative Survey

Quantitative survey data were collected electronically using Qualtrics Survey Software. Survey responses had the potential to reveal self-identifying in an optional survey item, therefore confidentiality was assured by publishing findings in aggregate.

Qualitative Interview

Qualitative interview responses were audio recorded and transcribed verbatim except to exclude identifying information about the participants. Each interview was conducted solely by the author of this case study and followed the interview protocol that was established for this study. Identities of interview participants were known to the researcher and kept confidential by assigning alpha numeric codes to the transcribed files. Findings were published in aggregate and by alpha numeric code.

Data Analysis

Quantitative Survey

Quantitative survey data were analyzed for inferences to the larger population of the M&S community. Relationships between participants' professional characteristics and the level to which they reported a value of different PhD graduate skills were analyzed using descriptive statistics and correlations to the overall constructs in which the skills are categorized (Salkind, 2004).

Qualitative Interview

Qualitative interview transcriptions were reviewed for recurring themes regarding perceptions of PhD skills and methods of career preparation across the diverse career professionals who participated.

The methods by which the research questions were addressed and analyzed are summarized in Table 1.

Table 1

Research Questions and Data Sources

Research Question	*Data Source(s)*
1. To what extent do participants value the science, interdisciplinary, and PhD skill statements?	Survey of Interdisciplinary Science PhD Skills Items 1-35 Interview Protocol Items 1-4
2. What are the perceived advantages and disadvantages of the apprenticeship model for preparing interdisciplinary science PhD students for diverse career paths?	Interview Protocol Items 5
3. What barriers and advantages do participants identify regarding the implementation of an alternate pedagogical model for interdisciplinary science PhD students?	Interview Protocol Items 6-8

Delimitations and Limitations

A limitation of this study is that only one case subject was examined. The methodology for this study established both depth and breadth in understanding the UCF M&S PhD program and has the potential to be generalizable to the larger, national M&S community if other case subjects are later addressed in a future study. However, there were not enough data to assert such a statistical inference, nor is there enough to further generalize to all IDS science PhD programs.

Significance of the Study

The study of PhD student career preparation is not new. However, it was a new contribution to review the strengths and weaknesses it's related concepts when applied to interdisciplinary science PhD programs and diverse career pursuits of PhD students. This case study was intended to inform a clear pathway to diverse careers for graduates.

Summary

This case study produced findings on the limited topic of career preparation for IDS science PhD programs in the U.S. The methodology was designed to identify the perceived importance of various PhD, interdisciplinary, and professional science skills to prepare IDS early career scientists for diverse career paths. Meaningful results were used to inform discussion on new innovations to PhD career preparation methods within the apprenticeship frameworks.

CHAPTER TWO: REVIEW OF THE LITERATURE

Introduction

This chapter presents the skills needed by interdisciplinary (IDS) science PhD graduates to pursue diverse career paths and the ways universities can help prepare them. Educational research is well-documented on the topics of PhD pedagogical practices and interdisciplinary studies as separate topics. Research and therefore literature are lacking in tracking the careers of PhD holders in the U.S. This study is intended to further understand the needs of a specific professional community which draws upon an interdisciplinary field of study to learn more about how interdisciplinary science PhD students can be prepared for 21st century careers in academia, industry and government.

The literature presented in this chapter focuses on career preparation of PhD interdisciplinary studies and research programs. Searches on these topics were conducted across major library databases including Education Resource Information Center (ERIC EBSCOhost), SAGE Journals, Education Source (EBSCOhost), Taylor and Francis, Science Direct, Web of Science, dissertations published by ProQuest and Networked Digital Library of Theses and Dissertations (NDLTD) and dissertations internally catalogued at the University of Central Florida. Key phrase search terms included: “interdisciplinary PhD career preparation”, “interdisciplinary PhD career paths”, “interdisciplinary doctorate”, “doctoral apprenticeship”, “doctoral programs and interdisciplinary approach”, “doctoral and interdisciplinary and career”, “PhD careers”, “PhD skills”, “interdisciplinary skills”, and “professional scientist skills”.

The literature reviewed is presented according to the following sequence: interdisciplinary studies and research in higher education, current career paths for PhD graduates, methods of PhD career preparation provided by universities, and emerging models for PhD career preparation.

Interdisciplinary Studies and Research in Higher Education

J. Klein's work on interdisciplinarity over the course of over 30 years at Wayne State University makes her one of the leading scholars on interdisciplinary history, theory, and practice. Her 2010 book entitled *Creating Interdisciplinary Campus Culture* captures the necessary contributions of both interdisciplinary research and interdisciplinary studies to describe how traditional campuses can reconsider their existing organizational structures to better "address complex issues and broad themes, and solve problems that are too broad for a single approach" (p. 15). Klein's scholarship on common motivators for interdisciplinary research and studies at universities includes a need to understand complex issues presented in nature and society and also to understand the power provided by new technologies (Klein, 2010). Interdisciplinary research has also been a key strategic area of development for U.S. government-funded projects and organizations such as the Department of Defense, National Science Foundation, National Institutes of Health, and the National Aeronautics and Space Administration. This inevitably leaves many corporate contracting organizations to employ interdisciplinary problem solving strategies as well as recruiting and teamwork techniques (Klein, 2010).

History of IDS Studies

The history of interdisciplinary (IDS) studies is captured thoroughly and effectively in J. Simmons' (2011) doctoral dissertation on the topic of IDS studies. She summarizes that "interdisciplinary programs evolved out of a constant battle between general or liberal education and the study of specializations" (p. 86). This overview captures the pendulum-like conflict which higher education professionals have struggled over when implementing interdisciplinary studies and research initiatives.

The earliest notion of interdisciplinary study can be traced as back as far as to Ancient Greek philosophers Plato and Aristotle regarding their debates on establishing an order of disciplines and subjects (Klein, 2010). While several European universities initially developed PhD programs, beginning with Germany, eventually the order of disciplines and higher education spread to the U.S., where debates on specialization versus integrated studies took place as early as the 1930s (Simmons, 2011). Debate on interdisciplinary studies continued for many decades as interdisciplinary degrees and research began to be formally acknowledged in the U.S. in the 1960s. At first they were proposed as separate, integrated degrees developed in focused areas of IDS study such as women's studies and environmental studies. IDS topics could eventually be found infused at large across college curricula by the 1990s (Klein, 2010; Simmons, 2011).

Modern IDS PhD Studies

Educational research on IDS academic programs and research has grown as more IDS degrees are developed and graduates are produced. More specifically, modern research on IDS science PhD programs has largely focused on participants in nationally recognized programs which fund well-planned IDS topics with urgent societal needs, such as the Integrative Graduate Education and Research Traineeship (IGERT). The IGERT was the former name for the National Science Foundation's (NSF) grant program to reward interdisciplinary training and education. This effort still exists under NSF, but has been renamed as the Innovations in

Graduate Education track of their NSF Research Traineeship (NRT) (National Science Foundation, 2016). Borrego and Newswander (2010) studied IGERT programs to identify common learning outcomes for IDS graduate studies to include disciplinary grounding (typically through a core, introductory course), integration, teamwork (group assignments), communication, and critical awareness.

Disciplinary Boundaries and Bridges

Other educational research on IDS science PhD programs comes from analyzing the disciplines from which the programs originated for comparison. The concept of academic disciplines serving as boundaries is not new, and neither is the concept of bridging these departmental boundaries. Spelt et al. (2009) conducted a systematic literature review on interdisciplinary thinking in education to state the case for creating more interdisciplinary programs and course offerings in higher education. Spelt et al.'s (2009) review identified the subskills of IDS thinking, student conditions of IDS, and learning environment conditions for IDS, learning process conditions for IDS, and the relationships between each of these variables. They specifically addressed interdisciplinary learning theory as an advanced cognitive process, because the goal is to create a new interdisciplinary way of thinking and acquiring knowledge. Beauchamp and Beauchamp (2013) used the example of neuroscience as an interdisciplinary field as a basis to redefine disciplinary boundaries as bridges. Essentially, by simply studying departments as boundaries, researchers see them as bridging mechanisms across campus.

Further literature on IDS studies as boundary bridges includes Iacino's (2011) dissertation model on interdisciplinary team teaching which considered issues of workloads, diverse experiences, motivations, rewards, benefits, course development and management, institutional support, framing the message, and compatibility of teaching teams. Welch (2003) echoed similar sentiments when identifying future directions for strengthening IDS effectiveness in higher education administration and program delivery.

IDS Research

For many large universities, where teaching and research are intertwined, policy studies on academic research on IDS topics is also relevant. For example, Hall et al. (2008) identified collaboration readiness qualities that could measure an institutional climate for interdisciplinarity and therefore for the feasibility of implementing faculty clusters. Hall et al. (2008) evaluated research effectiveness based on short-term collaborative readiness factors such as contextual-environmental conditions, intrapersonal characteristics, and interpersonal factors, intermediate-term collaborative capacity, and long-term outcomes of collaborative products. Scales were employed to measure research orientation, history of collaboration, institutional resources, semantic-differential/impressions, interpersonal collaboration, collaborative productivity, cross-disciplinary collaboration activities, and completing deliverables.

As literature on IDS studies, research, and leadership topics emerge, a more complete picture is presented about the state of IDS on university campuses. These studies continue to contribute to the topic of IDS science PhD students and their career paths.

PhD Career Paths

To understand how universities prepare IDS science PhD students for diverse career paths, it is important to first review the literature on the career paths that PhDs pursue. This subsection presents the literature on PhD career paths, beginning with PhD graduates in general, then specifically regarding IDS PhD graduates, and ending with PhD career path studies outside of the U.S.

U.S. Studies

U.S. studies on PhD career paths are limited. In 2014, the U.S. Council of Graduate Schools (CGS) conducted a workshop and published a report on *Understanding PhD Career Pathways for Program Improvement* (Allum, Kent, & McCarthy, 2014). The focus of this report was that institutional, regional, and national data are lacking specific details on PhD employment beyond reporting on PhD holders' first jobs after graduation. More detailed employment information about their careers include the type of work they do and their long-term career trajectories. This report highlights a significant concern for U.S. higher education elaborated by the authors:

> Because the current indicators of doctoral program quality (e.g., citations, publications) take into consideration only scholarship produced within the academy, a substantial portion of the work doctoral recipients produce remains unmeasured. Our incomplete knowledge of these contributions to U.S. research, scholarship, and innovation prevents us from fully articulating the public and private value of graduate education. The lack of information about PhD graduates who work beyond the university additionally renders it impossible to know how well their doctoral education prepared them for these varied contexts. In other words, we need to know more. (p. iii)

As noted early in the CGS report, several other entities collect data on PhD holders' first job placement and salary. The most comprehensive is the National Science Foundation (NSF) Survey of Earned Doctorates (SED) which has been conducted annually since 1957 (National

Science Foundation, 2015b). Others are conducted by professional associations for specific fields within the sciences and humanities. For the purpose of this dissertation, a richer and deeper of understanding PhD career pathways would help in understanding how universities could better prepare PhD students for future diverse careers paths.

The NSF's most recent report *Doctorate Recipients from U.S. Universities: 2014* is based on the SED (National Science Foundation, 2015a). In 2014, U.S. institutions reported awarding 54,070 research doctorate degrees, which is the largest number ever reported by the SED. The majority of these degrees were awarded in science and engineering fields, which includes social sciences. Academic employment accounted for nearly half of all post-graduation commitments immediately after the PhD was earned; highest among humanities and other non-science and engineering fields (80%) and lowest among engineering (15%) and physical sciences (29%) doctorate recipients (National Science Foundation, 2015a). These SED results show a declining rate of academic employment post-graduation over the past 10 years, a theme that will recur in other studies addressed in this review of literature.

The employment rate of PhD graduates in academia is not necessarily a reflection of student preferences. Studies show that most PhD students wish to pursue academic careers (Campbell, Fuller, & Patrick, 2005; Conti & Visentin, 2015; Golde & Gallagher, 1999; Sommers-Flanagan & Christian, 2007).

However, the motivations behind student preferences for academic careers are difficult to pinpoint largely because of explicit and implicit biases which are communicated by faculty members who are in positions of influence and power over PhD students. Campbell et al. (2005) identified that students believe faculty members perpetuate a preference for academic careers, to the point where they give students "the impression that other career paths are inferior" (p. 156). Campbell et al. (2005) also report that students worry that a faculty member will no longer provide valuable advising if their non-academic career interests become known to their faculty advisors. This concern about the repercussions of disclosing a non-academic career preference seems realistic given that other studies have confirmed that faculty advisors prefer to clone themselves (Blackburn, Chapman, & Cameron, 1981; Gardner et al., 2014; Golde & Dore, 2001), or at least expect a return on their investments of time and social capital by advancing the academic state of their discipline (Campbell et al., 2005; Ferris et al., 2009).

Further, Campbell et al. (2005) found that PhD students were largely unaware of non-academic career paths due to the academic culture in their PhD programs. Similar results were found by Sommers-Flanagan and Christian (2007) which led to recommendations to improve graduate education by establishing connections between stakeholders, providing career planning and guidance, broadening training for careers outside academia, preparing students for faculty careers, and mentoring (Sommers-Flanagan & Christian, 2007).

This concept was further addressed by Foote's (2010) recommendation to utilize Austin and McDaniels' (2006) framework for doctoral student professional development. The domains of this framework are application, discovery, integration and teaching; the responsible stakeholders as agencies and foundations, professional associations, universities, graduate programs, and faculty; and preparation strategies of modeling, conversations, professional seminars, internships, and certificates (Austin & McDaniels, 2006).

Interdisciplinary PhD Career Paths in the U.S.

Studying interdisciplinary PhD career paths is even more difficult than studying those of all PhD graduates, and is important as interdisciplinary skills are desired by employers. Campbell et al. (2005) noted that "interdisciplinarity is becoming a key requirement for many jobs" (p. 157) and PhD students desire a "global job market, where collaboration between industry, universities, and government agencies in the norm rather than the exception" (p. 157). To realistically prepare students for faculty careers, they need to be exposed to tasks that are beyond research such as faculty meetings, search committees, administration, and financial budgeting (Campbell et al., 2005; Foote, 2010; Sommers-Flanagan & Christian, 2007). Also, to properly prepare for faculty careers, pedagogical preparation is needed if they will be teaching, in addition to research preparation.

To gain the perspective of students, Golde and Dore (2001) studied doctoral student perceptions of doctoral education based on a survey by the Pew Charitable Trusts. Golde and Dore (2001) pointed out that "the Ph.D. is a research degree, and as such, the students reported, their programs emphasize training in research, often to the exclusion of other skills" (Golde & Dore, 2001, p. 12). Further, "survey data show that even in preparing students for research-oriented faculty careers, doctoral programs are falling short" (p. 12). Only 27.1% of participants (N=2505) reported that their program prepared them to collaborate in interdisciplinary research, though half felt confident and comfortable in doing so, and more than half (61.2%) were interested and looking forward to it. This aspect of interdisciplinary research fell under the category of encouraging students to push the boundaries of their discipline.

Exposure to topics in ethics was also found to be lacking in PhD student preparation. Golde and Dore (2001) found that "the data indicate that the ethical dimension of faculty and professional life - how to act responsibly and in the best interests of the profession - is not, as often assumed, part of graduate training" (p.14). On the topic of career paths, most PhD students desired a tenure-track faculty position in academia, however, most did not acquire such a job after PhD completion. Further, students reported a lack of available workshops on the non-academic job market, and whether they had pursued internships to learn more about industry and government positions. From this, Golde and Dore (2001) reported "'survey results indicate that programs are better at helping students find academic positions than at helping students to explore and secure jobs in government, industry, and the non-profit sectors" (p. 19).

Studies Outside of the U.S.A.

Career pathways of PhD graduates have also been studied in university systems in countries beyond the USA. In a study of two European institutes of technology in Switzerland and Sweden, Conti and Visentin (2015) found that post-PhD careers could be predicted by the cohort size of a PhD student's program. The majority of their PhD holders preferred research-intensive careers in high-level research universities or research and development (R&D) intensive firms. However, as the cohort size increased, more PhD graduates were likely to be employed in low-ranked universities and non-R&D intensive companies, and also technology startups and administration. The authors found that increased cohort sizes showed a decrease in the availability and compensation for the preferred employment categories.

Di Paolo (2016) also used mathematical modeling in studying PhD holders in Spain. While Conti and Visentin (2015) adjusted for monetary aspects of employment, Di Paolo instead used them as a more predominant aspect of his study. Di Paolo (2016) found that four years post-graduation, PhD holders in non-academic fields were more satisfied with their salaries, but less so with their overall job quality and tasks. This study was restricted to PhD graduates under the age of 50 at the time of PhD completion. The emphasis on job satisfaction is important because that is an aspect of employment which is inherently familiar to all people and is something that is sought out as much as is realistically possible.

Beyond learning about PhD career pathways, efforts in the United Kingdom have specifically been undertaken to highlight the diverse career opportunities to PhD students and community members – essentially trying to bridge the communication gap to show students the rich opportunities in academia, industry, and government, and show these employment sectors the opportunities for hiring PhD graduates. Of their many efforts to help their doctoral graduates market themselves, many online resources have been developed such as the electronic book *10 Career Paths for PhDs* (University of Warwick, n.d.).

Established Methods for PhD Career Preparation

While career preparation has been studied in many contexts, especially among undergraduate and underrepresented student minority groups (Sadler, Burgin, McKinney, & Ponjuan, 2010), the emphasis of this case study is to present research that specifically addresses the needs of IDS science PhD students along with their faculty and programs. Practices for PhD career preparation are summarized in this section within the concepts of apprenticeships, mentoring, research supervision, and socialization.

Apprenticeship

This literature review on apprenticeship models begins with two works which provide comprehensive overviews on the topic. First, J. Randi's (2000) section on "Apprenticeship" in the *Encyclopedia of Psychology*, provides a concise description and history of apprenticeship. From Randi's (2000) description, apprenticeship is first viewed in terms of its historical use for vocational apprenticeships for crafts and trades. Randi (2000) also mentions modern innovations on apprenticeship models for global education purposes as conceptualized by cognitive apprenticeships.

Second, Ferris, Perrewé, and Buckley's (2009) book chapter "Mentoring PhD Students Within an Apprenticeship Framework" work also provides a brief overview of the history of apprenticeships going back to Ancient Greece. Randi (2000) and Ferris et al. (2009) go on to explain that formal psychological study of cognitive apprenticeship is rooted in sociocultural developmental perspectives along with cognitive psychology. There are differences, however, between vocational (or craft/trade) and cognitive apprenticeships. Vocational apprenticeships emphasize acquiring physical skills, while cognitive apprenticeships emphasize thought processes (Ferris et al., 2009). Given these differences, and given the nature of doctoral studies, this study and the review of literature will focus more specifically on cognitive apprenticeships.

Ferris et al.'s (2009) work has been one of the most direct publications regarding the application of apprenticeship models within the PhD mentorship experience. The authors heavily reference Collins et al.'s (1986, 1991) foundational work on the topic and further it to examine the history of faculty-student relationships within doctoral studies programs. They specifically reference Collins et al.'s (1986) empirical findings on the practices of apprenticeships, and change the sequence of Collins et al.'s (1986, 1991) last two steps. Ferris et al. (2009) present an apprenticeship sequence of (1) modeling, (2) scaffolding, (3) coaching, and (4) fading. They further identify major issues which include important observations regarding the often tricky to navigate interpersonal aspects of faculty-student relationships. More specifically, they state "The very characteristics of this relationship which involve close and frequent interaction among people of high intelligence and great interests, but unequal status, suggest that there is the opportunity for inspirational guidance at the one extreme, and conflicts and difficulties at the other" (Ferris et al., 2009, p. 273).

Ferris et al. (2009) also capture previous findings on the apprenticeship model by highlighting the importance of how political skills are developed during the formal and informal mentoring processes. Since much of apprenticeship, and therefore PhD mentorship, is contextual, social construction of knowledge is something that protégés observe early on as their advisors navigate their own political scenarios in the first step of modeling.

Some difficult aspects of the interpersonal relationship which is part of apprenticeship were also identified by Ferris et al. (2009) beyond political naiveté to include tolerance for ambiguity, emotional agility, and ability to assume a subservient role. The latter of these aspects is informed by Hawley's (2003) description (as cited in Ferris et al. (2009)) as a student's ability to assume a role of "neophyte" in the game of earning a PhD . This is assuredly a difficult concept for all PhD students to navigate, but is often a bigger issue for older PhD students as "such a role is probably most distasteful to the student who has held a position of authority in the outside world and must quickly adjust to the relatively powerless status of a student" (Hawley, 2003, p.26). Hawley's (2003) mention of older PhD students is relevant to IDS science PhD students because IDS programs have been found to attract older students who crave the autonomy and flexibility that IDS studies provide (Dietz & Eichler, 2013).

Ferris et al. (2009) also summarized years of observing faculty-PhD student interactions and proposed guidelines for progression, evaluation, and tracking. A PhD student's first and second year are typically characterized by content mastery and regular, frequent evaluation. The third and fourth year are largely dedicated to accumulating research experience. Careful, constructive feedback needs to be offered regularly and early monitoring is necessary so that no one slips through cracks. Eventually, when it comes to the final apprenticeship step of fading, the authors characterize the steps to include introducing the PhD student to former PhD graduates (of the same mentor) to expand the current student's professional network. A gradual sense of closure is cultivated by focusing on wrapping up research projects. And, lastly, there is a focus on future-needed skills such as how to deal with journal reviewers and to become a good journal reviewer. They even go another step to prepare both students and faculty members for what comes after the mentoring is over: redefining the relationship. Here, strong communication is required regarding new roles and relationship and a shift is made to career and research management and research collegiality. There is no perfect timeline for redefining the role; this will require judgment from both parties. Other challenges that Ferris et al. (2009) identified (even if unadvised) included friendships between the mentor and protégé (which should not be the case at the beginning), multi-student mentoring, generational issues, success in the organization sciences, and faculty training, evaluation, and promoting a culture of mentorship within academic units.

As referenced by Ferris et al. (2009), much of the earliest work on cognitive apprenticeships was led by A. Collins, whose studies will be presented in more detail here. Initially, much of his work was used to develop empirical evidence for cognitive apprenticeships in the education processes for young children in school settings. Collins, Brown, and Newman's (1986) work differentiated the methods used by teachers to impart problem-solving skills to students in the subject areas of reading, writing, and mathematics. Many of the methods involved having teachers walk students through a new technique together until the skill was successfully acquired and could be demonstrated by the student alone. The importance of Collins et al.'s (1986) is in their early documentation of the dialogues in which each learning process occurred, including the number of back-and-forth dialog sets that were needed at the beginning of a particular process in comparison to the number that were needed at the end of the process. In some cases this took a significant amount of time, even weeks, from first exposure to the technique until a final demonstration of mastery.

The reading and writing examples from Collins et al.'s (1986) study were focused on foundational skills for grade school children and did not involve any mention of vocational or career preparation. While their examples are not specific to the study of doctoral mentoring processes, this study still provides valuable insight as to how the theory and concept of cognitive apprenticeship were initially operationalized and studied for results. Lessons gleaned from Collins et al.'s (1986) cognitive apprenticeship studies can be applied to many contexts, including doctoral student advising.

More specifically, Collins et al. (1986) break down the practice of apprenticeships across the four phases of (1) modeling, (2) scaffolding, (3) fading, and (4) coaching. The scaffolding, coaching and fading are relevant for interdisciplinary studies because they are basic coaching techniques that should, theoretically, be applicable in any setting (Collins et al. 1986). Then, Collins, Brown, and Holum (1991) furthered their model of apprenticeship to add the steps of articulation, reflection, and exploration to focus on the environments of cognitive apprenticeships within the principles of content, method, sequencing, and sociology. The apprenticeship model steps, Collins et al. (1991) proposed, are part of the principle of method. Within the principle of content, knowledge and strategies are included to develop expertise. Sequencing identifies the activities needed for learning which include global before local skills, increasing complexity, and increasing diversity of practice. And lastly, Collins et al.'s (1991) principle of sociology identifies the social construction of knowledge through learning environments to include situated learning, community of practice, intrinsic motivation, and cooperation.

Billett (2016) published a recent and comprehensive review of literature on apprenticeships. In this work, he compared the historical context of apprenticeship as a mode of learning, to the modern innovations turning the concept into a model of education. For this review, Billett (2016) is concerned with the implications that arise when applying apprenticeship out of its original context. Billett begins by first addressing that a large premise of using apprenticeships to understand learning is the social engagement that occurs during this process. This premise is further supported by many human learning and development perspectives including cognitive, social constructivism, genetic epistemology, and contemporary anthropology. Billett further posits that to understand learning through apprenticeships it is necessary to recognize that the process is specific to each individual person. More specifically, he identifies several other premises of understanding these processes to include that (1) a person's individual interpretation of an experience and effort is central to her learning, (2) apprentices are constantly innovating their occupations just by engaging daily in their "occupational tasks" (p. 615) , (3) understanding that learning is the process of constructing knowledge while development is the process of accumulating the constructed knowledge, and (4) considering the distinction between personal and institutional facts. The institutional facts are those which are accumulated within the social world, occupations, education, and "workplace norms and practices" (p. 616).

Billett's (2016) literature review highlights the social aspects of PhD career preparation are a large part of the PhD experience. If PhD students are engaging mostly through an apprenticeship with a faculty member as a sole mentor, it is reasonable to expect that a PhD student who wishes to work in industry or government would perceive the experience to be incomplete if only having experienced mentorship within the university environment. The student would have missed any social and professional engagement in activities that are more relevant to his desired career sectors.

Noonan, Ballinger, and Black (2007) used focus group methodology to conduct a formative assessment for their own peer mentoring program within their special education doctoral program. Noonan et al. (2007) framed their study within Vygotsky's social constructionism and cognitive apprenticeship, the stages of mentoring leading to autonomy, and communities of practice. Noonan et al.'s (2007) work focused on predominantly non-traditional students, making several references to Knowles' (1972) theoretical framework for andragogy and learning needs of adults. Noonan et al.'s (2007) findings on doctoral mentorship were grouped across the themes of relationship, motivation, professional socialization, instruction, opportunity, and procedures. As hypothesized, students (protégés) were found to focus most on the aspects of mentorship which included "guiding, assisting, keeping on track" (p.258), peer mentors focused on the interpersonal aspects of the relationship, and faculty focused on the socialization and career preparation aspects. Noonan et al. (2007) further mapped out mentor behaviors and mentoring outcomes to align with the stages found in the apprenticeship and mentoring models in their conceptual framework.

Mentoring

Despite efforts to standardize or formalize doctoral mentoring (Rose, 2003), it is still based heavily on human relationships. This means that mentoring must remain dynamic at some level, allowing for flexible and sensitive considerations of changing needs for both student and advisor. Regarding the apprenticeship model, Park (2005) reflects on the PhD as a qualification in and of itself as a credential for supervising. "The traditional practice was to regard successful completion of a PhD as an apprenticeship that then bestows eligibility to supervise others" (p.195).

On the topic of choosing a mentor, Rose's (2003) proposed ideal mentor scale (IMS) was intended to help mentees and mentors address their own expectations for a mentoring relationship across the three constructs of integrity, guidance, and relationship. The concept of communicating expectations is always the first step in the mentorship process, so the development of the IMS was a concrete step towards doing so. The scale was not designed to determine a match for a student with a faculty mentor, but it requires student respondents to identify their own expectations of a mentoring relationship which they may not have realized or articulated. Bell-Ellison and Dedrick (2008) later attempted to validate the constructs developed in this scale, but were unable to provide statistical support. By including the IMS in this literature review, it is not intended to stipulate that all student expectations are warranted, realistic, or legitimate. However, an important first to addressing mentoring needs is to help students recognize potentially latent thoughts or preconceived notions about it. Statements on the IMS regarding expectations of a mentor ranged from academically straightforward such as a mentor should "Show me how to employ relevant research techniques," to personality types "Be a cheerful, high spirited person," or how a student wants to be treated, "Treat me as an adult who has a right to be involved in decisions that affect me" (Rose, 2003, pp. 485-486). Rose's work has practical applications to be used for incoming doctoral students to help them address which points are (or are not) realistic to expect of an academic mentor.

On the topics of gender and mentoring, Lyons, Scroggins, and Rule (1990) found no significant difference in mentoring by gender, despite their hypothesis that male students would be mentored at a higher rate. On the quality of the mentorship, they found that doctoral students who had "a close working relationship with a faculty member had a fuller education than their counterparts who had not" (Lyons et al., 1990, p. 277). They also separate the concepts of mentor and graduate supervisor, again, noting that they are not always the same – a common misconception that students do not always recognize.

While mentoring definitions and expectations vary among individuals, Rose's (2005) study followed up to see if any were correlated with independent characteristics of gender, citizenship, academic discipline, age, or status of research milestone completion. The author continued to use the IMS and its subscales grouped under the categories of integrity, guidance, and relationship. Some variations were found in mentoring needs across age, gender, and citizenship, but not across academic discipline or milestone status. Overall, Rose (2005) concludes that "individual differences seem to play a larger role than demographic or academic attributes in students' determinations of the importance of guidance" (p.76).

Blackburn, Chapman, and Cameron's (1981) study investigated mentor perspectives of the nature and quality of relationships with protégés. They found that "mentors overwhelmingly nominated as their most successful protégés those whose careers were essentially identical to their own - i.e., their 'clones'" (Blackburn et al., 1981, p. 315). This was operationalized to the level of being employed at a similar type of university based on research classification. They further determined mentor perspectives to reflect that "...those who are regarded as most successful are those who replicate the mentor's experience" (p. 320). However, Paglis, Green, and Bauer's, (2006) later study on mentoring concluded that while it positively affected student self-efficacy and productivity, mentoring was not found to have a significant effect on a student's commitment to a research career. They posit that the most effective mentoring includes a realistic view of the professoriate and academic researcher to the point where it is no longer an attractive option.

Mentoring can also affect a student's time to degree. Maher, Ford, and Thompson (2004) found statistical significance for variables among women doctoral graduates who were considered early finishers such as a "strong commitment to finish in a timely manner", "helpful advisor/committee", "productive prior professional experience", " taking a special class/finding a particular faculty mentor", and "dissertation went smoothly/able to quickly overcome problems" (Maher et al., 2004, p. 392). Beyond quantitative results, their qualitative interview responses revealed themes of commitment to timely degree completion, working relationships with faculty, funding opportunities, family issues, research experiences, and capability to make 'the system' work for them.

Research Supervision

The following literature review on doctoral research supervision literature is primarily discussed from the perspectives of faculty, students, and both faculty and students, in addition to measurement tools which have been developed to address these studies. Much of the research comes from the U.S., Australia, U.K., and Europe.

Faculty perspectives

A clear introduction for this topic comes from Halse and Malfroy's (2010) overview:

> Doctoral supervisors play a critical role in doctoral education, and ‘good’ doctoral supervision is crucial to successful research education programs... Research underlines the links between the quality of doctoral supervision and student progression and attrition rates ..., and completion rates have reputational and financial implications for universities in an increasingly competitive higher education marketplace. (p. 79)

Further, they note that "the pedagogy of doctoral supervision has been described as poorly articulated and under-theorized..., and, by others, represented as a sort of secret business" (p. 80). In their interviews of faculty supervisors, the researchers uncovered that a theme of 'professionalism' emerged in nearly every interview to describe the professional work of doctoral supervision. Then, within that theme, they uncovered five key facets.

The first facet was a learning alliance, or an "agreement between supervisor and student to work on a common goal, namely the production of a high quality doctorate" (p.83). This agreement requires mutual respect, flexibility, commitment to degree completion, communication, and strategies for progress between the doctoral supervisor and student. The second facet, habits of mind, involves the ability of doctoral supervisors to learn and reflect to appropriately judge and make decisions. The third facet of scholarly expertise was found to be central to supervising doctoral students. The doctoral supervisors in their study further described this as "theoretical knowledge acquired through reflection and thinking" and described the "principal joy...to advance their own scholarly expertise" and "intellectual pleasure" (p. 86). The fourth facet, technê, is the category for "the creative, productive use of expert knowledge to bring something into existence or accomplish a particular objective, and to give an account of what has been produced" (p. 87). The doctoral supervisors interviewed in this study identified four competencies included within technê as (i) ability to communicate appropriately within the discipline, (ii) ability to use equipment, software, and resources, (iii) skills to manage information and data, and (iv) expertise in guiding student organization and time management. The fifth facet was contextual expertise, or knowledge and understanding of doctoral study, or described as seeing their roles as doctoral supervisors as having a "noble purpose" in academia (p. 87).

H. Lee (2008) utilized interview methodology to understand how doctoral supervisors conceptualize the way they mentor PhD students. Overall, five main approaches were identified: functional, enculturation, critical thinking, emancipation, and developing a quality relationship. Many of these approaches align with the phases of apprenticeship models previously addressed (Collins et al., 1991, 1986; Ferris et al., 2009). Lee (2008) also addressed difficulties in mentoring relationships reported by PhD supervisors as those of the supervisor's professional role in contrast to her own personal self, and dependence or independence of their doctoral student. The power that supervisors' own experiences as PhD students have over their current supervisory practices was illustrated in this study.

The concept of self-reflection for PhD supervisors can be added upon with Vilkinas' (2008) use of a model typically used for managerial and government supervision when applied to that of PhD supervision. Interview content was analyzed using the integrated competing values framework (ICVF) to determine that faculty participants "were task-focused and were not able to deliver paradoxical roles; nor were they able to reflect on their supervisory capabilities and learn from those reflections" (p.297). By utilizing this model, Vilkinas (2008) found that some faculty members avoid the strain of paradoxical demands and focus only on one role instead. The ICVF model utilizes the dimensions of people-task and external-internal orientations to inform five operational roles: developer, innovator, monitor deliverer, broker, and the central role of integrator. PhD supervisors were asked to provide activities they undertook as part of supervising research students, identify which they most enjoyed doing, and whether they reflected on their research supervision capability. A majority described having a hands-on approach, enjoyed watching students develop, and did not enjoy supervising students who did not progress. Some even felt that they controlled the thesis more than they should have. They reported support that was characterized as intellectual, emotional, and structural. The study of faculty enjoyment of their roles and tasks is novel in comparison to the majority of studies which focused solely on determining roles and tasks.

Guise et al. (2012) conducted a study on interdisciplinary mentoring in interdisciplinary research careers of women's health directors. Utilizing a mixed methods approach, they found that on average, successful mentoring relationships were characterized with team mentoring (averaging three mentors per scholar), weekly mentoring meetings between a scholar and a primary mentor, explicit communications regarding mentoring agreement (typically formalized by written contract), annual evaluations of scholars, mentors, and program leadership, and institutional support for mentoring by way of education programs, tool kits, and rewards. Having more than one advisor or mentor was also found to be successful by Ives and Rowley (2005). Characteristics of unsuccessful mentoring relationships included time constraints, unclear expectations, and lack of support for scholar, mentor, or both. Guise et al (2012) reported that all scholars in their study were able to self-select their mentors pending approval by leadership.

Student Perspectives

Zhao, Golde, and McCormick (2007) surveyed students to understand how they chose a faculty advisor and rated advisor behaviors. Student selection of advisor was based on three factors: advisor reputation, intellectual capability, and pragmatic benefits. Student perceptions of advisor behaviors were categorized as academic advising, interpersonal care, career development, and cheap labor (this was an unfavorable behavior). Humanities students reported highest satisfaction with advisor behaviors. Further, they were able to determine that "there are pronounced disciplinary differences in the way doctoral students in the US approach the choice of an advisor, and also in the way the advising relationship is conducted" (pp.276-277).

Faculty and Student Perspectives

Ives and Rowley (2005) studied the progress of PhD students based on the selection process that was used to match them with dissertation supervisor. Their work was a cross-disciplinary study at an Australian university with PhD students and doctoral supervisors from the arts, business and economics, computer and information technology, engineering, and science. The themes which emerged from their study included how supervisors were assigned to students, the formal supervisory arrangements, informal supervision, and the match between student and supervisor. When studying the continuity of supervision, they found two major disruptions: students' personal problems and ill health and changes of supervision both temporary and permanent. They considered each student's thesis progress or discontinuation, and their satisfaction with supervision across three different dates or data points in the student's PhD career to learn more about satisfied students who remained satisfied and later became dissatisfied, and those who began dissatisfied and remained so. In all the cases of dissatisfied students, they were linked to inexperienced faculty supervisors who had "lower academic appointments" (p.549). They conclude with four recommendations for supervisory practice which include: (i) "supervisors and students need to feel that they have choices" (p.552) including feeling free to decline a recommendation to be matched with a student or advisor, (ii) although positive interpersonal relationships are important, professor expertise turned out to be a deciding factor for students who made steady progress in their research, (iii) have two formal supervisors who are active in supervising research who meet at least quarterly with the student, and receive written work from the student, and (iv) designate a back-up arrangement when a supervisor takes leave or is unavailable.

Malfroy (2005) used ethnographic methodology to emphasize seminars as an alternative method of passing along career preparation and research ideas for PhD students outside of the student-supervisor relationship. It was concluded that seminars could take the form of either research groups in large research laboratories or program-wide speaker series which expose students to new research methods, topics, and areas of practice. The author specifies:

> Whilst the importance of the primary relationship between a supervisor and a student remained integral to the overall management and creative endeavour, the addition of other factors, including the use of panels, the changes to management of candidatures, and the unacknowledged sharing between supervisors in supporting the students' research ideas, indicated more flexible and open practices and processes in doctoral education. (p.176)

Measurement Tools

Some tools such as surveys, scales, and formulas have been developed along the way to study interactions between doctoral students and their faculty research supervisors. Since tools, in and of themselves, are not the main topic of this dissertation study, they will be not be discussed in depth. However, to provide a complete review of the literature, it is important to mention a few which have been published on this topic. Mainhard et al.'s (2009) questionnaire on supervisor-doctoral student interaction (QSDI) was proposed to measure student perceptions of a supervisor's interpersonal style. Pearson and Kayrooz's (2004) Reflective Supervisor Questionnaire (RSQ) was designed to help PhD supervisors utilize reflection on feedback and self-reflection to understand how they practice supervision. The scales for the RSQ are grounded in hypothesized constructs of expert coaching, facilitating, mentoring, reflective practice, and sponsoring. They are intended to be used alongside four areas of "facilitative supervisory practice” (p. 99) which include facilitating the candidature, mentoring, sponsoring, and reflective practice.

In a study on faculty productivity based on PhD production, Crosta and Packman (2005) found that distribution of PhD supervision was most equal among faculty in the physical sciences, then less equal in biological sciences and humanities, and least among faculty in the social sciences. Among factors which affected a faculty member's likelihood to supervise a PhD student, the researchers found that in the humanities and biological sciences, there was a negative relationship between a faculty member's years since earning his/her own PhD and the number of PhD students that person would supervise; not so for biological and physical sciences. They also found that in general, PhD supervision increases and then decreases based on a faculty member's life cycle at the university case study.

Socialization to Doctoral Education

The concept of socialization is related to PhD studies in the context of using the PhD experience to help students develop and form identity in the communities of the doctoral level of study, content and professional areas of the study.

Baker and Lattuca (2010) described the functions of mentors and mentoring relations by grouping their behaviors into the categories of career support and psychosocial support. Further, that "social network theory does not replace theories of mentoring, but rather acknowledges that individuals rely on multiple mentors, or a ‘network’ of mentoring relationships, to navigate their personal and professional lives" (p. 810). This is related to the concept of recommending a team or group mentoring approach to mentoring (Guise et al., 2012) which aligns closely with the teamwork that naturally comes with IDS work (Borrego & Newswander, 2010; Klein, 2010;

Millar, 2013). Baker and Lattuca (2010) further refer to the developmental network of a protégé as those who take on a developer role for "knowledge development and information sharing" in addition to providing diversity of ideas (p. 811).

Regarding professionalization to the professional area of study, PhD mentorship boasts a long reputation for socializing PhD students to careers in academia. In many aspects, the discussions and recommendations which were presented on studies of research supervision mirror Austin's (2002) regarding socialization to academic careers. Even at the turn of this century, she documented concerns that academic professionals were not even finding PhD socialization adequate for the changing tasks of professorship, let alone professionals in other career paths (Austin, 2002). She recommended changes to institutions of higher education in professor development such as changing approaches to teaching and learning, increasing diversity of students, new technologies, changing societal expectations of academia, demanding faculty lifestyles, and changing conditions of the academic job market. From this study, she recommended changing the doctoral experience to include "systematic and developmentally organized opportunities for students to learn about the many aspects of faculty work" (p. 114), more regular feedback, advising, and assessment from faculty members, making "deliberate use of informal peer relationships to foster socialization" across departments (p. 115), and encouraging self-reflection in students.

Further, the professionalization aspects of academia that were called for under the section of research supervision are mirrored within the literature on socialization as well. Foote's (2010) call to make the explicit implicit includes exposing doctoral students to the lesser known aspects of academia to develop important implicit skills such as budgeting, committee work, political savvy, and interpersonal relationships. Foote also calls for "upgrading the expertise of senior faculty as much as of early career faculty" (p. 15). This last aspect, requiring continued professional development of all faculty would be difficult to enforce given the autonomy that faculty members enjoy and the emphasis of research-related tasks that is typically valued in research universities. However, continued development in this area could enhance the socialization aspects of academic professionalization.

Gardner (2008) also researched current doctoral student socialization practices and found that minorities were disproportionately disadvantaged using current practices. This adds another dimension to Blackburn et al.'s (1981) work on faculty preferences to clone themselves. If faculty are intentionally working to clone research content experts, are they also choosing to mentor and clone with people whose demographic characteristics are similar? Gardner found that the socialization in the departments in her study did not "take into account the diversity of backgrounds and experiences of today's students" (p.130).

> From the analysis of the socialization experience of doctoral students in chemistry and history at two institutions, five groups of doctoral students emerged who described their experience as one that did not 'fit the mold' of traditional graduate education including women, students of color, older students, students with children, and part-time students. These students discussed negative interactions with others, structural impediments to success, and general feelings of "differentness" that affected their overall satisfaction and integration in their degree programs. (p. 130).

Challenges for IDS PhD Advising

Boden, Borrego, and Newswander (2011) scrutinized the difficulty that comes with administering interdisciplinary academic programs as "culture of disciplinarity that dominates most higher education institutions and stands as a barrier to coexistence of a fully legitimate culture of interdisciplinarity" (p. 742). Much of the administrative issues have to do with the organizational structure of departments which universities use for allocating resources. To support any effort, even interdisciplinarity, there has to be a mechanism to obtain resources and it becomes difficult because oftentimes "deans and department heads are unwilling to commit their own resources to benefit other divisions" (p. 742). Other barriers were presented as:

> If professors cannot survive the promotion and tenure process by conducting interdisciplinary research or supervising interdisciplinary theses and dissertations, then they cannot create or sustain the organizational culture required for socialization to an interdisciplinary research career. The result is additional time and frustration for students, supervisors who discourage interdisciplinary thesis projects, and student feelings of isolation that could ultimately lead to attrition. (p. 745)

Beyond the documented reasons which make typical PhD advising problematic in modern contexts, there are additional complications in advising interdisciplinary science PhD students. Early work conducted by Golde and Gallagher (1999) identified challenges of students who wish to conduct IDS research in traditional doctoral programs. They stated that “the current structure ties students to a home department, discipline, and advisor, thus encouraging disciplinary specialization. This system discourages interdisciplinary research by doctoral scientists." (p.282). They further identified four challenges to students conducting IDS research:

(1) finding an advisor, (2) mastering knowledge and reconciling conflicting methodologies, (3) finding an intellectual community, and (4) overcoming fears.

Graybill et al. (2006) wrote from the perspective of PhD students involved in an NSF-IGERT-awarded IDS PhD program. They categorized the progress of the IGERT graduate student experience from a period of naissance “where is my home?”, to navigation “what do I prioritize?”, through maturation “how do I integrate and represent my scholarship?” (p.760). They emphasized that students in their IDS cohort had to "develop dual intellectual communities, disciplinary and interdisciplinary... in at least two places on campus (two largely disjunct sets of faculty, degree requirements, and peers" (p.760) Efforts to maintain membership in dual communities often prolonged the naissance period of development, which typically resulted in longer time to degree for IDS students. The prolonged aspect of IDS PhD work was further described by Hibbert et al. (2014) as "For those engaged in interdisciplinary scholarship, this process of identity formation may be further complicated by the need to negotiate multiple interdisciplinary identities" (p. 88).

The emotional toll of IDS work for graduate students was also reflected on by Metz (2001) as she reported leading an interdisciplinary seminar for doctoral students in education. Metz reflected on the "emotional tasks and difficulties" in IDS graduate work such as the need for "unlearning" some of the disciplinary approaches and social backgrounds that students had adopted over the years (p. 15).

Hibbert et al. (2014) also discuss the aspects of choosing a supervisor which are complicated for IDS students:

> The majority of the students we interviewed described embarking on an ID project with an idea of the type of research they wanted to do, then looking for faculty who could support their research. They talked about the difficulty of finding a supervisor who had expertise in all areas of the topic; usually, they ended up working with someone who knew one particular part of the project quite well (p.94).

Other challenges that IDS PhD students may encounter are not specific to being PhD students, but rather being IDS researchers; in other words, they also experience the same challenges that actual IDS faculty and researchers experience. At a broad level, Lau & Pasquini (2004) describe tensions in the U.K. when "academics often refuse to acknowledge the problems of interdisciplinary scholarship" (p. 49). Other key points that they found in their interviews included the "ideological split" between disciplines, "polarization of research groups", generational shifts, and "logistical and institutional obstructions to interdisciplinary scholarship" (p.49).

To improve the situation for IDS PHD students, Graybill et al. (2006) recommended providing institutional support to facilitate and encourage IDS research across departmental boundaries, encouraging students to feel a sense of ownership for their IDS experiences, serious planning efforts for both students and departments, maintaining flexibliity, and practicing appreciative inquiry. Welch (2003) also proposed recommendations which echoed the sentiments of Klein (2010) and others in the categories of curriculum, teaching methods, faculty development, administration, and program delivery.

Emerging PhD Preparation Models

Cason's (2016) dissertation on preparing PhD students for diverse career paths was operationalized in a way to focus on their communication skills; more specifically, their "ability communicate the value of their research across multiple contexts" (p. 11). Cason recommends that this step occur after basic competency in the field, but before the final culminating experience. Learning to communicate to a wide audience is further posited within the concepts of social structures and social capital. Cason proposed socializing doctoral students to diverse career paths through an institutional program, named Preparing Future Scholars, at Arizona State University. In addition to the program, a self-reflection activity is included which aligns with recommendations from other studies in this review of literature (Halse & Malfroy, 2010; Hancock & Walsh, 2016; Pearson & Kayrooz, 2004; Vilkinas, 2008). Every PhD study participant who went through this program as an intervention treatment reported feeling the need to practice these skills more.

However, Cuthbert and Molla's (2015) study points out that there are doubts as to whether professionalization training is useful to non-traditional PhD candidates who “possess considerable life and work experience” (p. 48). In their critique over whether social skills are valued in workplaces, they state that “large R&D companies in Europe preferred graduates with deep disciplinary knowledge and expertise” (p. 48).

Hancock and Walsh (2016) also conceptualize preparing PhD students for diverse career paths by referencing a new status to become knowledge workers. They "refer to 'knowledge worker' to reflect the extent to which many STEM doctoral graduates will assume in knowledge-intensive roles across society and the economy, many of which may not involve conducting scientific research" (p. 47). In their work, they suggest that the apprenticeship model to produce professional scientists can be distilled to their equation of "disciplinary knowledge + research skills + scientific norms = professional scientific identity" (p.40). However, to adjust for today's economic and educational climates, they suggest adapting this formula for creating knowledge workers by replacing disciplinary knowledge with interdisciplinary knowledge, and adding the concepts of transferable skills, reflection, and occupational experience. Their distilled formula for a reconceptualized STEM doctoral identity is presented as "interdisciplinary knowledge + research and transferable skills + reflection + occupational experience = knowledge worker" (p. 47). To accomplish this, they suggest reforms to create interdisciplinary discussion spaces, promote guided reflection among doctoral students, and encourage doctoral students to work (gain occupational experience) so that they can "experience sites of scientific knowledge production or application outside the university" (p.46).

Summary

PhD career paths have been studied in the U.S., but not at the level of depth that is necessary to draw further conclusions (Allum et al., 2014; National Science Foundation, 2015a, 2015b). Even so, until measures and studies progress to include specific details on PhD career trajectories, current trends can still be reviewed to inform how PhD students are prepared for their careers. The PhD preparation methods presented in this literature included apprenticeships, mentoring, research supervision, and socialization. Core concepts of interdisciplinary studies, and the needs of interdisciplinary programs and students were addressed within the constraints of institutional culture and how administration is organized. Given the current climate, innovations on PhD preparation methods are emerging such as efforts to promote communication of transferable skills and promote the value of hiring PhD graduates in government and industrial professional areas.

The motivation to research PhD career preparation methods for interdisciplinary (IDS) science PhD to pursue diverse career paths was presented in this chapter. To explore the study research questions, methodology is addressed in chapter three.

CHAPTER THREE: METHODOLOGY

Introduction

This case study explored research questions regarding interdisciplinary (IDS) science PhD skills that are valued by professionals across diverse career paths, use of the apprenticeship model for preparing IDS PhD graduates for their careers, and alternate pedagogical models for IDS PhD students. Variables were measured using both quantitative and qualitative instruments developed specifically for this study. The study methodology is presented in this chapter, organized into four sections: selection of participants, instrumentation, data collection, and data analysis. The quantitative and qualitative aspects of this study are further addressed within each section of this chapter.

Selection of Participants

Study participants were selected using nonrandom sampling techniques, with an aim to collect approximately 100 survey participants and 10 interviewees. Single stage sampling design was utilized due to the researcher's access to the population and ability to sample them directly (Creswell, 2009). The same population was utilized to recruit participants for both the survey and interview portions of the study. The population included students, graduates, and professionals across diverse career paths affiliated with the subject of this case study: the known professional and social networks of the interdisciplinary Modeling and Simulation (M&S) PhD program at the University of Central Florida (UCF) (N = ~1,000).

Quantitative Survey

All members of the study population (N = ~1,000) were invited to participate in an online survey for the quantitative portion of this study. Recruitment messages were sent through the

UCF M&S e-mail group for seminars and community announcements and posted on UCF M&S social media accounts through Facebook and LinkedIn. Survey participants were volunteers and were not incentivized with any direct or monetary reward. The only anticipated benefit was indirect for those who wished to contribute to the overall M&S community of students and professionals.

Survey participants were asked to identify their career sector, years of career experience, years involved in the M&S community, highest level of education and the field in which their highest degree was earned (survey items 31-35, Appendix C). Participants who identified as academia were asked to further identify their roles among the choices of full-time faculty, administrators, PhD students, adjunct faculty, and PhD mentors who are not faculty. Information about institutional affiliations was not collected for participants in this group to protect their anonymity in the reporting results. Participants who reported working in government and industry were not asked to identify their roles any further. These survey items can be seen in Appendix C.

Qualitative Interview

Interview participants were purposively sampled (Creswell, 2009) to result in a similar number of participants representing the three career paths that were the focus for this case study: academia, government, and industry. Participants were recruited using two approaches: recommendations from a well-established member of the M&S community and an optional survey item invited volunteers for interviews (survey item 39, Appendix C). The first interview recruitment approach utilized the founding director of the case study program for recommendations on M&S community members who could contribute varying points of view.

This individual is well-known in the community through his own work and has the formal expertise of assessing M&S community needs from the time when he was responsible for developing and growing the UCF M&S PhD program. The second interview recruitment approach utilized a final survey item which was optional for all participants. The interview invitation in the survey (item 39) read:

> As a member of the Modeling and Simulation community, if you would like to participate in a short interview regarding the preparation of PhD students for career success, please provide your name and best contact email. Any contact information provided here will be separated from your previous responses prior to analysis and stored separately.

Instrumentation

This case study utilized mixed methodological instrumentation as both a quantitative survey and qualitative interview were implemented. Both instruments are described in more detail in the following sub-section.

Quantitative Survey

To inform how IDS PhD students could be prepared for diverse career paths, this study set-out to determine the skills which were valued by professionals in academia, industry, and government. A review of the literature uncovered several instruments related to measuring relationships between PhD students and advisors (Mainhard et al., 2009; Pearson & Kayrooz, 2004). However no such instrument could be found to measure the perceived value of PhD, IDS, and professional science skills in one comprehensive instrument from the perspective of professionals in the field. For this reason, the Survey of PhD, Interdisciplinary, and Science

Skills was developed as a new instrument for this study (Appendix C). The Survey was utilized as a one-time survey and presented 35 short statements edited from publications of the Irish Universities Association (2015), National Science Foundation (Gamse et al., 2013), and the Burroughs Wellcome Fund & Howard Hughes Medical Institute (2006). Details on the way each of these sources was used to form the final survey are provided in the following sub-sections.

PhD Skills

PhD skill statements for this study instrument were based on the 2014 *Irish Universities' PhD Graduate Skills Statement*. Of their 35 original statements, 21 were selected for use in the final instrument development and were edited to elicit Likert-type responses and for brevity to encourage participation. Each statement also corresponds to one of seven categorical groupings, or constructs, which include research skills and awareness, ethics and social understanding, communication skills, personal effectiveness and development, team-working and leadership, career management, and entrepreneurship and innovation.

Content from the UK was selected because, as previously addressed in the review of literature, there is no centralized standard for doctoral education in the U.S. (Allum et al., 2014). While some statements on transferable PhD skills are presented on career resource center websites for individual universities (University of Michigan University Career Center, 2016), there was no U.S. standard to use as the basis for creating a new instrument. However, the education system in the U.K. has many publically available publications on this topic (University of Warwick, 2016). The UK Department for Education is operated as a centralized ministerial department through their Ministry of Education (United Kingdom Government Services, 2016). They are able to demonstrate a documented effort over many decades of centralizing standards for higher education and further promoting jobs for masters and doctoral graduates to their larger job markets for academia, industry, and government (University of Warwick Coventry, 2016).

Science Skills

Five statements on professional science competencies (survey items 22-26) were drawn from the Burroughs Wellcome Fund and Howard Hughes Medical Institute's (2006) publication, *Making the Right Moves: A Practical Guide to Scientific Management for Postdocs and New Faculty*. The statements drawn from this guide reference specific technical skills which are utilized daily by professional scientists who run laboratories. Topics included data management, technology transfer, teaching and designing courses, laboratory leadership, and mentoring abilities.

Interdisciplinary Skills

Statements on core interdisciplinarity competencies were utilized from Gamse et al.'s (2013) report on *Essential Competencies for Interdisciplinary Graduate Training in IGERT*. The statements from this report continue to accurately reflect the nature of interdisciplinarity as previously referenced in the review of the literature (Borrego & Cutler, 2010; Borrego & Newswander, 2010, 2010; Klein, 2010; Newswander & Borrego, 2009). Of the six original statements, four were selected for use in the final survey (items 27-30) and were edited to elicit Likert-type responses and for brevity and consistency.

Qualitative Interview

Semi-structured, open-ended interviews were conducted to collect more in-depth information about why and how various skills and PhD preparation techniques are valued. These data, in addition to the quantitative survey responses indicating which skills are valued, provide a more complete level of information by allowing participants to take their time and provide detailed responses (Creswell, 2009).

Interview items were developed to further address the research questions regarding participants' opinions of how they perceive PhD students are prepared and mentored as well as perceived barriers and advantages of implementing alternate pedagogical models. All interview items were asked of all interview participants and pre-determined prompts were selectively executed as needed, based on the interviewer's judgment. The researcher for this case study conducted all interviews according to the established protocol (Appendix E), audio recorded them, took notes, transcribed, and analyzed for thematic content based on Braun and Clarke's (2006) six-phase guide to qualitative thematic analysis.

Validity and Reliability

Study results were intended to accurately reflect the needs of the larger U.S. M&S community by utilizing sampling techniques and methodology which increase validity. External and content validity are further addressed in this sub-section.

External validity was assured by utilizing survey and interview sampling designs to draw from all diverse career paths included within the professional community of the subject for this case study. The combination of survey and interview methodology was intended to achieve results which could answer both general and specific questions for a richer level of data based on Creswell's (2009) mixed method approaches. Specifically, survey methodology was used to measure the general preferences within the M&S professional community; that is, which skills are most valued in different professional sectors. The interview methodology was used to follow-up in greater detail and depth to understand why and how different skills and career preparation techniques are valued. Results were further intended to contribute to the broader conversation of IDS PhD programs in general.

Content validity of the survey and interview instruments were initially determined utilizing expert judgment (Lunenburg & Irby, 2008) by nine experts including a UCF professor of educational leadership and team of eight educational leadership doctoral candidates and professionals. The experts reviewed survey items and interview questions for clarity, wording, grammar, and succinctness. The final, edited quantitative and qualitative instruments were determined to accurately communicate and measure the study research questions.

Measures were not available prior to the start of this study because these were new scales specifically developed for this study. After data collection was completed, items from the Survey of PhD, Interdisciplinary, and Science Skills were grouped by the constructs they were organized under from their corresponding publications (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2006; Gamse et al., 2013; Irish Universities Association, 2014). Each construct was then treated as its own separate scale for data analysis: PhD Skills, Interdisciplinary Skills, and Professional Science skills. Survey scales varied by the number of items each included.

Reliability calculations for the survey scales were conducted as part of the data analysis portion for this study. The 21 items used for the PhD skills scale were found to be the most reliable of the three scales overall (α=.90), then professional science skills scale (5 items; α=.76), and lastly interdisciplinary skills scale (4 items; α=.58).

Within the PhD skills scale, several constructs were separated out as subscales: research skills and awareness (6 items; α=.75), communication skills (3 items; α=.72), personal effectiveness and (5 items; α=.64), entrepreneurship and innovation (4 items; α=.81), and ethics, teamwork, and career management (3 items; α=.48).

Data Collection

Quantitative Survey

Qualtrics survey software was utilized to distribute the study survey and collect quantitative survey responses. To elicit the largest possible response, communications regarding the survey and requests for participation were prepared according to Dillman, Smyth, and Christian's (2014) tailored design method. Their method is grounded in the social exchange theory of human behavior, predicting that a person will be motivated to do something if the perceived benefits exceed the perceived costs. In the case of a voluntary survey with no monetary reward, benefits of participation were emphasized by communicating verbal appreciation, enjoyment of an interesting task, and feeling a sense of reward from helping to improve the overall M&S community.

A schedule for reminder messages was also implemented based on Dillman et al.'s (2014) tailored design method to be sent at four different times over a 30-day period, which overall yielded 133 responses. A description of the communication schedule is provided in this section in narrative form, while a summary of the schedule and corresponding response rate is presented in Figure 1 (Appendix F). On day one, formal invitations were sent to request survey participation using language to maximize a positive social exchange. The initial e-mail communication also included the study informed consent form (Appendix A). By day 10, 60 responses had been received and a second e-mail request was sent to convey that others had responded, show appreciation for their participation, and ask for the continued help of those who needed a reminder that their participation would be appreciated. By day 22, 109 responses had been received and a final e-mail reminder was sent noting scarcity of opportunity to respond as this would be the last reminder and emphasizing consistency with previous behavior to better the M&S community. At the end of day 30, the survey was closed with a total of 133 responses and a message of thanks was sent to describe the overall participation and future benefits of participating in this research study (Dillman et al., 2014). The schedule and nature of the communications were executed to encourage maximum survey participation based on Dillman et al.'s (2014) data defining the threshold between perceptions of feeling annoyed or nagged in comparison to feeling helpfully reminded about a valuable task.

Qualitative Interview

Requests for interview participation were sent individually by e-mail based on the recruiting methods previously addressed in this chapter (E-mail request template can be found in Appendix D). Interviews were conducted either in person or by phone to best accommodate each participant's preference and encourage participation. Each of the 10 overall interview participants received an informed consent (Appendix B) in the initial e-mail invitation. Second reminders were sent to three participants who did not reply to the initial invitation. A final communication of thanks was sent to each participant after the interview was complete.

Confidentiality was ensured for interview participation by assigning each person an alphanumeric code related to his/her professional sector such as Academia1, Government2, etc. Interview responses were audio recorded and transcribed verbatim except to exclude identifying information about participants. Typed interview transcriptions referenced participants only by the alphanumeric codes of their professional sectors (Academia1, Government2, etc.).

Interview protocol developed for this study was executed (Appendix E), beginning with an audio recorded informed consent process. The audio recording process was also disclosed prior to data collection. Protocol further included items designed to learn more about skills that were valued, perceptions of PhD mentoring practices, and an open-ended request for more information regarding insights to the topic of preparing interdisciplinary science PhD graduates for diverse career paths.

Data Analysis

Quantitative Survey

Quantitative survey data analysis was based on Salkind's (2004) statistical guidelines. Specifically, descriptive statistics were calculated to explore relationships between participants' professional characteristics and the extent to which skills and their accompanying constructs were valued. Analysis of variance (ANOVA) inferential tests were run to determine whether there was a significant difference among different professional groups (Salkind, 2004). To analyze internal consistency reliability, items within each construct were analyzed using Cronbach's alpha calculations as reported in chapter three (Evergreen, Gullickson, Mann, & Welch, 2011; Salkind, 2004).

Qualitative Interview

Braun and Clarke's (2006) six-phase guide to thematic analysis was used to analyze qualitative interview responses for this study. Phase one, familiarizing oneself with the data, consisted of typing transcriptions of all audio recorded interview data and "repeated reading of the data… in an active way – searching for meanings, patterns" (p. 16). This was done by highlighting meaningful quotes and noting initial ideas and summaries for interview responses alongside the raw data for consideration in later phases. In phase two, categories of codes were generated to organize interview response data into meaningful groups. Code creation was driven by the data using latent, inductive, techniques to create interpretive meanings that were interesting to the analyst based on the semantics of the exact words used in the interview response. Examples of created codes included mathematics skills, lifelong learning personality trait, and issues of depth with IDS research.

Phase three, searching for themes, utilized the codes generated in phase two and mapped them to themes using tables to visually aid in categorization. One theme, for example, included grouping all mentions of needs for mathematical, engineering, physical, and statistical skills in a theme for mathematics and technical background. In phase four, the themes were reviewed and refined to determine which would be retained, combined, and possibly discarded. In phase five, the themes were defined by quotes from the data and named based on what was interesting about them their relevance to the overall story presented by the data. And finally, in phase six a report was produced using counts of participants whose responses aligned within each coded theme.

Summary

This chapter outlined the methodology utilized to address the purpose of this case study and related research questions. The study population was provided by the subject of the case study and participants were selected from its known social and professional networks. The Survey of PhD, Interdisciplinary, and Science Skills was developed as a new quantitative instrument for this study; validity and reliability were calculated based on data from study participants. Qualitative instrumentation followed semi-structured interview methodology using interview protocol prepared for this study. Data collection procedures for survey participation were designed according to tailored design method (Dillman et al., 2014) and procedures for the interview were executed according to developed protocol. Finally, methods for quantitative and qualitative data analysis were documented. Results of the data collection and analyses follow in chapter four.

CHAPTER FOUR: PRESENTATION AND ANALYSIS OF DATA

Introduction

This study was conducted to collect and analyze perceptions of stakeholders regarding the ways interdisciplinary science PhD students prepare for diverse career paths. The purpose of this study was accomplished by surveying and interviewing stakeholders regarding the skills they value, the methods universities can use to prepare IDS science PhD students for their careers, and barriers and advantages to their proposed alternative pedagogical models. The analyzed data is presented in this chapter for the three stated research questions. Steps taken to prepare the data for analysis and descriptive statistics for the quantitative survey and qualitative interviews are presented first and then each research question is addressed separately.

Preparing Data for Analysis

Quantitative Survey Data

To prepare survey data for analysis, items from the Survey of PhD, Interdisciplinary, and Science Skills were grouped by the constructs they were organized under from their corresponding publications (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2006; Gamse et al., 2013; Irish Universities Association, 2014). Each construct was then treated as its own separate scale for data analysis: Interdisciplinary Skills, Communication Skills, Personal Effectiveness/Development, Research Skills and Awareness, Entrepreneurship and Innovation, Professional Science, and Ethics, Teamwork, and Career Management. Survey scales varied by the number of items each included.

Likert-type responses from survey participants were coded as ordinal data in the order of Strongly Agree (4), Somewhat Agree (3), Somewhat Disagree (2), and Strongly Disagree (1).

Based on survey design guidelines (Krosnick, 2002; Krosnick & Presser, 2010), responses of Do Not Know and non-responses were not calculated for statistical testing, however counts were still tabulated for analysis.

Qualitative Interview Data

To prepare interview data for analysis, Braun and Clarke's (2006) six-phase guide to thematic analysis was followed. In the first phase of becoming familiar with the data, each interview was transcribed from its audio recording according to study protocol (Appendix E). Phase two generated initial codes whereby interesting phrases, ideas, quotes were highlighted within the transcriptions inducing meanings to be interpreted in later phases. In phase three, themes were searched by combing through the highlighted material, and in phase four, themes were reviewed for overlap and consistency. Phase five resulted in using semantical techniques to define and name themes based on actual words and phrases taken from the interview data. The final report of themes from interview responses was produced in phase six.

Descriptive Statistics

Quantitative Survey Data

Survey Participants

The quantitative methodology of this case study aimed to collect approximately 100 responses to the newly developed Survey of PhD, Interdisciplinary, and Science Skills. An invitation to complete the survey was sent to approximately 1,000 members of the UCF M&S professional community. A total of 133 responses were collected from the online survey, for a response rate of 13.3 percent. However, 37 of these responses did not provide any data beyond the informed consent item, which was the first item of the survey. Therefore, only 96 responses complete enough to yield data were analyzed, yielding a 9.6 percent rate of responses which could be analyzed.

Descriptive statistics were collected from participant responses to survey items 31-37. The majority of survey participants described themselves as being in the academic career sector (n = 48), being in their current professional sector for one to five years (n = 42), being involved in the Modeling and Simulation community for one to five years (n = 40), holding a master's degree as their highest level of education (n = 52), having the field of modeling and simulation for their highest level of education (n = 20), and having worked in a university research laboratory (n = 64). Each of these descriptive variables is addressed in the following subsections with corresponding tables.

Professional Career Sector. Survey item 31 asked participants to select from a list of career sector categories that applied to them. Table 2 reports survey participants according to self-reported career sector. Overall, survey participants (N = 96) represented each of the diverse career paths that were the focus of this case study: academia, government, and industry. Some participants self-identified as more than one of these career paths, and were therefore assigned to hybrid categories of academia and government, academia and industry, government and industry, and academia, government, and industry. Remaining participants did not identify any career sector. The career sector represented by most survey participants was academia (n=48), then industry (n=13), academia and industry (n=12), government (n=11), unidentified (n=4), academia and government (n=3), government and industry (n=3), and lastly those who represented all career sectors of academia, government, and industry (n=2).

Table 2

Survey Participants by Career Sector (N=96)

Career Sector	*Participants*	*Participant Percent*
Academia	48	50.00
Government	11	11.46
Industry	13	13.54
Academia and Government	3	00.03
Academia and Industry	12	12.50
Government and Industry	3	00.03
All: Academia, Government, and Industry	2	00.02
No career sector identified	4	00.04

Note: Participants were not duplicated nor did they overlap between career sector groups.

Participants who identified a career sector of academia, including academia hybrid categories, were asked to further specify their roles in academia in survey item 31a by selecting as many of the preset choices with which they identified: full-time faculty (*n*=23), administrator (*n*=6), PhD student (*n*=32), adjunct faculty (*n*=8), and non-faculty mentor to PhD students (*n*=5). Table 3 presents the analysis of roles in academia reported by survey participants.

Table 3

Role in Academia (n=65)

Career Sector		*Role in Academia*				
	n	*Full-Time Faculty*	*Administrator*	*PhD Student*	*Adjunct Faculty*	*Mentor, Non-Faculty for PhD students*
Academia	48	20	4	23	2	3
Academia and Government	3	0	1	0	3	1
Academia and Industry	12	2	1	8	3	1
All: Academia, Government, and Industry	2	1	0	1	0	0

Note: Some overlap between academic roles as participants could choose more than one.

Of all participant characteristics collected in this study, professional career sector was focused on the most. Remaining participant characteristics are still discussed in the following sub-sections, but several of the remaining characteristics are presented within corresponding professional career sectors to provide a more descriptive detail of survey participants.

Time in Current Professional Sector. Length of time in current professional sector was established using survey item 32 which asked participants "How long have you been in your current professional sector?" Response options were available in increments of five years. The highest response was for one to five years (*n*=42), then 11-15 years (*n*=13), six to 10 years (*n*=9), 16-20 years (*n*=8), none or not applicable (*n*=7), 21-25 years (*n*=6), 26-30 years (*n*=6), and 31 years or more (*n*=5). Table 4 reports the length of time participants have been in their current professional sector.

Table 4

Length of Time in Current Professional Sector (N=96)

Career Sector	*Years*							
	0	*1-5*	*6-10*	*11-15*	*16-20*	*21-25*	*26-30*	*31+*
Academia	3	27	6	7	3	1	0	1
Government	1	3	1	2	2	0	0	2
Industry	0	3	2	2	1	1	3	1
Academia and Government	0	1	0	0	1	1	0	0
Academia and Industry	0	6	0	1	1	2	1	1
Government and Industry	0		0	1	0	1	1	0
All: Academia, Government, and Industry	0	1	0	0	0	0	1	0
No career sector identified	3	1	0	0	0	0	0	0

Time Involved in Modeling and Simulation Community. Length of time in in the overall modeling and simulation community was established using survey item 33 which asked participants "How many years have you been involved in the M&S community?" Response options were available in increments of five years. The highest response was for one to five years (*n*=40), then six to 10 years (*n*=20), none or not applicable (*n*=9), 11-15 years (*n*=9), 16-20 years (*n*=6), 26-30 years (*n*=6), 21-25 years (*n*=5), and 31 years or more (*n*=1). Table 5 reports the time involved in the modeling and simulation community by current professional sector.

Table 5

Time Involved in Modeling and Simulation Community (N=96)

Career Sector	*Years*							
	0	*1-5*	*6-10*	*11-15*	*16-20*	*21-25*	*26-30*	*31+*
Academia	4	24	11	5	3	0	1	0
Government	1	3	1	2	1	2	1	0
Industry	1	4	2	0	0	2	3	1
Academia and Government	0	1	1	1	0	0	0	0
Academia and Industry	1	5	4	0	2	0	0	0
Government and Industry	0	0	0	1	0	1	1	0
All: Academia, Government, and Industry	0	1	1	0	0	0	0	0
No career sector identified	2	2	0	0	0	0	0	0

Highest Level of Education. Highest level of education was established using survey item 34. Most survey participants reported their highest level of education as a master's degree (*n*=52), then doctoral degree (*n*=28), bachelors degree (*n*=13), and other (*n*=2). One participant did not respond to this survey item. Table 6 reports highest levels of education by current professional sector.

Table 6

Highest Level of Education (N = 95)

Career Sector	*Highest Degree*			
	Bachelors	*Masters*	*Doctoral*	*Other*
Academia	6	21	20	1
Government	1	8	2	0
Industry	1	9	3	0
Academia and Government	0	2	1	0
Academia and Industry	1	9	1	0
Government and Industry	0	2	0	1
All: Academia, Government, and Industry	1	1	0	0
No career sector identified	3	0	1	0

Field of study for highest level of education was established using survey item 35. Responses were collected using an open text field which resulted in re-organizing some responses which overlapped or were misspelled. Responses were highest for survey participants in Modeling and Simulation, STEM fields overall, and fields of psychology. Other fields of study represented included arts and humanities, behavioral sciences, education, health and public affairs, and business. A list of all fields of study identified for participant highest level of education is reported in Table 7.

Table 7

Field of Highest Level of Education in Rank Order (*N*=96)

Academic Field	*n*
Modeling and Simulation	20
Engineering & Computer Science	18
Psychology	15
Physics	4
Mathematics	2
Accounting	1
Business Information Management	1
Business Intelligence	1
Communication	1
Computing And Information Systems	1
Counseling	1
Digital Media/Virtual Reality	1
Energy Engineering	1
Human Resource Management	1
Image Processing	1
Industrial Ergonomics	1
Instructional Technology	1
Interactive Technology	1
International Business	1
International Relations	1
Industrial	1
Business Administration (Logistics)	1
MBA Entrepreneurship And Strategy	1
Human Factors and Ergonomics	1
Nonprofit Management and Instructional Design and Technology	1
Nursing	1
Philosophy	1
Political Science	1
Public Administration	1
Public Health And Physician Assistant Studies	1
Solar Energy	1
Technical Communication	1
Texts & Technology	1

University Research Laboratory Experience. Survey item 36 asked participants whether they had worked in a university research laboratory. Those who responded yes to this item were prompted to identify the academic field in which their laboratory was situated (survey item 35a) and activities which they had personally contributed to or experienced in the laboratory (survey item 35b). Table 8 shows that a majority of 66.67% of survey participants reported having worked in a university research laboratory (*n*=64). Participants who had laboratory experience reported it mostly in the fields of human factors psychology, simulation and training, and several engineering related fields (survey item 36b).

Table 8

University Research Laboratory Experience (N=96)

Worked in a University Research Laboratory	*Participants*	*Participant Percent*
Yes	64	66.67
No	32	33.33

Participants who indicated having worked in a research laboratory were asked to further indicate activities to which they had personally contributed in survey item 37. Response options were preset and more than one could be selected. Results are reported in Table 9. The most common laboratory activities reported among survey participants were having searched research literature (*f*=58), analyzed data (*f*=56), collected data or ran study participants (*f*=50), and presented at meetings (*f*=50). Participants who selected the option to report other activities filled in the free text with responses such as “defined strategic objectives and technical milestones of research and development projects with academic and government lab collaborations”, “coordinated with workers in construction and traffic engineers”, “applied for funding (internal & external grants)”, “marketing, administrative”, and “developed software”.

Table 9

Ranked Laboratory Experience (N=96)

Laboratory Activity	*f*
Searched research literature	58
Analyzed data	56
Collected data/ Ran study participants	50
Presented at meetings	50
Wrote literature reviews	40
Managed others in the lab	39
Managed project timelines	38
Researched a novel topic which did not have funding	33
Decided on research topics for the laboratory	30
Rotated through more than one laboratory	29
Managed a budget	20
Other	8

Note. Survey participants were able to select as many laboratory activities as applicable.

Survey Items

Quantitative survey data relied on responses to the Survey of PhD, Interdisciplinary, and Science Skills items 1-30. To address descriptive statistics, some general data are presented in this section. Data which was more specifically related to testing the research questions are presented in the following sections.

On each of the 30 survey items, participants rated their level of agreement regarding the perceived importance for professionals in their career sector to have each skill. As previously described, Likert-type responses from survey participants were coded as ordinal data in the order of Strongly Agree (4), Somewhat Agree (3), Somewhat Disagree (2), Strongly Disagree (1), and Do Not Know. Responses of Do Not Know were not calculated for data analysis, however it is important to mention that this response option was utilized by survey participants for at least one item in each scale. The survey item rated highest overall was “Apply principles of ethical conduct of research" (*M* = 3.87, *SD* = .04), and the item rated lowest overall was "Lead a science laboratory" (*M* = 2.74, *SD* = .81).

Survey items which elicited the most responses of Do Not Know were "Appreciate the skills required for the development of entrepreneurial enterprises" (*n* = 7), "Understand technology transfer" (*n* = 5), "Critically reflect on experiences and act on such in a cycle of self-improvement" (*n* = 4), and "Lead a science laboratory" (*n* = 4). There was only one survey item which did not elicit any response at all, "work in a team with individuals prepared in different disciplines." Table 10 reports the frequency of responses, mean, and standard deviation scores for all 30 survey items. Counts of Do Not Know and non-responses for each survey item are also included in Table 10.

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Table 10

Frequency of Responses and Descriptive Statistics for Survey of PhD, Interdisciplinary, and Science Skills Items (N = 96)

Survey No.	*Item*	*f*	*Strongly Agree (4)*	*Somewhat Agree (3)*	*Somewhat Disagree (2)*	*Strongly Disagree (1)*	*Do Not Know*	*No Response*	*Mean*	*Std Dev.*
1	Exhibit knowledge of advances and developments in the field.	96	80	15	0	1	0	0	3.81	.46
2	Employ appropriate research methodologies.	96	84	10	1	1	0	0	3.84	.47
3	Solve research problems and interpret research results.	96	81	13	1	1	0	0	3.81	.50
4	Demonstrate knowledge of health and safety procedures.	96	43	39	9	2	3	0	3.32	.74
5	Knowledge of funding and grant application procedures.	96	37	42	13	3	1	0	3.19	.77
6	Apply basic principles of project and time management.	96	69	23	1	0	3	0	3.73	.46
7	Apply principles of ethical conduct of research.	96	85	8	2	0	1	0	3.87	.39
8	Demonstrate effective writing and publishing skills.	96	69	22	3	0	2	0	3.70	.52
9	Use appropriate forms and levels of communication.	96	70	20	3	1	2	0	3.69	.59
10	Communicate research to diverse audiences.	96	61	30	4	1	0	0	3.57	.63
11	Operate with independence and initiative to accomplish goals.	96	66	24	2	1	3	0	3.67	.58
12	Demonstrate key rhetorical skills, including persuasion.	96	55	32	7	1	1	0	3.48	.64
13	Initiate new projects, react to new needs, resolve problems.	96	62	31	2	0	1	0	3.63	.53
14	Handle difficulties in an appropriate way.	96	76	15	2	0	3	0	3.80	.46
15	Critically reflect and act on cycle of self-improvement.	96	59	32	1	0	4	0	3.63	.51
16	Work in a collaborative environment.	96	66	19	8	0	3	0	3.62	.64
17	Know transferable skills for academia and non-academia.	96	57	30	4	2	3	0	3.53	.69
18	Understand the role of innovation and creativity in research.	96	66	23	6	0	1	0	3.63	.58
19	Be aware of and understanding intellectual property issues.	96	57	29	9	1	0	0	3.48	.70
20	Appreciate the skills of entrepreneurial development.	96	29	40	18	2	7	0	3.08	.80
21	Understand the contribution of knowledge transfer to society.	96	45	38	11	1	1	0	3.34	.75
22	Lead a science laboratory.	96	16	45	22	9	4	0	2.74	.81
23	Mentor and be mentored by others.	96	65	25	3	2	1	0	3.61	.61
24	Manage data and utilize laboratory notebooks when needed.	96	50	33	12	0	1	0	3.40	.71
25	Understand technology transfer.	96	46	33	10	2	5	0	3.35	.77
26	Teach and design courses.	96	24	43	21	8	0	0	2.86	.86
27	Develop depth of knowledge in one discipline or field.	96	61	28	5	1	1	0	3.57	.65
28	Recognize strengths and weaknesses of multiple disciplines.	96	63	30	2	0	1	0	3.64	.52
29	Apply approaches and tools from multiple disciplines.	96	70	25	1	0	0	0	3.72	.47
30	Work in team with others prepared in different disciplines.	96	74	16	3	0	2	1	3.76	.50

*Note.*Survey items are abbreviated in this table, as full text is provided in Appendix C.

Survey Scales

Table 11 presents general descriptive statistics for scales constructed based on items 1-30 of the Survey of PhD, Interdisciplinary, and Science Skills. The survey scales which resulted in the highest rating were tied between Ethics, Teamwork, and Career Management (*M*=3.67, *SD*=.41) and Interdisciplinary Skills (*M*=3.67, *SD*=.36). The scales with the next highest means were Communication Skills (*M*=3.66, *SD*=.46), Personal Effectiveness/Development (*M*=3.65, *SD*=.37), and Research Skills and Awareness (*M*=3.62, *SD*=.39). The scales rated lowest were Entrepreneurship and Innovation (*M*=3.38, *SD*=.56) and Professional Science Skills (*M*=3.19, *SD*=.54). Survey scales which elicited the most responses of Do Not Know were Personal Effectiveness/ Development, Entrepreneurship and Innovation, and Professional Science.

Table 11

Scale Descriptive Statistics in Rank Order by Scale Mean (Possible Range 1-4, N=96)

Scale Name	*Number of Items*	*Lowest Item Mean*	*Highest Item Mean* ↓	*Scale Mean*	*Scale Std Dev.*
Ethics, Teamwork, and Career Management	3	3.53	3.87	3.67	.41
Interdisciplinary Skills	4	3.57	3.76	3.67	.36
Communication Skills	3	3.57	3.70	3.66	.46
Personal Effectiveness/Development	5	3.48	3.80	3.65	.37
Research Skills and Awareness	6	3.19	3.84	3.62	.39
Entrepreneurship and Innovation	4	3.08	3.63	3.38	.56
Professional Science	5	2.74	3.61	3.19	.54

The following sub-sections present descriptive statistics for each of the survey scales in descending order of highest mean.

Ethics, Teamwork, and Career Management Scale. Descriptive statistics for the Ethics, Teamwork, and Career Management Scale are presented in Table 12. This scale included three items with item means which ranged from 3.53 to 3.87. The standard deviation for scale items ranged from 0.39 to 0.69. The item "apply principles of ethical conduct of research" had the highest mean in this scale (*M*=3.87, *SD*=.39) and was also the item with the highest mean for the whole survey. Overall, participants reported highly valuing the skills of ethics, working in a collaborative environment, and being aware of transferrable skills between academic and non-academic careers.

Table 12

Descriptive Statistics: Ethics, Teamwork, and Career Management Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range**	*Mean*	*Std Dev*
7. apply principles of ethical conduct of research.	96	2.00-4.00	3.87	.39
16. work in a collaborative environment.	96	2.00-4.00	3.62	.64
17. demonstrate awareness of transferable skills to both academic and non-academic positions.	96	1.00-4.00	3.53	.69

Note. Survey of PhD, Interdisciplinary, and Science Skill items were rated 1-4 by participants.

Interdisciplinary Skills Scale. Descriptive statistics for the Interdisciplinary Skills Scale are presented in Table 13. This scale included four items with item means ranging from 3.57 to 3.76. The standard deviation for scale items ranged from 0.47 to 0.65. The item "work in a team with individuals prepared in different disciplines" had the highest mean in this scale (*M*=3.76, *SD*=.50). Overall, participants reported highly valuing the skills of developing knowledge in a discipline, learning approaches and tools from multiple disciplines, recognizing the strengths and weaknesses of multiple disciplines, and working in interdisciplinary teams.

Table 13

Descriptive Statistics: Interdisciplinary Skills Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
27. develop depth of knowledge in one discipline or field of study.	96	1.00-4.00	3.57	.65
28. recognize the strengths and weaknesses of multiple disciplines.	96	2.00-4.00	3.64	.52
29. apply approaches and tools from multiple disciplines to address research problem.	96	2.00-4.00	3.72	.47
30. work in a team with individuals prepared in different disciplines.	96	2.00-4.00	3.76	.50

Communication Skills Scale. Descriptive statistics for the Communication Skills Scale are presented in Table 14. This scale included three items with item means ranging from 3.57 to 3.70. The standard deviation for scale items ranged from 0.52 to .63. The item "demonstrate effective writing and publishing skills" had the highest mean in this scale (*M*=3.70, *SD*=.52). Overall, participants reported highly valuing the skills of writing, publishing, and communicating research to diverse audiences.

Table 14

Descriptive Statistics: Communication Skills Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
8. demonstrate effective writing and publishing skills.	96	2.00-4.00	3.70	.52
9. effectively use appropriate forms and levels of communication.	96	1.00-4.00	3.69	.59
10. communicate research to diverse audiences.	96	1.00-4.00	3.57	.63

Personal Effectiveness/Development Scale. Descriptive statistics for the Personal Effectiveness and Development Scale are presented in Table 15. This scale included five items with item means ranging from 3.48 to 3.80. The standard deviation for scale items ranged from 0.46 to 0.64. The item "handle difficulties in research or other professional activities in an appropriate way" had the highest mean in this scale (*M*=3.80, *SD*=.46). Overall, participants reported highly valuing the skills of operating independently, persuading others, initiating new projects, and handling professional difficulties appropriately.

Table 15

Descriptive Statistics: Personal Effectiveness/Development Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
11. operate in an independent and self-directed manner, showing initiative to accomplish clearly defined goals.	96	1.00-4.00	3.67	.58
12. demonstrate key rhetorical skills, including how to persuade others of a viewpoint's merits.	96	1.00-4.00	3.48	.64
13. initiate new projects, proactively reacting to newly identified needs or aiming to resolve persistent problems.	96	2.00-4.00	3.63	.53
14. handle difficulties in research or other professional activities in an appropriate way.	96	2.00-4.00	3.80	.46
15. critically reflect on experiences and act on such in a cycle of self-improvement.	96	2.00-4.00	3.63	.51

Research Skills and Awareness Scale. Descriptive statistics for the Research Skills and Awareness Scale are presented in Table 16. This scale included six items with item means ranging from 3.19 to 3.84. The standard deviation for scale items ranged from 0.46 to 0.77. The item “comprehend and effectively employ appropriate research methodologies” had the highest mean in this scale (*M*=3.84, *SD*=.47). Overall, participants reported highly valuing the skills of exhibiting knowledge in their field, comprehending research methodologies, and forming and applying research solutions. Items that were less valued in this scale were about knowledge of health, safety, and funding sources in research environments.

Table 16

Descriptive Statistics: Research Skills and Awareness Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
1. exhibit knowledge of advances and developments in the field.	96	1.00-4.00	3.81	.46
2. comprehend and effectively employ appropriate research methodologies.	96	1.00-4.00	3.84	.47
3. formulate and apply solutions to research problems and effectively interpret research results.	96	1.00-4.00	3.81	.50
4. demonstrate a knowledge of health and safety procedures in the research environment.	96	1.00-4.00	3.32	.74
5. have a broad knowledge of relevant funding sources and grant application procedures.	96	1.00-4.00	3.19	.77
6. apply basic principles of project and time management.	96	2.00-4.00	3.73	.46

Entrepreneurship and Innovation Scale. Descriptive statistics for the Entrepreneurship and Innovation Scale are presented in Table 17. This scale included four items with item means ranging from 3.08 to 3.63. The standard deviation for scale items ranged from 0.58 to 0.80. The item "understand the role of innovation and creativity in research" had the highest mean in this scale (*M*=3.63, *SD*=.58). Overall, participants reported somewhat valuing the skills of understanding innovation and creativity in research and intellectual property issues. Items that were less valued in this scale related to developing entrepreneurial enterprise and contributions of technology transfer to society.

Table 17

Descriptive Statistics: Entrepreneurship and Innovation Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
18. understand the role of innovation and creativity in research.	96	2.00-4.00	3.63	.58
19. demonstrate an awareness and understanding of intellectual property issues.	96	1.00-4.00	3.48	.70
20. appreciate the skills required for the development of entrepreneurial enterprises.	96	1.00-4.00	3.08	.80
21. understand the contribution that knowledge transfer can make to society.	96	1.00-4.00	3.34	.75

Professional Science Scale. Descriptive statistics for the Professional Science Scale are presented in Table 18. This scale included five items and had the lowest mean of all survey scales. Scale item means ranged from 2.74 to 3.61. The standard deviation for scale items ranged from 0.61 to 0.81. The item "mentor and be mentored by others" had the highest mean in this scale (*M*=3.61, *SD*=.61). Overall, participants reported somewhat valuing the skills of managing data and understanding technology transfer. Items that were less valued in this scale related to teaching and designing courses and leading a science laboratory.

Table 18

Descriptive Statistics: Professional Science Scale (N = 96)

Item *It is important for professionals in my field to…*	*n*	*Range*	*Mean*	*Std Dev*
22. lead a science laboratory.	96	1.00-4.00	2.74	.81
23. mentor and be mentored by others.	96	1.00-4.00	3.61	.61
24. manage data and utilize laboratory notebooks when necessary.	96	2.00-4.00	3.40	.71
25. understand technology transfer.	96	1.00-4.00	3.35	.77
26. teach and design courses.	96	1.00-4.00	2.86	.86

Qualitative Interview Data

The qualitative study methodology aimed to collect approximately 10 responses. This target was met with a total of 10 interviews conducted. Since women are a minority in STEM fields (Gardner, 2008) and the M&S community is a relatively tight-knit community, descriptions of interview participants will remain categorized only by professional sector and will not include information about gender, professional organizations or positions, or years of experience in order to retain anonymity for participants.

However, career sectors of interview participants were used to establish context for the case study. As addressed in Chapter 1, employment for graduates of the UCF M&S PhD program is nearly split evenly between the career sectors of academia and government and industry. This even distribution was ensured for qualitative interview participants and is reported in this section. Additional information about advising experiences of qualitative interview participants was collected and will be reported in this section, which mirrored the diverse advising experiences reported by UCF M&S PhD students and graduates.

Career sectors of interview participant were collected using interview item one (Appendix E) which asked participants to tell the researcher about their professional background. Responses to this interview item were analyzed and assigned to the career sectors which were the focus of this case study: academia (*n*=2), industry (*n*=2), and government (*n*=2). Similarly to the quantitative survey responses, some interview participants also self-identified as more than one career path to create hybrid categories of government and academia (*n*=2), government and industry (*n*=1), and one whose career had spanned all three career sectors of academia, government, and industry (*n*=1). While some participants may have overlapped between survey and interview participants, the amount of overlap could not be determined because survey responses were collected anonymously. Overall, career sectors of interview participants were distributed relatively evenly among the three professional career paths that were the focus of this study. Table 19 reports interview participants by their career sector.

Table 19

Interview Participants by Career Sector (N=10)

Career Sector	*n*	*% Total*
Academia	2	20
Government	2	20
Industry	2	20
Government and Academia	2	20
Government and Industry	1	10
All: Academia, Government, and Industry	1	10

Note: Participants were not duplicated nor did they overlap between career sector groups.

Testing the Research Questions

Descriptive statistics were used to test the three research questions of this case study. Data analysis was conducted as summarized in Table 1. To briefly restate, the first research question asked about the extent to which participants valued various skill statements. It was tested using both quantitative and qualitative methods. Quantitative analysis was based on Salkind’s (2004) guidelines using responses to the Survey of PhD, Interdisciplinary, and Science Skills (Appendix C) using descriptive statistics and Analysis of Variance (ANOVA) to compare the means of professional career sectors and the degree to which each scale was valued.

Qualitative analysis for research question one was conducted based on Braun and Clarke's (2006) six-phase guide to thematic content analysis using interview responses that were collected in this case study (Appendix E, items 1-4). Further qualitative thematic content analysis from the interviews was further utilized to test the second research question (interview item 5) and the third research question (interview items 6-8). Specific results for each research question are presented in the following subsections.

Research Question 1

Question 1: To what extent do participants value the science, interdisciplinary, and PhD skill statements? To answer research question one, analyses were conducted on the quantitative data from the Survey of PhD, Interdisciplinary, and Science Skills and qualitative data from the case study interviews.

Quantitative Results

Survey participants self-identified their own professional career sectors (survey item 31) and their level of agreement regarding the importance of skills identified in the Survey of PhD, Interdisciplinary, and Science Skills (survey items 1-30). Career sector responses were collected using the categories of academia (AC), government (GOV), and industry (IND). Survey participants who responded using more than one career sector category were assigned new hybrid categories to capture their responses, such as academia and government (AC-GOV), academia and industry (AC-IND), government and industry (GOV-IND), and academia, government, and industry (AC-GOV-IND). Participants who did not identify any career sector, but still rated the survey items were categorized as unidentified (UN-ID).

Survey Items. Responses to survey items were analyzed by participant career sector and are reported in Table 20. The item with the highest mean among the most career sectors was "work in a collaborative environment" in five out of eight career sectors: government (GOV), industry (IND), academia and industry (AC-IND), government and industry (GOV-IND), and unidentified (UN-ID). This item was part of the newly combined Ethics, Teamwork, and Career

Management Scale which was also rated highest by the most career sectors. The item with the lowest mean rating among the most career sectors was “lead a science laboratory” in five out of eight career sectors: AC, IND, AC-IND, GOV-IND, and UN-ID. This item was part of the Professional Science scale which was rated lowest by the most career sectors.

Within the career sector of academia, there was a two-way tie for the survey items with highest means for “formulate and apply solutions to research problems and effectively interpret research results” (M = 3.96) and “apply principles of ethical conduct of research” (M = 3.96), while the survey item with the lowest mean was “lead a science laboratory” (M = 2.89). Government responses with the highest means were also tied among five survey items: “exhibit knowledge of advances and developments in the field”, “comprehend and effectively employ appropriate research methodologies”, “apply basic principles of project and time management”, “work in a collaborative environment”, and “work in a team with individuals prepared in different disciplines” (M = 3.91). Government responses with the lowest mean was for the survey item “teach and design undergraduate courses” (M = 2.73). Industry responses were highest for the survey item “work in a collaborative environment” (M = 3.96) and lowest for “lead a science laboratory” and “teach and design courses” (M = 2.15).

Table 20 *Survey Item and Scale Means Reported by Professional Career Sector (N=96, Possible Range 1-4)*

	Professional Sector							
Scale	*AC*	*GOV*	*IND*	*AC-GOV*	*AC-IND*	*GOV-IND*	*AC-GOV-IND*	*UN-ID*
Item *n*	48	11	13	3	12	3	2	4
Research Skills and Awareness	**3.74**	**3.71**	**3.39**	**3.44**	**3.53**	**3.50**	**2.58**	**3.71**
Exhibit knowledge of advances and developments in the field.	3.88	3.91[a]	3.92	3.67	3.67	3.67	2.50[b]	3.75
Employ appropriate research methodologies.	3.94	3.91[a]	3.69	3.67	3.83	3.67	2.50[b]	4.00[a]
Solve research problems and interpret research results.	3.96[a]	3.73	3.69	3.33	3.83	3.67	2.50[b]	3.75
Demonstrate knowledge of health and safety procedures.	3.47	3.55	2.77	3.50	3.27	3.00	2.50[b]	3.50
Knowledge of funding and grant application procedures.	3.45	3.27	2.54	3.00	2.92	3.00	3.00	3.25
Apply basic principles of project and time management.	3.77	3.91[a]	3.69	3.00	3.64	4.00[a]	2.50[b]	4.00[a]
Ethics, Teamwork, and Career Management	**3.68**	**3.82[a]**	**3.46**	**3.78**	**3.83[a]**	**3.67**	**2.83**	**3.92[a]**
Apply principles of ethical conduct of research.	3.96	3.82	3.77	4.00	3.83	4.00	3.00	3.75
Work in a collaborative environment.	3.46	3.91	3.96	3.50	3.83	4.00	3.00	4.00
Know transferable skills for academic and non-academic positions.	3.62	3.73	2.83	3.67	3.83	3.00	2.50	4.00
Communication Skills	**3.75**	**3.67**	**3.39**	**3.33**	**3.67**	**3.78**	**3.00**	**3.83**
Demonstrate effective writing and publishing skills.	3.83	3.73	3.54	3.33	3.45	3.67	3.00	4.00[a]
Effectively use appropriate forms and levels of communication.	3.76	3.73	3.38	3.33	3.83	4.00[a]	3.00	3.75
Communicate research to diverse audiences.	3.67	3.55	3.23	3.33	3.67	3.67	3.00	3.75
Personal Effectiveness/Development	**3.65**	**3.73**	**3.56**	**3.64**	**3.75**	**3.60**	**3.00**	**3.65**
Operate with independence and initiative to accomplish goals.	3.64	3.82	3.77	4.00[a]	3.64	3.67	3.00	3.50
Demonstrate key rhetorical skills, including persuasion.	3.45	3.64	3.31	3.33	3.92	3.33	2.50[b]	3.50
Initiate new projects, react to new needs, and resolve problems.	3.67	3.82	3.54	3.33	3.55	3.67	3.00	3.75
Handle difficulties in an appropriate way.	3.89	3.73	3.54	4.00[a]	3.90	3.67	3.00	3.75
Critically reflect and act on cycle of self-improvement.	3.61	3.64	3.67	3.67	3.73	3.67	3.00	3.75
Entrepreneurship and Innovation	**3.45**	**3.46**	**2.96**	**3.08[b]**	**3.50**	**3.75**	**2.86**	**3.58**
Understand the role of innovation and creativity in research.	3.67	3.73	3.38	3.33	3.73	4.00[a]	3.00	3.75
Be aware of and understand intellectual property issues.	3.65	3.36	2.77	3.33	3.58	3.67	3.00	4.00[a]
Appreciate the skills of entrepreneurial enterprise development.	3.10	3.27	2.69	2.67[b]	3.33	3.33	2.50[b]	3.33
Understand the contribution of knowledge transfer to society.	3.38	3.45	3.00	3.00	3.42	4.00[a]	3.00	3.25
Professional Science	**3.30**	**3.24**	**2.65**	**3.40**	**3.09**	**3.47**	**3.10**	**3.50**
Lead a science laboratory.	2.89[b]	2.82	2.15[b]	3.00	2.60[b]	3.00[b]	3.00	2.50[b]
Mentor and be mentored by others.	3.67	3.82	3.38	3.67	3.27	4.00[a]	3.00	4.00[a]
Manage data and utilize laboratory notebooks when necessary.	3.56	3.36	3.00	3.00	3.18	3.67	3.00	3.75
Understand technology transfer.	3.40	3.45	2.58	4.00[a]	3.50	3.67	3.00	4.00[a]
Teach and design courses.	2.98	2.73[b]	2.15[b]	3.33	2.83	3.00[b]	3.50	3.50
Interdisciplinary Skills	**3.74**	**3.73**	**3.54**	**3.83**	**3.52**	**3.92**	**2.86**	**3.69**
Develop depth of knowledge in one discipline or field of study.	3.71	3.55	3.62	3.00	3.33	3.67	2.50[b]	3.25
Recognize the strengths and weaknesses of multiple disciplines.	3.69	3.73	3.38	4.00[a]	3.55	4.00[a]	3.00	3.75
Apply approaches and tools from multiple disciplines.	3.83	3.73	3.38	4.00[a]	3.58	4.00[a]	3.00	3.75
Work in team with individuals prepared in different disciplines.	3.74	3.91[a]	3.77	4.00[a]	3.64	4.00[a]	3.00	4.00[a]

Notes. [a]Highest score within each career sector for each scale and item. [b]Lowest score within each career sector for each scale and item. Survey items are abbreviated in this table, as full text is provided in Appendix C.

Survey Scales. Responses to survey items were also grouped by survey scales and analyzed by participant career sector categories in Table 20 and separated out in Table 21. Analyses were conducted to determine which scales were rated highest and lowest in each career sector category. Within the career sector of academia, the Communication Skills Scale had the highest mean (M = 3.75), while the scale with the lowest mean was the Professional Science Scale (M = 3.30). Government participants rated the Ethics, Teamwork, and Career Management Scale with the highest mean (M = 3.82) and the Professional Science Scale with the lowest mean (M = 3.24). Industry responses were highest for the Personal Effectiveness/Development Scale (M = 3.56) and lowest for the Professional Science Scale (M = 2.65).

The survey scale with the highest mean among the most career sectors was Ethics, Teamwork, and Career Management in three out of eight career sectors: GOV (M=3.82), AC-IND (M=3.83), and UN-ID (M=3.92). The scale with the lowest mean among the most career sectors was Professional Science, which was distributed among six out of eight career sectors: AC (M=3.30), GOV (M=3.24), IND (M=2.65), AC-IND (M=3.09), GOV-IND (M=3.47), and UN-ID (M=3.50). Despite having the lowest mean among the most career sectors, the Professional Science Scale also had the highest mean among the AC-GOV-IND professionals whose careers had spanned all three sectors (n=2, M=3.10).

Table 21

Survey Scale Means Reported by Professional Career Sectors (N=96, Possible Range 1-4)

Scale	*Professional Sector*							
	Academia (AC)	*Government (GOV)*	*Industry (IND)*	*Academia & Government (AC-GOV)*	*Academia & Industry (AC-IND)*	*Government & Industry (GOV-IND)*	*Academia, Government, and Industry (AC-GOV-IND)*	*Unidentified (UN-ID)*
n	48	11	13	3	12	3	2	4
Research Skills and Awareness	3.74	3.71	3.39	3.44	3.53	3.50	2.58[b]	3.71
Ethics, Teamwork, and Career Management	3.68	3.82[a]	3.46	3.78	3.83[a]	3.67	2.83	3.92[a]
Communication Skills	3.75[a]	3.67	3.39	3.33	3.67	3.78	3.00	3.83
Personal Effectiveness/ Development	3.65	3.73	3.56[a]	3.64	3.75	3.60	3.00	3.65
Entrepreneurship and Innovation	3.45	3.46	2.96	3.08[b]	3.50	3.75	2.86	3.58
Professional Science	3.30[b]	3.24[b]	2.65[b]	3.40	3.09[b]	3.47[b]	3.10[a]	3.50[b]
Interdisciplinary Skills	3.74	3.73	3.54	3.83[a]	3.52	3.92[a]	2.86	3.69

Note. [a]Highest and [b]lowest scores within each career sector.

Analysis of Variance. Prior to conducting Analysis of Variance (ANOVA) calculations, the hybrid career sector groups including government were grouped together under the category 'Government PLUS' to be of comparable size with the other career sector groups of Academia (*n*=48), Government (*n*=11), Industry (*n*=13), and Academia and Industry (*n*=12). The 'Government PLUS' group consisted of the career sector categories of Academia and Government (*n*=3), Government and Industry (*n*=3), and Academia, Government, and Industry (*n*=2). A one-way between groups ANOVA was conducted to compare the effect of career sector on survey scales and is reported in Table 22.

There was a statistically significant effect of career sector on perceived scale value at the $p < .005$ level for the scales of Research Skills and Awareness [$F(4, 87) = 5.287$, $p = .001$] and Professional Science [$F(4, 87) = 4.564$, $p = .002$]. Further post hoc analyses using Tukey's Honest Significant Difference (HSD) procedure indicated significant comparisons within the values reported for the Research Skills and Awareness scale as participants in the Academia sector ($M = 3.74$) rated these skills as significantly more valuable than participants in the Industry sector ($M = 3.39$) and Government PLUS sectors ($M = 3.25$) with a 95% confidence interval of the difference between means of Academia and Industry from .04 to .67 and for Academia and Government PLUS from .12 to .87 on a 1-4 scale. Within the significant comparisons found in the Professional Science scale results, Tukey HSD analyses indicated that participants in the Academia sector ($M = 3.30$) rated these skills as significantly more valuable than participants in the Industry ($M = 2.65$) and Government PLUS ($M = 3.35$) sectors and further between Industry and Government Plus sectors with a 95% confidence interval of the difference between means of Academia and Industry from .21 to 1.09 and Industry and Government PLUS from -1.34 to -.06 on a 1-4 scale.

Statistical significance was not established for the effect of career sector for the scales of Ethics, Teamwork, and Career Management [$F(4, 87) = 2.092$, $p = .089$], Communication Skills [$F(4, 87) = 2.245$, $p = .071$], Personal Effectiveness/ Development [$F(4, 87) = 1.285$, $p = .282$], Entrepreneurship and Innovation [$F(4, 87) = 2.344$, $p = .061$], and Interdisciplinary Skills [$F(4, 87) = 1.460$, $p = .221$].

Table 22

Analysis of Variance (ANOVA) of Scale Ratings by Career Sector

Scale	*Source*	*df*	*SS*	*MS*	*F*	*P*
Research Skills and Awareness	Between groups (Combined)	4	2.735	.684	5.287	.001*
	Within groups	87	11.251	.129		
	Total	91	13.986			
Ethics, Teamwork, and Career Management	Between groups (Combined)	4	1.367	3.42	2.092	.089
	Within groups	87	14.214	.163		
	Total	91	15.581			
Communication Skills	Between groups (Combined)	4	1.871	.468	2.245	.071
	Within groups	87	18.132	.208		
	Total	91	20.003			
Personal Effectiveness/ Development	Between groups (Combined)	4	.688	.172	1.285	.282
	Within groups	87	11.647	.134		
	Total	91	12.335			
Entrepreneurship and Innovation	Between groups (Combined)	4	2.804	.701	2.344	.061
	Within groups	87	26.021	.299		
	Total	91	28.826			
Professional Science	Between groups (Combined)	4	4.705	1.176	4.564	.002*
	Within groups	87	22.419	.258		
	Total	91	27.123			
Interdisciplinary Skills	Between groups (Combined)	4	.765	.191	1.460	.221
	Within groups	87	11.4			
	Total	91	12.165			

**Note*. Statistical significance at the $p < .005$ level

Qualitative Results

Case study interviews were conducted to collect qualitative data for Research Question 1. Interview protocol (Appendix E) was followed and analyses were conducted on participant responses to interview items one, two, three, and four along with corresponding prompts and probes:

1. Tell me about your professional background.
    a. How many years?
    b. What's your daily work like?
2. Please tell me about skills that you believe are important in your profession.
    a. Tell me more about that.
    b. Do you recall any thoughts that co-workers have shared with you about other skills that are important in your career sector?
    c. *Probes: problem solving, reporting writing, presentation experience, management skills, budget experience?*
3. What makes an ideal candidate for employment in your profession?
4. In your profession, do you anticipate any future directions regarding the employees they hope to hire?

Analyses revealed that some of the valued skills provided by interview data aligned with the constructs, or scales, measured by the quantitative survey portion of this case study. Examples of these interview themes which overlapped with survey data included communication, listening, and interpersonal skills, critical thinking skills, interdisciplinary skills (sometimes referred to as breadth of knowledge), ability to work independently and manage time, and teamwork. Themes which emerged from interview data, which were not addressed in survey items included proficiency in a mathematical and technical background and the personality trait of being a “lifelong learner.” A summary of themes that emerged from three or more interview participants is reported in Table 23 by participant career sector.

Table 23

Themes: PhD Skills Valued by Career Sector (N=10)

	Career Sector						
	Academia (AC)	*Government (GOV)*	*Industry (IND)*	*Government & Academia (GOV-AC)*	*Government & Industry (GOV-IND)*	*Academia, Government, & Industry (AC-GOV-IND)*	*Total*
n	*2*	*2*	*2*	*2*	*1*	*1*	*10*
Theme							
Mathematics skills, Technical background	2	1	2	2		1	*8*
Communication, listening, and interpersonal skills	0	2	1	2	1	1	*7*
Critical thinking/Creative problem solving	0	1	1	1	0	1	*4*
Extreme intellectual curiosity/Lifelong learner	0	1	1	1	1	0	*4*
Interdisciplinary skills/Breadth of knowledge	0	0	1	1	0	1	*3*
Able to work independently/Manage time	1	1	0	0	0	1	*3*
Teamwork	0	2	0	0	1	0	*3*

The themes which emerged among the majority of interview participants are addressed with more detailed interview data within this subsection. These included establishing proficiency in a mathematics and technical background (*n*=8) and communication and listening skills (*n*=7).

Mathematics/Technical Background. Proficiency in mathematics or a technical background emerged as a theme among eight out of 10 interview participants in the career sectors of academia (*n*=2), government (*n*=1), industry (*n*=2), government and academia (*n*=2), and academia, government, and industry (*n*=1). Overall, the sentiment was repeated that IDS science PhD graduates needed to have a strong mathematics and/or technical background. Specific feedback from an industry professional illustrated the perceived importance of this skill when stated as "I think that in the current environment the most important thing is a mathematical background…It's the language that allows genuine interdisciplinary understanding." A professional in academia further stated that IDS science PhD graduates ought to be able to "connect every piece into how do you express a problem practice and quantitatively. In simple words, mathematics modeling… Can you can express the problem into mathematics?" The same theme emerged from a government professional who stated "An ideal candidate would be someone who possessed both a technical background and… master's degree or higher."

Communication and Listening Skills. The second most common theme uncovered in interview content analysis was for communication and listening skills. This theme was also represented quantitative survey scale in this case study. Seven of 10 interview participants mentioned this skill and represented the career sectors of government (*n*=2), industry (*n*= 1), government and academia (*n*= 2), government and industry (*n*= 1), and academia, government, and industry (*n*=1). None of the solely academic interview participants mentioned this skill. One government professional clarified further that "Communication skills are extremely important, both verbal and written… We have to be extremely careful how we write, what we say, and also what we don't say." A government-academic professional stated "When we talk about something that's very much interdisciplinary, it really helps to listen to your counterparts and to listen to them on why things happened." An industry professional explained that within a company, professionals have to be able to justify their work to employees in other departments so that even non-technical professionals uninvolved with a particular project, but responsible for funding it or providing other resources could conclude "Ok, now I know what you're doing." One professional whose career has spanned all three categories of academia, government, and industry furthered the understanding of this theme:

> I deal with a lot of pretty sophisticated, pretty challenging technical or research concepts, and being able to boil those down into a global message for people is really challenging. Even people who are expert communicators struggle with that. That's definitely something that is a nuance and critical skill.

Research Question 2

Question 2: What are the perceived advantages and disadvantages of the apprenticeship model for preparing interdisciplinary science PhD students for diverse career paths? Content analysis for Research Question 2 was conducted on participant responses to interview item five which asked participants "What is your understanding of how PhD students are prepared for their careers? In your opinion, which career paths are students being prepared for?" The interview item did not explicitly mention the apprenticeship model so as not to lead the participants towards any perceived bias from the interview. Participant responses which identified the apprenticeship model by name or description were analyzed for thematic content. Since the apprenticeship model was not specifically asked or prompted, data for this research question were limited to a small number of participant responses. A summary of the themes that emerged from two or more interview participants is reported in Table 23 by participant career sector.

Table 24

Themes: Advantages and Disadvantages of the Apprenticeship Model by Career Sector (N=10)

	Career Sector						
	AC	*GOV*	*IND*	*GOV-AC*	*GOV-IND*	*AC-GOV-IND*	*Total*
Theme *n*	*2*	*2*	*2*	*2*	*1*	*1*	*10*
Disadvantage: Academic career preparation only	0	0	2	2	0	0	*4*
Both advantage and disadvantage: Depends on the student	0	0	0	1	1	1	*3*
Both advantage and disadvantage: Depends on faculty advisor	2	0	0	0	0	0	*2*

The themes which emerged among the most interview participants are addressed with some detailed interview data within this subsection. These included the perceived disadvantage that apprenticeships prepare students for academic careers only (*n*=4) and that apprenticeships rely heavily on the specific student and faculty member involved (*n*=5), which could be perceived as either a disadvantage or advantage depending on individual characteristics.

Disadvantage: Apprenticeship results in academia-only career preparation

Apprenticeships as academia-only career preparation emerged as a theme among four out of 10 interview participants in the career sectors of industry (n=2) and government and academia (n=2). Further, interview data revealed that PhD preparation alone was not perceived to provide enough problem solving opportunities or support for diverse career preparation. This perception was illustrated by an industry participant who shared that PhD students

> …are being trained by academics to stay within academia… The people that come out would not be able to necessarily walk into a job in industry or into other areas… These are people who are trained to write papers, not to produce solutions to actual real-world problems. My biased opinion, but that's what I feel.

A second industry professional further qualified:

> Well, I think it depends on the individual... I guess it depends on what they've been exposed to along the way. Some of them get fellowships or assistantships…I don't want to say 'caught' but they're in this academic environment all the time and their world is that world. But then there's people who …took time off and worked and then went back and got the PhD so now not only have they gotten different degrees, but they've worked in different places and that experience helps them see what's going on…I hate to say real world, but real applications as opposed to textbook type of problems.

Interview participants in the government-academia hybrid category responded with the same sentiment regarding PhD students being prepared for academic careers only. More specifically, they shared the following comments in their interview responses:

> Typically, PhD students are treated as people who are going to become teachers or academics themselves. And, so, a lot of the people that want to be practitioners, or may not want to be academics don't get the support they need. And so they don't get involved in project-management and they don't get involved in pulling together the teams. They get involved in doing things that support an academic-type career: writing a lot of papers, doing some teaching, and basically emulating their professors… I think in a typical academic program, the assumption is that anybody that's trying to get a PhD really would like to become a tenure-earning faculty member at some institution. I don't think that's an accurate assumption. I think it's a perfectly reasonable assumption if you're a faculty member and that's what you did and that's what you admire. But, it turns out that most PhD holders ultimately don't become faculty members and that's especially true in STEM-sorts of efforts… You're going to have a different kind of career for most of the people because the number of faculty positions are limited. So, a thing that I've tried to emphasize is that universities really should be thinking about people who want a different career path. Or at least preparing them, just in case they don't get that tenure-earning faculty position they're looking for."

Both Advantage and Disadvantage: Apprenticeships Vary Based on Students and Faculty

Other common themes included that the nature of apprenticeships depends highly on the individual advisor and student involved, which could be seen as either advantages or disadvantages given specific, situational variables. These variations in apprenticeship experiences emerged as a theme from five out of 10 interview participants. These concerns were distributed across interview participants in several career sectors. Emphasis on the reliance on student variables was emphasized by participants in the career sectors of government and academia (*n*=1), government and industry (*n*=1) and academia, government, and industry (*n*=1). Emphasis on the reliance on faculty variables was emphasized by participants in the career sector of academia (*n*=2).

One academia participant, in particular, shared:

> So I've seen students... where by that third year, they really have a feeling of what they want to do so if they're going into industry, their advisor will make sure they have more internships to get out into the industry field. Maybe two or three spots so they can get a feel for how that works. If you want to go to a startup, they'll start to give them some credibility with some papers and also by going out to intern so they know how larger companies run, and to do academia you really want to not intern and focus more on doing high quality research journals. I think in general, it was one of the experiences I had that made you appreciate the job of that training model. As long as you have a good working relationship with your advisor. When that fails, there's usually a problem with the working relationship between the student and the advisor.

The professional whose career had spanned all three sectors explained that "It depends on the student. The professional, the mid-career folks aren't going to get involved in labs. They're going to do classes and hopefully get some kind of mentorship."

Research Question 3

Question 3: What barriers and advantages do participants identify regarding the implementation of an alternate pedagogical model for interdisciplinary science PhD students?

Content analysis for Research Question 3 was conducted on participant responses to interview items six, seven, and eight:

6. Thinking about people who graduate from interdisciplinary science PhD programs... In an ideal world, how would they be prepared for their careers?
    a. *Probe: What would be the positive attributes? For students? For faculty? For employers?*
    b. *Probe: What would be the negative attributes? For students? For faculty? For employers?*
    c. *Probe: What would be the barriers to implementation?*
7. Again, for interdisciplinary science PhD students... What experiences would prepare them for diverse career paths to include academia, industry, and government?
8. Have you ever mentored a PhD student? Thinking back to your experiences with mentoring a PhD student, what would have made the experience more successful for you and the mentee?
    a. *Probe: For independent study, directed research, internship, dissertation, etc.?*

Analyses revealed themes for suggested alternate approaches for diverse career path preparation such as requiring internships, experiential learning, or shadowing other professionals (*n*=6), requiring more project-based education with interdisciplinary topics and group work (*n*=5), and requiring technical, broad-based knowledge and flexibility (*n*=5). A summary of themes that emerged from a majority of interview participants is reported in Table 25 by participant career sector.

Table 25

Themes: Alternate pedagogical models for IDS Science PhD Students (N=10)

	Career Sector						
	AC	*GOV*	*IND*	*GOV-AC*	*GOV-IND*	*AC-GOV-IND*	*Total*
n	*2*	*2*	*2*	*2*	*1*	*1*	*10*
Theme							
Internships, experiential learning, exposure, and shadowing	1	1	2	1	1	0	*6*
Project-based curriculum with interdisciplinary group work on interdisciplinary topics	0	1	1	2	1	0	*5*
Allow more flexibility, but within a technical, broad-based knowledge framework	2	1	2	0	0	0	*5*

Each of the themes reported in Table 25 is addressed with more detailed interview data within this subsection to include a description and perceived advantages and barriers to implementation.

Alternate Pedagogical Model: Internships, Experiential Learning, Exposure, and Shadowing

Description and Advantages. An internship, experiential learning, and/or shadowing experience was suggested as an alternate pedagogical method by six out of 10 interview participants spanning all career sectors of academia (*n*=1), government (*n*=1), industry (*n*=2), and some hybrid sectors of government and academia (*n*=1), and government and industry (*n*=1). Interview responses expressed that these experiences should be not only be accessible, but actually required for all IDS science PhD students to prepare them for diverse career paths. This recommendation was shared with the intent that students would gain knowledge of the actual tasks involved with a career in each sector, through active exposure to each one. An industry professional further elaborated on this concept from personal experience:

> One of the things that I think is not a good model… is the model of funding that has gone on so far… currently, I can only talk about the one program I'm associated with, PhD students for M&S come in and they're immediately scooped up by a lab, and they have to or else there's no money to fund them… It has to be done through somebody else's lab. They stay with that lab from beginning to end, doing that professor's work with that professor's approach and really, in many ways, seeing nothing else. And this is a financial thing. I almost think that shouldn't be allowed. I think they should be forced…out in industry or government, or somewhere. Encouraged or forced or something where they're out on the shop floor, so to speak. And, in something preferably, they have no experience or interest in. Actually... If they come in and they're expressing an interest in epidemiology, send them to a manufacturing firm. And force them. I know this sounds terrible, I'm talking the ideal way… But, in spirit, you have to force them outside of their comfort zone.

A government-academia professional further confirmed that there was no other way to get the valuable experience that internships provide, by stating "there's nothing like actually doing it… Then you can see at these companies… how they do their operations, handle things and you can pick out what are the things you are lacking personally before you start doing the job."

A form of experiential learning would also help students gain knowledge of the different levels of work-life balance they can look forward to in each sector. An academic professional expanded on this concept that students should experience each career field

> …So they understand if they actually want to pursue that or if they don't want to pursue that. So if they have the discipline to want to show up at nine and leave at five or work where other people are workaholics and work from eight o'clock to two in the morning and work on something random and bring their work home with them and are sending out emails at four AM to people. So I think a lot of it's based on your personality and how you want to work so I think experiencing both through experiential learning is important so you get a feel for…a little taste of the academia world, a little taste of the industry world and, you know, as much government as you can get.

An industry professional mentioned networking as another important value of internships, "It's that networking that helps you open up opportunities, I believe." Combined with the concept of internships is the concept of shadowing professionals in those career fields. An academic professional who experienced this level of mentorship elaborated on it as

> Right now you would have to make sure they know that they're going to have be prepared to play the game… My advisors basically showed me everything about the process that they could so when I could go to committee meetings and people were out of the room I was usually invited to stay in the room to see how things worked behind the scenes. Any research meetings with the faculty I was normally invited to, I was basically not allowed to talk, but by the end I was able to participate. So, basically let them behind the scenes to see how the process works behind closed doors as much as you can helps prepare them for what they need to do. I think the biggest advantage was trying to figure out the process of helping write grants, helping pitch ideas, helping to research.

A government professional furthered the advantages of shadowing and internships in relation to the other administrative tasks that come along with many jobs,

> The positives for all stakeholders is that we get a much more well-rounded student… Two things that PhD students do not really grasp in my opinion is that they don't grasp the concept of money and they don't grasp the concept of time very well. Because they never really had to deal with those concepts so when they get hit by those two concepts they really throw them for a loop.

Barriers and Disadvantages. Interview participants identified disadvantages of internships and shadowing to include issues of attrition, difficulties with faculty networking with industry, and the time that it takes to supervise internships correctly. On the issue of attrition, one academic professional elaborated

> The negative attributes are that is scares the bejesus out of people. Most professors are on the borderline of almost becoming broke at any particular point, so you're almost broke but, it's a numbers game… , so on the one hand you look like you're flush, on the other hand you're broke. So when students shadowed, they got very scared off that they were going to lose their funding at any point…they were hedging their bets…scared about the bigger picture and the bigger world. So it scared off a few people in general. The response to that, is that's okay because it's sort of purpling out of the pile to actually pursue a career in academia so it's better to get scared off before you get into it than get scared off in your first year. So if you look at everyone you're scaring off (basically everyone but me, but that's okay) that's OK because they're not going to get a job at the end of it. That's the negative side.

A government professional further elaborated on the time-consuming nature of internships as, "The negative for the student themselves and for the faculty is that it takes longer because they're stopping their education for periods of time." An industry professional recalled mentoring an intern regarding an organization's misuse of that intern on the job being assigned "busy work because they don't have time to do it or they don't want to do it so they're just giving it." However, the same industry professional acknowledged that this was also an opportunity for leadership and interpersonal skill development in encouraging the intern to speak up and request a reassignment for more meaningful work. Internships were also identified to be time consuming for faculty members to supervise, as one academic professional stated, "I don't think a lot of faculty will be up to that. 'I have other responsibilities now… this committee, that committee, the other committee… if I don't bring in 100 or 200 thousand in grants, etc,' all of which are true…"

Alternate Pedagogical Model: Project-Based Curriculum with Interdisciplinary Group Work on Interdisciplinary Topics

Description and Advantages. Of the 10 participants interviewed, half mentioned that an IDS science PhD program should be project-based with interdisciplinary topics and groups. This theme was found in the interview content from interview participants in government (*n*=1) and industry (*n*=1), government and academia (*n*=2), and government and industry (*n*=1). As an industry professional elaborated, "In a project-based environment with a set of goals, again the objective would be 'hey we need to teach these folks how to do research.'" Another industry professional stated that an advantage of project-based curriculum would be the confidence it would inspire in graduates

> Where they have to come in and model and simulate various different fields in various different application areas that they know perhaps initially nothing about whatsoever. And develop the confidence where they say 'I know enough math, I know enough statistics, I've had enough statistics, I've had enough experience interviewing subject matter experts' because that is one of the key things that is not trained.

A government-academia professional further stated that the nature of these projects should be interdisciplinary, with advice to students to "participate in a project that's interdisciplinary… It's good to have opportunities like that in a department or across departments. Direct exposure and being actually part of it would be the best if that's possible. And maybe more than one in a career." Another government-academia professional elaborated,

> I think if you have truly an interdisciplinary program, I think that helps with that where you're able to work out projects or work out problems… Most of my proposals,,, are all people that don't have computer science degrees necessarily. The last proposal I did was with a group, one was a philosopher, plus there was a data miner and the other one a computer engineer. You have to be able to do these things because you can't get the job done right unless you can do it in that type of manner with an interdisciplinarity.

Participating in interdisciplinary teams while in a PhD program was postulated to also result in acquiring team-working skills across disciplinary boundaries and learning resources that come with different disciplines. An industry-government professional elaborated on this point by saying

> So, I think with the IDS aspect, the ability to kind of, sort of speak, play in the sandbox with lots of different disciplines and personalities [is ideal career preparation for IDS

> graduates]… You have your mathematicians, your engineers, your research psychologists, and those are the types… folks in physics or chemistry or something like that… Typically with different disciplines, you've got different personalities that are going through those types of programs… Understand that there's other people with resources that are able to help you accomplish your goal.

Barriers and Disadvantages. Interview participants noted that the process of designing group-based, interdisciplinary projects is time consuming for faculty members and can still lead to the same downfalls of any other group assignment where members to do not contribute equitably. As a government-academia professional stated, "Now the down side of this, is the cost and the laying out, getting these things developed cause these classes aren't developed yet." A government-industry professional further expanded on this as

> There's some times that people think 'Well, I don't need to exactly pull my weight' and when you've got four people on a team, think 'I'm covered'. I've seen that happen. I wouldn't say that it's because of an interdisciplinary team, I've seen it just because it was team. That goes back to team dynamics.

Another barrier to implementing group, interdisciplinary projects is the issue of communication. Many students often do not know arrive with experience or knowledge of communicating with others from different academic backgrounds or disciplines. One academic professional described this as "the frustration of different terminology, jargon, sometimes even personally understanding…underestimating or overestimating other people because you're in a different domain." The same academic professional noted that while cross-disciplinary communication is a difficult lesson to teach and facilitate in graduate level classes, it is valuable. More specifically, the academic professional stated

> You have to know how to communicate with people in a different discipline. You have to know how to sell yourself or your skills or your tools. Especially these days you do not have to recreate the tools or the wheel.

An industry-government professional reflected that while group work and interdisciplinary communication have challenges, they can be addressed by added training in communication such as "etiquette or playing rules" for IDS or group work.

Alternate Pedagogical Model: Allow More Flexibility within a Technical, Broad-Based Knowledge Framework

Description and Advantages. Of the 10 participants interviewed for this case study, half mentioned that students needed technical, broad-based knowledge with flexibility for choosing elective courses and dissertation topics that aligned with their own professional and personal goals. The participants who indicated this preference were evenly distributed across the professional sectors of academia (*n*=2), government (*n*=1), and industry (*n*=2), though did not represent any hybrid groups. To first express the need for technical knowledge, and then the need for flexibility to adapt to different working environments, the following excerpt is provided from interviewing an industry professional,

> You need somebody who can seamlessly go into any field, almost any field, and with relatively small preparation time, just learn the specifics of that field and be able to bring M&S skills to that. Then …people coming out of there would be hired because they could say 'Oh, they have a PhD in M&S, this is somebody we can hire to come in and fix

things.' My ideal PhD student is somebody who comes in who's extremely flexible who very quickly identifies what's going on in my lab and then comes in and suggests solutions and says 'Have you looked at this? Gee, I've read this article, I've read this book, I saw this on TV, or I have a friend who's doing this thing, would that be of interest in your lab? Is that something I could pursue under your mentorship?'

An academic professional noted that a technical background is critical before flexibility can be emphasized, "Know how to crunch data. Every field needs that… Start from there."

Another industry professional expressed appreciation for graduates with strong interdisciplinary preparation as, "I love interdisciplinary programs because there's that broad exposure that I would be looking for. So they know how to do this, they know how to do that, can they put it all together?"

On the flexibility that was deemed necessary by interview participants, a government professional elaborated on this need at the doctoral level to suit an individual student's goals,

> Tailor projects to help you meet some of your either scientific or managerial goals… I think when you get into a doctoral program, it's really a lot more about what that person's goals are… I'm assuming they're kind of self-selecting to go into an interdisciplinary program because they have interdisciplinary goals. Right? And, if they have very specific goals, maybe they would choose a program that was not as interdisciplinary. The issue that I think it's going to be is when you end up in the real world, eventually you have to go back to work, right? You end up in the real world, I think you'll find yourself inevitably in an interdisciplinary environment.

Advantages to flexibility within a technical, broad-based knowledge framework were shared largely by professionals in the government and government-academia career sectors. More specifically, one government professional pointed out that allowing flexibility for student research topics forced faculty members to improve and expand as teachers. To explain this further, the same government professional shared,

> I had an opportunity to teach last semester and the group that I had, they came from lots of different backgrounds and had lots of different goals and they asked questions, frankly, that weren't part of the core material for the course… So, it really kind of stretched the model for that course. I think some students raised questions that were of interest to other students that maybe if it was just left up to me and what my background was, I probably would have, you know, taught the course one way. But based on the interaction, I stretched the model of what I thought was possible for that course. And, so I think it made the course better. And I learned things. You can't know everything, in spite of either how long you've been around or how much you think you know.

A government-academia professional shared a similar sentiment regarding flexibility for student research serving as a source for faculty improvement and growth by stating

> I think faculty members that understand that producing people that can fit in a lot of different areas and can go out beyond our specific technical area are much better professors overall. When I have an introductory talk with a new faculty member or a new student, I tell them, 'you have permission and you're even expected to poke around and go around the whole place and talk to anybody and ask them what they do and tell them about yourself.' So, people that take advice and do it, are going to be much more

> likely to succeed. The only negative I can think of from many people's perspective is, 'oh, this is taking up time." On the other hand, if your job is to be educating the next generation, that time is not subtracting from what you do. It's part of what you do.

Government and government-academia professionals also pointed out the advantages of graduates with flexible, interdisciplinary programs often made for better teammates in workplace settings. A government-academia professional framed this within the communication skills that are developed in interdisciplinary, flexible curricula, as the benefit of "understanding how to explain things and how to communicate other than at the highest intellectual level of whatever technical specialty we have, that's a valuable skill."

Barriers and Disadvantages. Qualitative interviews did not reveal any disadvantages of requiring a technical specialty area in an interdisciplinary program. However, the aspect of flexibility within the technical, broad-based education framework that were found to be advantageous was also acknowledged to have several disadvantages. Thematic interview content which revealed disadvantages to flexibility in a PhD program included the issues of breadth compared to depth, misalignment with tasks of future jobs after PhD, difficulties of not being assigned a dissertation topic, and difficulties for faculty in identifying individual needs for multiple advisees.

Regarding the controversy of breadth compared to depth in interdisciplinary programs, a perceived disadvantage to faculty members was identified by an academic professional as "the advisor has to be very careful otherwise you go everywhere," and that the research "will not be traditional discovery and may not be in knowing everything," The same concern was shared by another academic professional who found the disadvantage for IDS faculty in both advising students and pursuing their own academic careers, “in most programs interdisciplinarity is a downfall because you might be good at a lot of things but you’re not going great at the one thing you need to do to get tenure, so it’s a hard tenure battle.” An industry participant further noted the disadvantage of flexibility in an IDS PhD program regarding the hiring processes in companies,

> The other side of that is when you go to get the job, well ‘we’re hiring a mechanical engineer.’ ‘Yeah, but I have some experience doing that.’ ‘Yeah, but have you ever focused on mechanical engineering?’ ‘Yeah, but I have this broad background.’ So I see that a lot of people struggle with that as far as trying to find a job. Typically the jobs that are filled are for a particular area. They want to hire an aerospace engineer that knows how to do propulsion. ‘We want to hire this person to do this.’ ‘We want to hire this person to do that.’ But what about those people that have those interdisciplinary? It’s a little more challenging and I think there are certainly areas that I think that it’s useful as far as the people hiring.

The issue of a graduate’s expectations not being met at work after completing a flexible PhD research program was expanded upon by an industry professional:

> They can’t have somebody say ‘Well, I’m a PhD, and I specialize in going outside the box.’ You know? Outside the box? You’re right outside the building. They can’t put up with that. So, there is a downside… Let’s say you’re at a job… You’re not just an independent consultant coming in for a particular project which ideally you’ve probably chosen where you’ve gone to an industry and said ‘I have this idea, how about we work out a proposal.’ You’re actually an employee of that company. There’s a lot that needs

> to be done that just needs to be done. There's a lot of… you know, I by nature, am a researcher, I'm an intellectual. I spent a lot of my life debugging awful C code. I mean, there are tasks that have to be done. There are deadlines that have to be met, and many, many times, you find yourself unable to proceed with your ideas as an employee. At least, I've spent most of my professional life having brilliant ideas that my employer was not interested in. Because we had deadlines, we had things, they didn't have the resources to go off in this direction. If you've trained a PhD to think that the world is their oyster, that it's all about professional, you know, come up with creative solutions and that person gets hired and all of a sudden is hit in the face with the fact that they were being hired to do a job and all those other skills are great but their employer, in the end, is interested in bottom line and deadlines. And maybe the employer might find that difficult. Because they don't want to hire someone they have to fight with to get them to empty garbage. I'm not saying that they're going to empty the garbage, I'm using that as a metaphor. But there's a certain amount of garbage that has to be emptied and floors mopped in any business.

Interview participants identified that a barrier to implementing a flexible interdisciplinary PhD program was in appealing to more than one student. A government participant expanded on this concept:

> Obviously you're not going to be teaching classes with three students so I think it has to be thought out in terms of 'how am I going to provide flexibility within the framework in some interdisciplinary program?'… 'How do I spend the resources that I have in order to

> provide as much crosscutting opportunities, interdisciplinary opportunities for those students to interact?'

Another barrier to implementing a flexible IDS PhD program was identified as the structure by which traditional universities are organized. An industry professional noted "Universities are traditional by nature, no matter what they say… Departments don't like people coming to them that they can't identify what they are." An academic professional furthered this concern of structural issues regarding how universities deal with IDS programs beyond what students experience, into the faculty experience:

> If their career is academia, the hardest thing for interdisciplinary students seems to be that tenure priorities are relatively broken or there are very few institutions that acknowledge interdisciplinary studies in the tenure process. So in some sense you're wanting the students to be interdisciplinary but you also have to learn to focus onto one core topic so they can get tenure in that department. So, if you're strong in computer science you have to do more computer science journals and hopefully you can also pull in some other skills.

Other Barriers Related to Implementing IDS Science PhD Programs

Separate from specific pedagogical models, interview data revealed other barriers related to the general topics of faculty mentoring, offering interdisciplinary PhD programs, and preparing PhD students for diverse career paths. While these data codes were not mentioned enough to be considered themes, their content was significant to the researcher and warranted some mention. A barrier related to faculty mentoring was expressed regarding university reward models, or more specifically, the lack of rewards for mentoring especially outside of their department. The academia-industry-government professional stated this as "It's certainly not unique, the professors are really rewarded for doing research. The professors get less, I always joked that they're professor points, they get less rewards formally for doing student mentorship or even teaching."

Another issue that was worth mention was the barrier to offering an interdisciplinary program as it relates to the culture of traditional universities and the communication required to work across disciplines. A government-academia interviewee stated

> The major barriers are cultural. 'That's not the way we've done things in the past,' or… within a larger organization. How to instill that as a cultural point? That has to come from the top. You can't just have rules. You have to do it, and you have to give positive feedback for good examples of that. And, maybe a little mild rapprochement for not. But mostly positive. I think people want to be part of a culture that is interdisciplinary and passes information around, and generally not isolated in particular domains. Unfortunately, universities are organized in those kind of domains, so bridging is difficult. But I do think that comes with time. I mean, from the president on down, that people have permission to do these things.

The barrier related to diverse career paths was brought up by a government professional concerned that these career paths do not integrate well with each other.

> I'm not sure that we mix that well together. I work with academia at different universities. You know they're their own little niche. I've never seen them interested in coming out of their niche...For example, their niche could be research. You can research a concept, but it's much more difficult to take that research and actually put that research

into a practical application. System integrated...That's what government and industry do. It's that application. It's very rare to see a researcher come out of their research umbrella.

Additional Analyses

Survey and interview participants were asked a final, open-ended question "Is there anything else that you would like the researcher to know about preparing interdisciplinary science PhD students for diverse career paths?" Content from responses was grouped by theme and reported in Table 26. The themes with the most responses included the need for collaboration and creating a sense of community for modeling and simulation professionals (n = 17), concerns that the meaning of IDS studies were often misinterpreted (n = 9), the importance of publishing and grant writing (n = 7), a need for passion for the field, technology, and intellectual curiosity (n = 6), interpersonal skills (n = 5), and industry experience or exposure (n = 5).

Table 26

Themes: Perspectives on Preparation of Interdisciplinary PhD Graduates (N=~100)

	Career Sector							
	AC	*GOV*	*IND*	*AC-GOV*	*AC-IND*	*GOV-IND*	*AC-GOV-IND*	*Total*
n	*28*	*7*	*8*	*3*	*8*	*3*	*2*	*59*
Theme								
Collaboration, community	6	0	4	1	4	1	1	*17*
People misunderstand meaning of IDS studies	2	1	2	2	1	0	1	*9*
Publishing and grant writing	4	1	0	0	2	0	0	*7*
Passion for field, technology, intellectual curiosity	1	1	1	0	2	1	0	*6*
Interpersonal skills	3	1	0	0	1	0	0	*5*
Industry experience/ exposure	2	0	3	0	0	0	0	*5*

The first two of these reported themes were mentioned by the most participants and are therefore addressed in more detail in the following sub-sections.

Collaboration and Community

Collaboration and community were mentioned by 17 of the approximate 100 interview and survey participants in the career paths of academia (*n*=6), industry (*n*=4), academia and government (*n*=1), academia and industry (*n*=4), government and industry (*n*=1), and academia, government, and industry (*n*=1). Participants in every career sector, except for government only, shared that fostering a sense of collaboration and community was important for a modeling and simulation IDS PhD program. An academia-industry professional explained that the program ought to have "knowledge of the different ways modeling and simulation fits in corporate and government organizations," and an academic stated that "knowledge of stakeholder groups (i.e., professional organizations)" was important. An academic-government professional reinforced that it was valuable to have "good connections with the operational community." A government-industry professional explained that community and collaborative interactions need not necessarily be formal

> I think part of it is giving people permission to come together from a work aspect of the IDS but also a personal aspect because I think when people get together on a personal level without having to talk about work or business or things like that, I think that's what really links people together.

The participant whose sector has spanned all three career paths stated that there should be

> Emphasis on maintaining and building relationships between government, industry, and academic stakeholders. Being able to network and demonstrate how and why interdisciplinary research is of benefit to science as whole, and more importantly to understand how different branches of M&S can support one another (for example how human factors plays a role in M&S work).

Reasons for valuing the M&S community were provided as well. One academic participant stated that a sense of community is good for "helping make connections in the community for internships for student experience, as well as corporate exposure." An industry participant also stated that beyond the benefits to students, there were benefits to community members who wish to remain involved in academia and that academia could benefit from this as well.

> So for example, the College of Engineering at UCF has an alumni just for the engineers and they get together and talk about how can they best make the engineering program at UCF better. And I just found out about that recently because they asked me to be a senior design reviewer… Anyway, there was a community of support for other [programs]…so I don't know how the interdisciplinary community is… Is there an entity that exists for people to say 'Hey, I'm thinking about going into this. What are the challenges? What are the benefits? What do I need to know?'… If there was a group like that that could share 'Hey, here's been my challenges and rewards of doing this type of study,' that would benefit the students, so they know at all levels, undergraduate, master's, PhD, these are the things you're going to face, that'd be useful.

IDS Studies Often Misunderstood

Collaboration and community were mentioned by 17 of the approximate 100 interview and survey participants in the career paths of academia (*n*=6), industry (*n*=4), academia and government (*n*=1), academia and industry (*n*=4), government and industry (*n*=1), and academia, government, and industry (*n*=1).

Nine of the approximate 100 interview and survey participants reported confusion about the nature of IDS studies among students and community members. This was reflected by participants in academia (*n*=2), government (*n*=1), industry (*n*=2), academia and government (*n*=2), academia and industry (*n*=1), and academia, government, and industry (*n*=1). As one academia participant stated, "Interdisciplinary should mean being strong in everything, not that you don't have to focus on anything. Students misunderstand that. Students need to focus on the triad of people, processes, and technology for their program." Another academia participant echoed that "understanding the difference between interdisciplinary and multidisciplinary approaches to research" was important for the IDS researcher to know about. The participant whose career spanned all three career sectors stated

> I think that you need to help students and faculty be able to articulate the value of the interdisciplinary degrees. Or even an interdisciplinary approach because oftentimes I find that people can't speak about it in a clear manner and it just makes it sound like it's just 'taking whatever courses I like' versus, 'no - there's a real coherency to it, there's a real rationale'… I'm a real believer… if an interdisciplinary Ph.D. is done right, I think that what it does is take two points in space and bridge them together to create a whole unique pathway that wasn't there before. Just by combining two disparate concepts - or three disparate concepts. Other Ph.D.'s are just about digging just a little bit deeper into a single silo. When cross disciplinary is done well, you get even more bang for the buck by combining those two things into something bigger and equally unique. I think that's really cool.

An industry participant further explained how community members should view IDS studies

> Being interdisciplinary does not mean you are not an expert. It does not mean you are a generalist in a variety of fields, i.e. a jack-of-all-trades. It means that you have become an expert hyper-focused on a problem that requires knowledge and skills from a variety

> of fields. Crossing disciplines is required because no field can address this one problem on its own.

An academia-government participant further supported IDS studies by stating

> One of the things that I think really has to develop is the idea that people that cross multiple fields are incredibly much more useful than people that are narrow in a single field. So, that's something that universities need to start thinking about.

The concern that IDS studies are often misunderstand also came with a warning from several participants who stated that this issue should be communicated to students prior to their start in an IDS PhD program. This was shared by participants in government-academia participant and industry.

Summary

This chapter was introduced by restating the purpose of the case study, research questions to be addressed, and the order in which they would be presented. This was followed by descriptive statistics for the samples drawn from both the quantitative Survey of PhD, Interdisciplinary, and Science Skills and the qualitative interview protocol, results of an ANOVA between career sectors and skills valued by survey participants, and interview responses grouped by theme and career sector.

Results from the first research question revealed that the skill rated highest by most career sectors were those grouped by the construct for ethics, teamwork, and career management, while the skills rated lowest by the most career sectors were those under the professional science skills construct. The item ranked lowest overall was for leading a science laboratory. Interview content revealed that participants most valued mathematics and technical skills, then communication and listening skills. Results from the second research question revealed that the apprenticeship model was perceived to have the disadvantage of only preparing IDS science PhD students for careers in academia, and the also both the advantage and disadvantage of having individualized processes and results given the specific individualized nature of advisor-mentor relationships. Results from the third research question revealed that participants would prefer to see IDS science PhD programs utilize alternate pedagogical models of internships, projects, and flexibility despite their disadvantages and barriers in addition to the barriers surrounding faculty mentoring, offering interdisciplinary PhD program, preparing PhD students for diverse career paths which are generally experienced in an IDS PhD program.

The next chapter will provide a discussion of these results. Discussion will be situated within the context of the literature reviewed for this study and propose recommendations for further research.

CHAPTER FIVE: SUMMARY, DISCUSSION, AND CONCLUSIONS

Introduction

Based on the study results presented in the previous chapter, chapter five provides a summary of this case study, discussion of findings, implications for practice, and recommendations for further research. Study implications and recommendations are provided in order to provide university officials with further resources on preparation techniques for IDS science PhD students and also ways in which students can further empower themselves to seek out experiences that will best prepare them for diverse career paths. Finally, this chapter ends with a summary of this case study in order to contextualize the content and scope of what this research attempted to accomplish.

Summary of the Study

This chapter is organized by first summarizing the purpose and design of the case study, followed by results related to preparing IDS science PhD students for diverse career paths. Results are then discussed within the context of its conceptual framework. Lastly, discussion is provided for this study's implications for practice and recommendations for further research.

The problem addressed in this case study was that interdisciplinary science PhD students needed to be prepared for entering diverse career paths, such as industry and government, in addition to academia, however many existing mentorship practices did not take these diverse career paths into account – specifically the apprenticeship model which continues to be the method of choice. The purpose of this study was to collect and analyze perceptions of stakeholders, such as graduate students, professors, and professional community members, regarding the ways interdisciplinary science PhD students can be prepared for diverse career paths. This case study was based on the needs and practices of interdisciplinary science PhD programs at large research universities. It was contextualized within the community of the Modeling and Simulation (M&S) PhD program at the University of Central Florida (UCF). This study was framed within the concepts and theories of interdisciplinary studies, skills expected of PhD graduates, and established methods for PhD career preparation which included the apprenticeship model and faculty supervision. Context for aligning the program with study participants was established using sampling techniques which ensured that characteristics of the study, specifically career sector, aligned with the proportions of the alumni career sectors of the case subject, among other population qualities.

The study was investigated using mixed methodology of a quantitative survey and qualitative interview. The quantitative Survey of PhD, Interdisciplinary, and Science Skills (Appendix C) was developed specifically for this study based on statements drawn from the *Irish Universities' PhD Graduate Skills Statement* (2015), the *Essential Competencies for Interdisciplinary Graduate Training in IGERT: Final Report* (Gamse et al., 2013) and *Making the Right Moves - A Practical Guide to Scientific Management for Postdocs and New Faculty* (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2006). Survey content validity was determined by utilizing expert judgment by nine experts including a UCF professor of educational leadership and team of eight educational leadership doctoral candidates and professionals. Items in the survey were organized by constructs which were treated as scales in the survey. Survey scale reliabilities were determined for the PhD skills scale (12 items; α=.90), professional science skills scale (5 items; α=.76), and interdisciplinary skills scale (4 items; α=.58). Within the PhD skills scale, several constructs were separated out as subscales and reliability calculations were conducted for research skills and awareness (6 items; α=.75), communication skills (3 items; α=.72), personal effectiveness and (5 items; α=.64), and entrepreneurship and innovation (4 items; α=.81). Qualitative interview protocol (Appendix E) was executed to obtain more in-depth information regarding the perceptions of various skills and PhD preparation methods.

This case study sampled 96 survey participants and 10 interview participants across career paths of academia, government, and industry, which were the focus of the study. Itemizations of survey participants by career sector and interview participants by career sector were provided in Table 2 and Table 4, respectively. Three research questions guided this case study and were investigated using mixed methodology:

Quantitative and Qualitative:

1. To what extent do participants value the science, interdisciplinary, and PhD skill statements?

Qualitative:

2. What are the perceived advantages and disadvantages of the apprenticeship model for preparing interdisciplinary science PhD students for diverse career paths?
3. What barriers and advantages do participants identify regarding the implementation of an alternate pedagogical model for interdisciplinary science PhD students?

Question one was answered quantitatively and qualitatively. Quantitative data were obtained from the Survey of PhD, Interdisciplinary, and Science Skills using descriptive statistics and an ANOVA calculation performed to compare the means of participants within career paths based on the degree of importance which they rated the various skills in the survey. Qualitative data were collected for all three research questions from the interview protocol and analyzed for thematic content.

Discussion of the Findings

Limited research exists on the topic of preparing IDS science PhD graduates for diverse career paths, largely focusing on only one aspect of this topic such as only on IDS studies, diverse career paths, or PhD graduates. The goal of this research was intended to better understand how the intersection of these topics can be studied together for the specific needs of IDS science PhD programs. This section discusses findings for each of the three guiding research questions of the study. It is important to include a reminder early in this chapter that the career sector of Academia as investigated in this quantitative portion of this case study included a wide array of participants whose roles ranged from student to professor, and several other categories in between. Such diverse participants within this category would undoubtedly have varying perspectives at the time they completed the survey portion of this study.

Research Question 1

To what extent do participants value the science, interdisciplinary, and PhD skill statements?

Quantitative results for this research question were reported with highest overall scores for the survey item of “work in a collaborative environment” and the survey construct of Ethics, Teamwork, and Career Management. The survey item reported with lowest overall scores was “lead a science laboratory”. The scale for Professional Science was scored lowest by the most career sectors. Qualitative results for this research question revealed that interview participants across all career sectors most valued mathematical and technical skills, and communication and listening skills.

Quantitative results favoring ethics and social understanding were aligned with results from Australian researchers Manathunga, Lant, & Mellick (2006) who found that doctoral students sought to develop these skills with guidance from their supervisors. The value placed on the ethics, teamwork, and career management construct was further aligned with studies that focused on doctoral student identity development and socialization (Baker & Lattuca, 2010; Boden et al., 2011; Borrego & Cutler, 2010). However, that the pure academia career sector did not score Ethics, Teamwork, and Career Management as the highest valued survey construct, is possibly reflective of Klein's (2010) reports on conflicting communications and cultures within traditional universities which struggle with offering IDS academic programs. Further, while academics often publish together in research teams, they are also bound by the tenure criteria of their disciplinary departments to publish as corresponding authors and are often less rewarded for leadership roles within departments or research teams (Golde & Gallagher, 1999; Millar, 2013). As PhD graduates increasingly pursue careers in government and industry, in addition to academia, issues of addressing teamwork and leadership skills in IDS science PhD programs may arise more often.

Low reported scores for the Professional Science construct and the survey item for leading a science laboratory were in contrast to Golde and Dore's (2001) findings which indicated that new faculty members often reported that many of their extra committee and administrative duties surprised them. Though, from interviews, it was clear that research and higher order skills were preferred because those skills could later transfer or trickle down to lower order, more direct tasks such as budgeting and teaching. Regarding the interview results, an emphasis on mathematical and technical skills aligned with this study's emphasis on an IDS science PhD program. Borrego & Cutler (2010) similarly found in their analysis of successful NSF IGERT proposals a common priority of technical learning outcomes. Emphasis on communication skills in the interview data were consistent with the literature that was reviewed for this study (Borrego & Cutler, 2010; Bridle, Vrieling, Cardillo, Araya, & Hinojosa, 2013; Cason, 2016; Galindo, Cabrera-Martinez, Abalos-Labruzzi, & Gómez-Galán, 2015; Halse & Malfroy, 2010; Spelt et al., 2009) as well as listening skills (Austin, 2002).

Additionally, a review of the survey items which elicited the most responses of Do Not Know is worthy of discussion. These items included "Appreciate the skills required for the development of entrepreneurial enterprises" (n = 7), "Understand technology transfer" (n = 5), "Critically reflect on experiences and act on such in a cycle of self-improvement" (n = 4), and "Lead a science laboratory" (n = 4). Participant motivations to select Do Not Know were not collected as they were not the focus of this study. However, Krosnick and Presser (2010) identify that reasons for selecting this option may include ambivalence about the topic, confusing or ambiguous language, a lack of understanding the prompt, and "the desire not to present a socially undesirable or unflattering image" (p.284). If study participants did not know about the content of these items, there may be a need to address this content in doctoral programs.

Research Question 2

What are the perceived advantages and disadvantages of the apprenticeship model for preparing interdisciplinary science PhD students for diverse career paths?

Qualitative interview content revealed a theme among government-academia and industry participants of a perceived a disadvantage of the apprenticeship model that only prepared or supported PhD students for careers in academia. Purely academic participants did not identify this aspect of the apprenticeship model in their interviews. This was somewhat consistent with the literature reviewed for this case study, particularly in seminal works on PhD mentoring and apprenticeship which specifically attributed a faculty member's advising efforts to replace himself or herself (Blackburn et al., 1981) and the historical purpose of PhD studies to further the institution of academia (Austin, 2002; Boden et al., 2011; Cason, 2016; Ferris et al., 2009; Foote, 2010; Gardner, 2008; Golde & Dore, 2001; Golde & Gallagher, 1999; Mangematin, 2000; Pearson & Kayrooz, 2004). Additional qualitative interview results were supported by the literature in that the quality of apprenticeships and their outcomes were highly dependent on the individual characteristics of the specific faculty advisor and PhD mentee (Billett, 2016; Conti & Visentin, 2015; Golde & Gallagher, 1999).

While some of the responses for research question two were aligned with the literature, data revealed a higher extent to which interview participants responded that the advisor-student relationship was the most important way to prepare for careers, especially for an IDS program. This is likely due to the disparity of designing IDS PhD programs without dedicated faculty, but still heavily relying on faculty-student advising from departmental faculty across campus as highlighted in some IDS literature such as Klein's (2010) *Creating Interdisciplinary Campus Culture*.

Research Question 3

What barriers and advantages do participants identify regarding the implementation of an alternate pedagogical model for interdisciplinary science PhD students?

Thematic content analysis of qualitative interview responses revealed alternate pedagogical models for IDS science students to include internships, project-based IDS work, and flexibility within a curriculum based on technical topics. The first recommendation was supported by six interview participants spanning all three career sectors who expressed that opportunities for internships, experiential learning, and/or shadowing should be provided for all IDS science PhD students in order to be prepared for diverse career paths. One industry participant specifically noted that PhD graduates often came with little experience managing money or time. This finding and the recommendation for internships and shadowing were supported by Campbell et al. (2005) and Foote (2010). Perceived disadvantages of internships and shadowing included issues of attrition, difficulties with faculty networking with industry, and the time that it takes to properly supervise internships for both students and faculty members.

The alternate pedagogical model for project-based IDS work in IDS teams was put forward by five interview participants who identified as industry, government, and government-academia career sectors; not from any purely academic participants. The aspect of this recommendation which is supported by the literature focuses on the informal learning that occurs within social interactions in team projects, formally referred to as social-constructive learning theory and perspectives (Campbell et al., 2005). Baker and Lattuca's work (2010) also took an IDS approach to identify how developmental networks and sociocultural learning theories intersect and demonstrated that learning in doctoral programs included interactions among institutional, departmental, and sociocultural perspectives. Further support for team projects came from literature reviewed for this study by Hartings, Fox, Miller, & Muratore (2015), König, Diehl, Tscherning, & Helming (2013), Mainhard et al. (2009), and Manathunga et al. (2006). The major barrier identified for this alternate model was that it was difficult and time-consuming for faculty communicate together and organize such meaningful, boundary-crossing assignments for students which was supported by Boden et al. (2011) and Klein (2010).

The third alternate model emphasized flexibility within a science IDS curriculum. This recommendation came from five interview participants whose career paths represented academia, government, and industry sectors. This recommendation was not found in interview content from hybrid career participants. The need for IDS programs to allow flexibility is common and was reported in the literature that was reviewed in this study (Dietz & Eichler, 2013; Graybill et al., 2006; Halse & Malfroy, 2010; Mangematin, 2000; Park, 2005). Similar to the second alternate pedagogical model, communication across university disciplinary boundaries was mentioned as a significant barrier to implementing this model as well, and remains supported by Boden et al. (2011) and Klein (2010).

Implications for Practice

While the practice of preparing PhD students solely for careers in academia has historical precedence (Ferris et al., 2009), PhD graduates now pursue other career sectors. Reasons for this include that careers in academia are no longer guaranteed given the growing numbers of PhD graduates and the stagnant or often shrinking number of faculty positions available (Larson et al., 2014), that career interests of graduates now include industry and government (Lee, Miozzo, & Laredo, 2010; Mangematin, 2000; Roach & Sauermann, 2010; Sauermann & Roach, 2012), and that industry and government organizations now prefer and actively recruit PhD graduates (Cyranoski et al., 2011). Findings from this case study indicate that the subject, an interdisciplinary science PhD program, shares this common concern for preparing students for diverse career paths in addition to other challenges involved with administering an IDS program.

Results from this study have implications for practice at universities which can be instituted by IDS science PhD programs.

PhD Skills

To begin, the skills valued by academic participants should continue to be upheld. However, skills valued by industry and government professionals should also be considered for implementation into IDS science PhD curricula. Specifically, that team-working and leadership skills were valued more by non-academic participants than academic could be addressed in curricula and instruction, and would align with one of the study's suggested alternate pedagogical models of project-based IDS team work. Additionally, PhD graduates could acquire skills such as managing money, time, and people through internships or shadowing that would be critical for pursuing diverse career paths, but would not necessarily be addressed in the program learning experiences. And lastly, flexibility was found to be a necessary component of an IDS program, but was limited by the faculty available for advising as IDS programs often do not have their own dedicated faculty or department (Klein, 2010).

Campus Culture

For universities seeking to establish a reputation for IDS studies and research, communication and cultural barriers need to be addressed to successfully implement an IDS science PhD program which prepares students for diverse career paths. Educating students and faculty about the traditional campus structure which separates disciplines into departments would be useful to help them navigate these reported concerns. Efforts to communicate this at orientation for new IDS science PhD students would be a useful way to provide this information to students upfront. Further, top university officials could pursue efforts to encourage and perhaps incentivize interdepartmental collaborations between faculty, staff, and students would help communicate a culture of interdisciplinarity (Klein, 2010).

Other PhD Support Networks and Opportunities

Additionally, this study is useful for students who may benefit from PhD opportunities outside of their faculty advising relationship, such as the suggestion to pursue an internship. Policy makers at universities may consider using this study to pursue support for developing targeted alumni groups for IDS programs who can provide further advising beyond what university personnel are able to provide.

Resources for Ongoing Faculty Mentorship Development

Regarding the perceived uneven quality of faculty advising, especially in IDS PhD programs, universities may also consider advising and mentoring models to continue to enhance the quality of services received by IDS science PhD students. They may also include further support and resources for faculty members develop as mentors for PhD students by bringing specific attention to topics that PhD students need advising on such as internships, shadowing, and group mentoring which are supported by the context and literature of this study.

Recommendations for Further Research

The purpose of this study was to investigate perceptions of stakeholders, such as graduate students, professors, and professional community members, regarding the ways interdisciplinary science PhD students can be prepared for diverse career paths. Data were collected and analyzed to answer the three research questions which guided this study. While several of the findings have significance, there remain some limitations to this study which should be addressed in future research.

Addressing Study Limitations in Future Research

Low Participation Rate

To begin, the study was limited by a low participation rate (9.6% of the estimated ~1,000 population size) and the community of just one specific IDS science PhD program. It is unknown if the specific nature of this case study is generalizable to all IDS science PhD programs or if some aspects are specific such as geographic influences.

Survey Organization

Constructs. Another limitation was that although this study utilized a quantitative survey which was organized by constructs, some single-construct items were grouped as a combined scale of Ethics, Teamwork, and Career Management. This was done to keep scale analyses as comparable as possible. Further research on this topic might offer incentives for participation in order to increase the response rate and lengthen the survey to include even distribution of items among survey constructs.

Participant Characteristics. A future study might also analyze quantitative survey participant characteristics further for those with identified roles in academia (Table 3) to filter out PhD students, or determine the PhD student's stage within the PhD program for further context. Additionally, true ordinal data could be pursued in a future study by having participants quantitatively rank their order of preference for skills presented in survey items within each scale.

Interview Organization

Qualitative interview feedback was limited by not specifically addressing the apprenticeship model. This was not done in this study so as not to bias the participants. However, the interview protocol could be re-considered so that the apprenticeship model was defined appropriately and perceptions could be collected directly. And lastly, while this study identified alternate pedagogical models and their barriers, a future study might ask participants to identify incentives which would be effective in implementing improvements to advising IDS science PhD students for diverse career paths.

Conclusions

The results from this case study extended the work of several studies on interdisciplinary PhD programs (Boden et al., 2011, 2011; Borrego & Cutler, 2010; Gardner, 2008; Golde & Gallagher, 1999; Graybill et al., 2006; Klein, 2010; Manathunga et al., 2006; Spelt et al., 2009) and preparing PhD graduates for diverse career paths (Cyranoski et al., 2011; Larson et al., 2014; Lee, Miozzo, & Laredo, 2010; Mangematin, 2000; Roach & Sauermann, 2010; Sauermann & Roach, 2012). Results indicate that in order to prepare students for diverse career paths, skills in ethics and social understanding need to be addressed during the PhD experience, along with other skills related to the construct of teamwork and leadership. Additional findings point to concerns with the apprenticeship model for preparing PhD graduates for their careers such as its strong implication for a career in academia and its reliance on the individual variables of the involved faculty member and student. Alternate pedagogical models of internships, project-based IDS team work, and flexibility were proposed for preparing IDS science PhD graduates for diverse career paths.

Summary

In summary, this case study intended to collect and analyze responses from stakeholders regarding the ways in which IDS science PhD students could be prepared for diverse career paths. It was guided by important, preceding research as outlined in chapter two, and designed based on the study methodology presented in chapter three. Study results presented in chapter four indicate that the purpose of this study was achieved, with this final chapter presenting implications and recommendations for future study. It is unmistakable that the topic of faculty mentoring is closely intertwined with the topic of PhD student career preparation, but the current practices for achieving this goal vary so greatly that there is little assurance that the standards for helping graduates' achieve maximum career goals are universally applied. While this study of PhD student career preparation was not a novel topic, this case study has revealed further strengths and weaknesses of related concepts when applied to interdisciplinary science PhD programs and diverse career pursuits of PhD students. Implications of this case study point toward a clearer pathway to diverse careers for graduates.

APPENDIX A:
IRB INFORMED CONSENT NOTICE FOR SURVEY

APPENDIX A: IRB INFORMED CONSENT NOTICE FOR SURVEY

University of Central Florida

Title of Project: Career preparation for interdisciplinary PhD students

Principal Investigator: Sabrina Gordon, Doctoral Candidate, Ed.D. in Education

Faculty Supervisor: Rosemarye Taylor, Ph.D.

You are being invited to take part in a research study. Whether you take part is up to you.

- The purpose of this study is to learn more about which skills are valued for preparing interdisciplinary science PhD students for diverse career paths.
- If you choose to participate in this study, you will be asked to complete the online Survey of PhD, Interdisciplinary, and Science Skills.
- This survey is expected to take approximately five (5) minutes to complete. This is the only request that will be made if you agree to participate in this study.

You must be 18 years of age or older to take part in this research study.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints please contact me (Sabrina.Gordon@ucf.edu) or my advisor, Dr. Rosemarye Taylor, Professor of Educational Leadership (Rosemarye.Taylor@ucf.edu).

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901.

We greatly appreciate your consideration of this request.

By clicking on this link you give your informed consent and begin the online survey: http://ucf.qualtrics.com//SE/?SID=SV_3LbL2psUse7gh0h .

APPENDIX B:
IRB INFORMED CONSENT NOTICE FOR INTERVIEW

APPENDIX B: IRB INFORMED CONSENT NOTICE FOR INTERVIEW

Title of Project: Career preparation for interdisciplinary PhD students

Principal Investigator: Sabrina Gordon, Doctoral Candidate, Ed.D. in Education

Faculty Supervisor: Rosemarye Taylor, Ph.D.

You are being invited to take part in a research study. Whether you take part is up to you.

- The purpose of this study is to learn more about perceptions of how interdisciplinary science PhD students are prepared for employment.

- If you choose to participate in this study, you will be asked to participate in an interview.

- The interview is expected to take approximately 20 minutes. Your interview response will be kept confidential by being assigned an alphanumeric code based on your professional career field.

- This is the only request that will be made if you agree to participate in this study.

You must be 18 years of age or older to take part in this research study.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints please contact me (Sabrina.Gordon@ucf.edu) or my advisor, Dr. Rosemarye Taylor, Professor of Educational Leadership (Rosemarye.Taylor@ucf.edu).

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901.

We greatly appreciate your consideration of this request.

APPENDIX C:
SURVEY OF PHD, INTERDISCIPLINARY, AND SCIENCE SKILLS

APPENDIX C: SURVEY OF PHD, INTERDISCIPLINARY, AND SCIENCE SKILLS

<< To be administered using Qualtrics survey software >>

Overview: There are 35 short items in this Survey of PhD, Interdisciplinary, and Science Skills. Items 1-30 were quoted or edited from statements from the following publications:

- Irish Universities Association (2015): Items 1-21
    - Full citation: Irish Universities Association (IUA). (2015). *Irish Universities' PhD Graduate Skills Statement*. Retrieved from http://hse.openrepository.com/hse/handle/10147/120285
- Burroughs Wellcome Fund and Howard Hughes Medical Institute (2006): Items 22-26
    - Full citation: Burroughs Wellcome Fund, & Howard Hughes Medical Institute. (2006). Making the Right Moves - A Practical Guide to Scientific Management for Postdocs and New Faculty. Howard Hughes Medical Institute and Burroughs Wellcome Fund.
- Gamse et al. (2013): Items 27-30
    - Full citation: Gamse, B. C., Espinosa, L. L., & Roy, R. (2013). *Essential Competencies for Interdisciplinary Graduate Training in IGERT: Final Report. GS-10F-0086K.* Retrieved from http://eric.ed.gov/?id=ED553183

Directions: For each item, please identify your level of agreement.

	It is important for professionals in my field to…	**Strongly Agree**	**Somewhat Agree**	**Somewhat Disagree**	**Strongly Disagree**	**Do Not Know**
1	exhibit knowledge of advances and developments in the field.					
2	comprehend and effectively employ appropriate research methodologies.					
3	formulate and apply solutions to research problems and effectively interpret research results.					
4	demonstrate a knowledge of health and safety procedures in the research environment.					
5	have a broad knowledge of relevant funding sources and grant application procedures.					
6	apply basic principles of project and time management.					
7	apply principles of ethical conduct of research.					
8	demonstrate effective writing and publishing skills.					
9	effectively use appropriate forms and levels of communication.					
10	communicate research to diverse audiences.					
11	operate in an independent and self-directed manner, showing initiative to accomplish clearly defined goals.					
12	demonstrate key rhetorical skills, including how to persuade others of a viewpoint’s merits.					
13	initiate new projects, proactively reacting to newly identified needs or aiming to resolve persistent problems.					
14	handle difficulties in research or other professional activities in an appropriate way.					
15	critically reflect on experiences and act on such in a cycle of self-improvement.					
16	work in a collaborative environment.					
17	demonstrate an awareness of transferable skills to both academic and non-academic positions.					
18	understand the role of innovation and creativity in research.					

	It is important for professionals in my field to…	**Strongly Agree**	**Somewhat Agree**	**Somewhat Disagree**	**Strongly Disagree**	**Do Not Know**
19	demonstrate an awareness and understanding of intellectual property issues.					
20	appreciate the skills required for the development of entrepreneurial enterprises.					
21	understand the contribution that knowledge transfer can make to society.					
22	lead a science laboratory.					
23	mentor and be mentored by others.					
24	manage data and utilize laboratory notebooks when necessary.					
25	understand technology transfer.					
26	teach and design courses.					
27	develop depth of knowledge in one discipline or field of study.					
28	recognize the strengths and weaknesses of multiple disciplines.					
29	apply the approaches and tools from multiple disciplines to address a research problem.					
30	work in a team with individuals prepared in different disciplines.					

Just a few more questions… Please briefly tell us about your own career path(s) and profession(s).

31. Select all that apply to your current professional sector:
    a. Academia: Full-time faculty
    b. Academia: Administrator
    c. Academia: PhD student
    d. Academia: Adjunct faculty
    e. Academia: Mentor, non-faculty for PhD students
    f. Government
    g. Industry
32. How long have you been in your current professional sector?
    a. 0 – Not applicable
    b. 1-5 years
    c. 6-10 years
    d. 11-15 years
    e. 16-20 years

f. 21-25 years
g. 26-30 years
h. 31 years or more

33. How many years have you been involved in the M&S community?
    a. 0 – Not applicable
    b. 1-5 years
    c. 6-10 years
    d. 11-15 years
    e. 16-20 years
    f. 21-25 years
    g. 26-30 years
    h. 31 years or more
34. What is your highest level of education?
    a. High school
    b. Bachelor’s degree
    c. Master’s degree
    d. Doctoral degree
    e. Other
35. What was the field of study for your highest level of education?
    a. <Open text response>
36. Have you worked in a university research laboratory?
    a. No
    b. Yes, in the field of: ________________
37. If you have worked in a university research laboratory, which activities did you personally contribute to or experience? (select all that apply)
    a. Searched research literature
    b. Wrote literature reviews
    c. Collected data/ Ran study participants
    d. Analyzed data
    e. Presented at meetings
    f. Rotated through more than one laboratory
    g. Decided on research topics for the laboratory
    h. Managed others in the lab
    i. Researched a novel topic which did not have funding
    j. Managed project timelines
    k. Managed a budget
    l. Other: ____________________
38. Please tell the researcher anything else you believe is important for preparing interdisciplinary science PhD students for career success.
    a. < Open text response >

39. As a member of the Modeling and Simulation community, if you would like to participate in a short interview regarding the preparation of PhD students for career success, please provide your name and best contact email. Any contact information provided here will be separated from your previous responses prior to analysis and stored separately. Thank you for your time.
    a. Name: ____________
    b. E-mail: ___________

APPENDIX D:
INTERVIEW RECRUITMENT E-MAIL

APPENDIX D: INTERVIEW RECRUITMENT E-MAIL

Dear [first name, last name]:

I am contacting you because [choose one: (A) your name was provided by Dr. Peter Kincaid OR (B) you responded to our Survey of Interdisciplinary Science PhD Skills] as someone who may be willing to provide feedback for a research study being conducted at the University of Central Florida (UCF).

The study aims to interview members of the Modeling and Simulation (M&S) community to learn more about their perceptions of interdisciplinary science PhD programs. Studies on such programs are limited, which is why it is so important to address some questions we have about your perceptions of them.

You are invited to review the attached Interview Informed Consent form to learn more about the study, how interview responses will be used, and how we will keep your identity confidential from the feedback you provide. I estimate that the interview will take 10- 20 minutes.

Interviews may take place in person or by phone to accommodate whichever mode is most convenient for you. If you are willing to participate, here are some days and times when I could schedule an interview with you:

- [Option 1]
- [Option 2]
- [Option 3]

Would you please write back to indicate if you would be willing to participate in an interview, and the day, time, and mode you prefer?

If you have any questions regarding this study, please feel free to contact me by phone or e-mail. I appreciate your consideration.

APPENDIX E:
INTERVIEW PROTOCOL

APPENDIX E: INTERVIEW PROTOCOL

[NOTE: As required by the UCF Institutional Review Board (IRB), a consent form (Appendix A) will be presented to each interviewee prior to the interview. Verbal consent will be recorded by interviewer.]

Introduction

Thank you for joining me today for this research study. As we begin, I would like to remind you that your involvement is voluntary.

- You can choose to stop this interview at any point.
- Your responses will be aggregated with those of other participants and will be identified by an alpha numeric code related to your professional career field.
- As a volunteer, you may indicate if you prefer to not answer a question or end the interview early for any reason.

Disclosure

I would like to take notes and audio record during this conversation so that I can transcribe it later for accurate reporting. The audio file will be destroyed once the transcription is complete. Would that be alright with you?

This should take approximately 10-30 minutes. Do you have any questions before we begin?

Protocol

I have prepared approximately eight items for our interview with some pre-established prompts which we may utilize if needed.

9. Tell me about your professional background.

a. How many years?

b. What's your daily work like?

10. Please tell me about skills that you believe are important in your profession.

    a. Tell me more about that.

    b. Do you recall any thoughts that co-workers have shared with you about other skills that are important in your career sector?

    c. Probes: problem solving, reporting writing, presentation experience, management skills, budget experience?

11. What makes an ideal candidate for employment in your profession?

12. In your profession, do you anticipate any future directions regarding the employees they hope to hire?

These next items have to do with how PhD students are prepared for their careers.

13. What is your understanding of how PhD students are prepared for their careers?

    a. In your opinion, which career paths are students being prepared for?

14. Thinking about people who graduate from interdisciplinary science PhD programs... In an ideal world, how would they be prepared for their careers?

    a. Probe: What would be the positive attributes? For students? For faculty? For employers?

    b. Probe: What would be the negative attributes? For students? For faculty? For employers?

    c. Probe: What would be the barriers to implementation?

15. Again, for interdisciplinary science PhD students... What experiences would prepare them for diverse career paths to include academia, industry, and government?
16. Have you ever mentored a PhD student? Thinking back to your experiences with mentoring a PhD student, what would have made the experience more successful for you and the mentee?
    a. *Probe: For independent study, directed research, internship, dissertation, etc.?*

Closing

17. Is there anything else that you would like me to know regarding preparing interdisciplinary science PhD graduates for their careers?

Thank you very much for your time.

APPENDIX F:
SURVEY RESPONSE RATE USING TAILORED DESIGN METHOD

APPENDIX F: SURVEY RESPONSE RATE USING TAILORED DESIGN METHOD

Dillman et al.'s (2014) tailored design method was utilized to elicit the maximum return rate for the survey portion of this study. Figure 1 illustrates the response rate in coordination with the number of requests and reminders made.

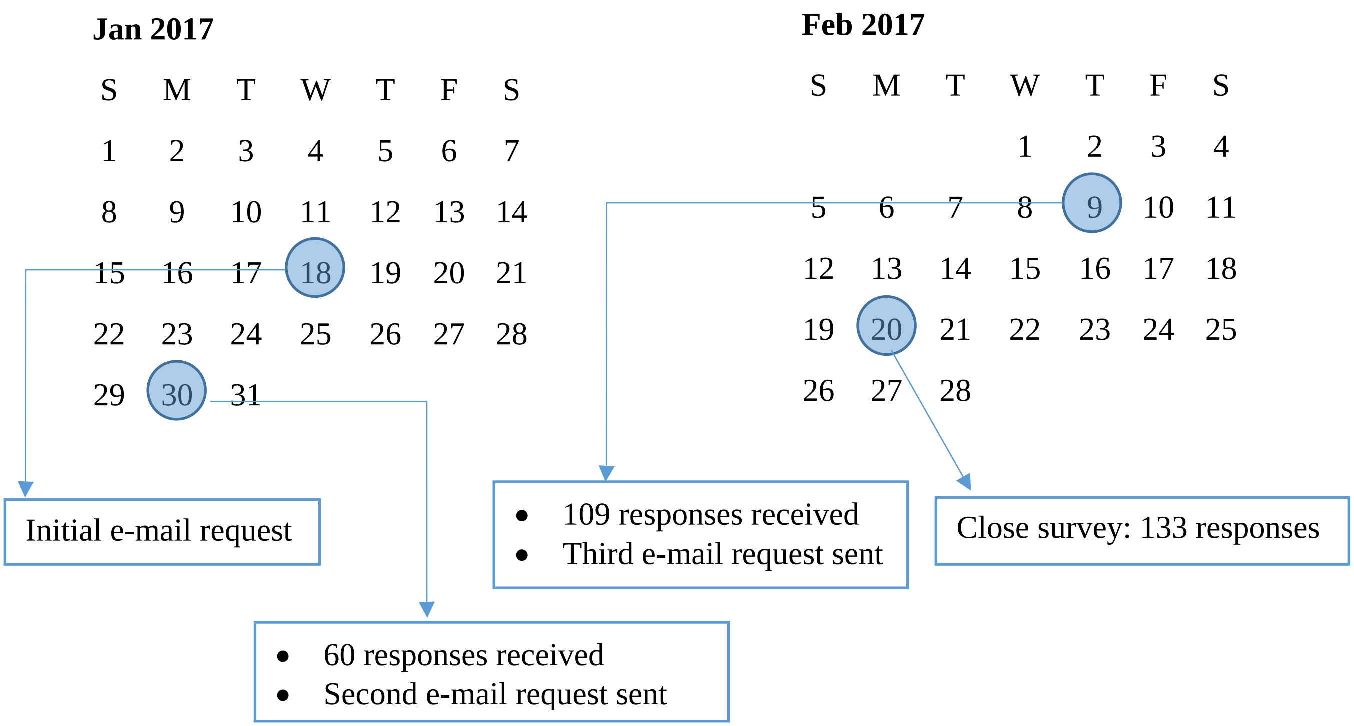

Figure 1 Response rates using tailored design method

APPENDIX G:
UCF INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL LETTER

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University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Exempt Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Sabrina Gordon** and Co-PI :**Rosemarye T. Taylor**

Date: **January 12, 2017**

Dear Researcher:

On 01/12/2017, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	Career preparation for interdisciplinary phd students based on employer-preferred skills: A case study
Investigator:	Sabrina Gordon
IRB Number:	SBE-16-12733
Funding Agency:	
Grant Title:	
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Gillian Amy Mary Morien on 01/12/2017 04:56:35 PM EST

IRB Coordinator

Page 1 of 1

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