The Entanglement of Gender, Science, and Interdisciplinarity: Standpoints of Women PhD Students in Interdisciplinary Traineeships

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THE ENTANGLEMENT OF GENDER, SCIENCE, AND INTERDISCIPLINARITY: STANDPOINTS OF WOMEN PHD STUDENTS IN INTERDISCIPLINARY TRAINEESHIPS

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ABSTRACT

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May 2020

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Grounded in the suggestion by Rhoten and Pfirman (2007) that the core practices of interdisciplinary research were embedded with gendered properties and thereby held the potential to offer more welcoming spaces for women's participation and advancement in scientific fields, this study investigated how women PhD students' participation in the specific context of interdisciplinary training programs influenced their educational and professional socialization. Narrative inquiry methodology guided in-depth interviews with 19 women PhD students who were participating in one of three National Science Foundation-funded Integrative Graduate Education and Research Traineeship (IGERT) programs at three research universities in the greater Northeast region of the United States. Overall, study findings illuminated ways in which interdisciplinary socialization contributed to the participants' experiences as PhD students and informed their personal, academic, and professional growth and future goals. Key findings highlighted the ways in which four modes of interdisciplinary practice – cross-fertilization, team-collaboration, problem-orientation, and field-creation – operated in an interdisciplinary doctoral student socialization environment. Findings also illuminated the existence of a highly experiential and epistemological dimension of processing interdisciplinary socialization experiences derived expressly from the standpoints of women doctoral students through which women made sense of, critically considered, and reclaimed interdisciplinarity.

Theoretical implications for feminist standpoint theory, gendered socialization theory, and the theory of academic capitalism are discussed in light of the findings. Additional implications are outlined for the education and training of doctoral students that highlight practical suggestions grounded in this study's findings for universities; governmental and other funding bodies and policy-making agencies; doctoral programs and departments; women and other populations of doctoral students; and communities around the world where interdisciplinary approaches to problem-solving are critical to advancing human, environmental, and technological adaptability and sustainability. Finally, several valuable

lines of future research that would further understanding of student outcomes in interdisciplinarity doctoral education, faculty work, and university organization are proposed.

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I write these acknowledgements as we are in the early weeks of navigating through the global turmoil of the COVID-19 pandemic. In this context, our work and our lives are differently contoured and the people, places, and things we are thankful for are magnified.

I have been thinking a great deal about the women who participated in this study. They represent hope for our futures in their determination to work to address complex real-world interdisciplinary problems and to openly demonstrate how science works in service to society to advance human and environmental health and sustainability. COVID-19 is the epitome of an interdisciplinary problem where trust between science and society in the name of public health is critical to the success of current and longer-term responses. Knowing these women are driven in ways that merge the production and application of interdisciplinary scientific knowledge with the public good at the forefront is a comfort. Without them and the trust they put in me as a researcher to listen to and retell their stories, this dissertation would not have been possible.

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A few years ago, I was convinced that this dissertation would constitute my life's work. It would be the individual accomplishment of which I would be most proud, a signal that I was worthy. This was true until the day my daughter Lily entered the world. Her presence in my life all at once gave me a new reason to see the dissertation through to completion and forever altered my definition of accomplishment. She, in fact, is my life's accomplishment and it is to her and my husband John that I dedicate this work. Now we celebrate.

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INTRODUCTION

Study Background

In the first decades of the 21st century, the United States has found itself in a tenuous position where the positive participation trajectories of women in STEM majors and fields are juxtaposed with largely disproportionate outcomes, especially in women's advancement to high-status positions in academe and industry (Fox, 2010; Fox & Stephan, 2001; Kulis, Sicotte, & Collins, 2002; Long & Fox, 1995; National Science Foundation (NSF, 2015). The disparity between women's participation rates and subsequent advancement in STEM education and careers continues to drive an important dialogue and empirical inquiry, especially related to the sociocultural experiences of women in STEM and the ways in which the prevailing culture of science is constraining women's progress and status, despite increases in the number of girls and women in the scientific educational pipeline.

Although progress has been made in terms of the number of women entering STEM degree programs and obtaining undergraduate and advanced degrees, women in STEM majors and careers continue to face issues of underrepresentation, differential career outcomes, and unwelcoming disciplinary and departmental climates (Hill, Corbet, & St. Rose, 2010; National Council of Graduate Schools, 2008; NSF, 2015). While women have increased their degree participation and attainment in all STEM fields and parity has been reached for women's degree attainment in the life sciences at the undergraduate and graduate level, these increases are much less notable in the physical, computer, and engineering sciences, especially at the graduate level (NSF, 2015). According to the NSF (2014), in 2013, women earned approximately 55% of all life science doctoral degrees, but only 23% of all engineering and 29% of all physical science doctoral degrees. In the physical sciences, which includes a number of historically well-resourced fields that enjoy high prestige, women remain underrepresented at the graduate level in astronomy (32%), atmospheric science (42%), chemistry (39%), computer science (18%), geological sciences (43%), mathematics (29%), ocean and marine sciences (32%), and physics (19%).

Despite evidence of the presence of more women and girls in the STEM educational pipeline, the overall rates of career advancement for women in virtually all science and engineering fields continues to be lower than the rates of men (Fox, 2010; Fox & Stephan, 2001; Kulis, Sicotte, & Collins, 2002; Long & Fox, 1995; NSF, 2015; Xie & Shauman, 2003). Fewer women than men actually pursue or remain in traditional routes in the academy, resulting in low representation of tenure-track and tenured women professors. Further, of the high proportion of STEM PhDs who migrate to non-academic careers in scientific industry, women disproportionally settle on the periphery of science or in non-science career fields (NSF, 2015). In fact, women with the highest level of training in STEM fields, those with doctoral degrees, are most likely to exit the scientific field, work part time, work on the periphery of scientific occupations, or opt for non-science careers (Fox, 2001, 2010; Fox & Stephan, 2001; Hill, Corbet, & St. Rose, 2010; NSF, 2015; Turk-Bicakci, Berger, & Haxton, 2014).

Persisting disproportionate educational and career outcomes for women in science continue to both interest and puzzle researchers and theorists. A number of empirical studies and a series of reports from task forces and government agencies have illuminated key institutional, cultural, and individual barriers to women's advancement in STEM education and careers (Ceci & Williams, 2011; Fox, 1999, 2001, 2010; Hill, Corbet, & St. Rose, 2010; Moss-Rascusin, Dovidio, Brescoll, Graham, & Handelsman, 2012; National Academy of Sciences, 2007; NSF, 2015; Rosser & Lane, 2002; Sheltzer & Smith, 2014; Valian, 1999). These investigations have highlighted issues that affect both men and women, but tend to affect women disproportionally, negatively impacting their inclusion as full participants in science and engineering disciplines. Commonly cited obstacles have included a lack of women in degree programs who can act as social peers, lack of women mentors and role models in faculty and industry leadership positions, family-unfriendly policies and practices that disproportionally impact women, and a culture that values individualistic pursuits and aggressive competition (DeWelde & Laursen, 2011; Erickson, 2012; Ferreira, 2002, 2003a, 2003b; Fox, 2001, 2010; Litzler, Lange, & Brainard, 2005; Sallee, 2011a), and perpetuates biased thinking and practices regarding women's aptitude for and fit with scientific pursuits (Moss-Racusin et al., 2012; Sheltzer & Smith, 2014).

Although the scientific ethos espouses gender-neutrality through its norm of universalism and its conceptualization of objectivity (Harding, 1991; Long & Fox, 1995; Merton, 1957, 1973), the few studies focused on exclusively women graduate students in STEM have consistently pointed to evidence of marginalization and experiences with discrimination (DeWelde & Laursen, 2011; Erickson, 2012; Ferreira, 2002, 2003a, 2003b; Fox, 2001, 2010; Kemelgor & Etzkowitz, 2001; Litzler, Lange, & Brainard, 2005; Sallee, 2011a). These studies have further probed additional contextual and organizational features that are important to consider in attempts to gain insight into persisting underrepresentation and differential outcomes for women in STEM. Investigations by Ferreira (2002, 2003a, 2003b) and others (Erickson, 2012; Etzkowitz, Kelemegor, & Uzzi, 2000; Kemelgor & Etzkowitz, 2001; Litzler, Lange, & Brainard, 2005; Sallee, 2011a), for example, have underscored the role of departments, programs, and research laboratories as important organizational contexts through which to understand the experiences of women graduate students in STEM. Etzkowitz, Kelemegor, and Uzzi (2000) and Ferreira (2002) found that the research laboratory served as a context in which women PhD students encountered both overt and subtle discrimination as well as differential socialization experiences than their male peers, resulting in inequitable access to information and training experiences. These and other studies have opened important windows on key sociocultural aspects of STEM doctoral socialization including mentoring and advising relationships, peer relationships, research and publication expectations, division of labor, and access or inclusion in scientific collaborations and networks. Further, a wave of alarming studies focused on graduate students seeking laboratory placements pointed to a continued culture of bias against women in science, finding that women are disproportionately excluded from professional training experiences in high-performing laboratories run by elite male faculty, impacting their career development, publication record, and access to scientific social networks that are critical for professional recognition and advancement (Moss-Racusin et al., 2012; Sheltzer & Smith, 2014). Taken together, these studies point to a highly complex education and training landscape characterized by inequity, bias, and an alternate reality for doctoral women in STEM that stands in firm contrast to the rosier picture of increased numbers of women pursuing and obtaining STEM undergraduate and graduate degrees.

Several researchers have speculated that interdisciplinary scientific programs may function as more welcoming spaces for women in STEM, especially at the graduate level, as evidenced by women's more frequent engagement in interdisciplinary science activity compared to their male counterparts (Rhoten & Pfirman, 2007). Specifically, Rhoten and Pfirman (2007) found that graduate-level women in STEM are engaging in greater proportion than their male peers in research experiences that draw on multiple disciplines and attend to multiple stakeholders. The authors suggested that interdisciplinary science and scientific research may be functioning as a space that is "serving as a strong entry point into scientific studies for women," offering a potential bridge to the persisting gender gap in science education and careers and making "better use of the talent of female scientists" (p. 72).

While the notion that women may be found more frequently engaging in interdisciplinary scientific research remains largely unexplored, several ongoing threads of research have been expanding in relation to the phenomenon illuminated by Rhoten and Pfirman (2007). For example, recent decades have seen an increased focus on interdisciplinary structures and strategies in research universities (Feller, 2002; Harris & Holley, 2008; Holley, 2009b, 2009c; Klein, 2010; National Academy of Sciences, 2005; Sá, 2008a, 2008b). In addition, a more focused debate around how to redesign and revitalize the education and training of the scientists and engineers of the future has emerged, which has included a discussion of what might constitute an appropriate mix of disciplinary and interdisciplinary focus (Boden, Borrego, & Newswander, 2010, 2011a, 2011b; Golde & Walker, 2006; Holley, 2009a, 2009b, 2009c, 2010; National Academy of Sciences, 2005; Nerad, 2004; Rhoten & Parker, 2004). Across these same decades, a persistent discourse around increasing the participation and advancement of women and people of color in STEM education and careers continues to develop and evolve (Fox, 2001; National Academy of Sciences, 2007; National Science Foundation, 2015; Rosser & Lane, 2002; Vallian, 1999). These and other related research threads are important in exploring the participation of women doctoral students in interdisciplinary training and research contexts.

Interdisciplinarity as a University Context

According to the National Academies of Science (2005), “Interdisciplinary thinking is rapidly becoming an integral feature of scientific research as a result of four powerful ‘drivers’: the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies" (p. 2). One of the key motivations for the pursuit of interdisciplinary research is that groundbreaking discoveries often occur at the intersections of academic disciplines, increasing the potential for noteworthy innovation that not only extends human understanding, but can also have direct application to the needs of society (National Academies of Science, 2005).

Moreover, major scientific agencies, including the NSF and the National Institutes of Health (NIH), are making interdisciplinary approaches a requisite for some of their largest grant competitions, which colleges and universities leverage as an institutional strategy to supplement revenue and differentiate themselves in a competitive marketplace (Feller, 2002; Geiger, 1990; Hearn, 2006; National Science Foundation, n.d.). Thus, institutions increasingly view interdisciplinarity as a financial strategy to access alternate streams of revenue from external agencies and foundations that favor interdisciplinary research proposals (Feller, 2002, 2007; Hearn, 2006). Along the same lines, public research universities may view interdisciplinarity as a means though which they may increase their degree of privatization by forging knowledge creation partnerships with external funders, thereby minimizing their reliance on state funds as a percentage of their overall operating budgets (Eckel & Morphew, 2009; Geiger, 2004; Slaughter & Leslie, 1997; Slaughter & Rhoades, 2004). In essence, the potential for great innovation and contribution to social and economic development, the need to access new patterns of external funding, and the desire for prestige are three intertwined forces that are solidifying and legitimizing interdisciplinary approaches to conducting research at research universities.

Interdisciplinarity as a Context for STEM Doctoral Training

Interdisciplinary strategies and structures in higher education increasingly overlap with the training of doctoral-level scientists and engineers. In 1998, the NSF began sponsoring the first major doctoral-level interdisciplinary research traineeship program known as the Integrative Graduate Education and Research Traineeship (IGERT), which is focused on educating PhD scientists and engineers in U.S.-based universities by building on the foundations of their disciplinary knowledge with interdisciplinary training. According to the IGERT.org (2018, ”Mission, History & Impact” section), the IGERT program “is intended to catalyze a cultural change in graduate education, for students, faculty, and institutions, by establishing innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries.” Further, a core goal of an IGERT program is “to facilitate greater diversity in student participation and preparation, and to contribute to the development of a diverse, globally-engaged science and engineering workforce” and, more specifically, to “increase participation of women and underrepresented minorities in science and engineering research and training” (IGERT.org, 2018, “Mission, History & Impact” section). Each new IGERT program was awarded approximately five years of funding, after which pre-existing IGERTs could apply for a period of extended funding.

These varied and evolving interdisciplinary structures and strategies have added new complexities and hybridized dimensions to the training and professional socialization of doctoral students in STEM. Given that women in STEM education are already encountering differential socialization environments than their male counterparts, it stands to reason that an increased emphasis on participation in interdisciplinary research collaborations as part of the doctoral experience may have special implications for women doctoral students, who are engaging in such work in greater numbers than their male counterparts (Rhoten & Pfirman, 2007).

Interdisciplinary Spaces as Welcoming Organizational Contexts for Women in STEM

Many feminist scholars and other sociologists of science argue that current explanations for women's continued underrepresentation in the STEM fields have not sufficiently or critically assessed the male-dominated social structure of science (Haraway, 1991, Harding, 1991, 2004, 2008; Rose, 1983). These scholars have underscored the existence of a masculinized scientific enterprise, which comprises an ethos and research practices created and institutionalized outside of the purview and participation of women and other minoritized populations who have been historically excluded from full participation both as scientists and as research study participants. The result, they suggest, has been an androcentric and, therefore, myopic body of scientific knowledge that both overlooks and oppresses the perspectives and participation of women in science. Discipline-bound research has been similarly critiqued for generating "partial knowledge" by divorcing itself from perspectives and methodologies outside of the disciplinary silo (Klein, 1990, 1996; Minnich, 2005; Nowotny, Scott, & Gibbons, 2001; Salter & Hearn, 1996).

Further, several empirical investigations and personal accounts from women scientists have suggested that the exclusionary culture of science—one that socially isolates women from informal and formal scientific networks and places a high value on individualistic pursuits and aggressive competition—has effectively pushed women scientists to the margins where they can do science in less crowded and more welcoming spaces in a way that connects them to alternate networks and collaborative relationships (Kemelgor & Etzkowitz, 2001; Sonnert & Holton, 1996; Traweek, 1988). Interdisciplinary research collaborations, in relation, are often cast as offering a less homogeneous and more inclusive organizational context for scientific research that draws on multiple disciplinary perspectives, which may include collaborations with wider networks outside of academe. In addition, interdisciplinary research is perceived as involving both an acknowledgement of and a commitment to social responsibility through a real-world problem-based approach to complex social, technological, health, and environmental issues that go beyond a single disciplinary perspective (Klein, 1990, 1996, 2010; National Academy of Sciences, 2005; Nowotny, Scott, & Gibbons, 2001; Salter & Hearn, 1996).

The higher education literature is currently devoid of studies that focus on the experiences of women PhD students in the context of interdisciplinary research environments in STEM or the inner workings of contemporary interdisciplinary research environments. Thus, the intersection of gender, science, and interdisciplinarity with respect to the training and socialization of women PhD students remains largely unexplored notwithstanding the fact that the PhD years represent a critical stage "from high school to faculty," when highly trained and accomplished women PhD students may be "vertically segregated," or leaked from the STEM education and career pipeline (Blickenstaff, 2005; Rosser, 2004, p. 61).

Further, and of utmost importance, women's explicit participation in IGERT traineeships has not yet been qualitatively explored. Focusing on women's IGERT participation is critical in two distinct ways. First, IGERT programs are expressly and intentionally designed to offer and support interdisciplinary STEM training to PhD students. Thus, IGERTs represent ideal settings from which to launch an exploration of women PhD students' socialization experiences and perceptions in the context of interdisciplinarity. Second, the final set of new IGERT programs were awarded five years of funding in October 2015. As a result, existing IGERTs have been nearing the end of their funded periods, and the newest IGERT programs funded in 2015 will be nearing the end of their NSF-funded project and traineeship activity in approximately the year 2020. Thus, with all funded IGERT activity coming to a close in or around 2020, the present study taps into a critical and waning timeframe in which the experiences and perceptions of current and active women IGERT trainees can be examined in context.

Statement of the Problem

While opportunities to engage in interdisciplinary modes of research represent a promising shift that may align more closely with the values and thinking of many women scientists, we can currently only speculate how or to what extent the increased prevalence of interdisciplinary modes of research and training opportunities supports, challenges, and shapes the socialization experiences of women PhD students and how these women develop as interdisciplinary science people as a result of their engagement in interdisciplinary scientific training.

The speculation that interdisciplinary science may be functioning as a space that is “serving as a strong entry point into scientific studies for women,” offering a potential bridge to the persisting gender gap in science education and careers and making “better use of the talent of female scientists” is both compelling and sits amid conflicting research findings (Rhoten & Pfirman, 2007, p. 72). On one hand, rhetoric and action to increase interdisciplinary curriculum and knowledge production practices in the university have flourished over recent decades (Feller, 2002; Klein, 1996, 2010; Harris & Holley, 2008; Holley, 2009a; National Academy of Sciences, 2005; Nowotny, Scott, & Gibbons, 2001; Sa, 2008a, 2008b). Further, characterizations of interdisciplinary research as offering more inclusive and collaborative structures and practices and a research focus on real-world problems that acknowledges an interest in and connection to society rather than the value-neutral objectivity or “disinterestedness” endorsed in the conventional scientific ethos have been thought to align more prominently with the preferences and practices of women in the sciences (Collins, 2009; Haraway, 1991; Harding, 1991, 2004, 2008; Harstock, 1998; Klein, 1990, 1996; Minnich, 2005; Rhoten & Pfirman, 2007; Rose, 1983; Rosser, 2004; Salter & Hearn, 1996).

On the other hand, researchers have pointed to a number of ways in which interdisciplinary structures and practices can be marginalized within universities that are organized for disciplinary pursuits (Feller, 2002, 2006; Holley, 2009a, 2009b, 2009c). In addition, researchers have found that those pursuing interdisciplinary degrees and training can experience a number of challenges related to achieving requisite disciplinary depth and interdisciplinary breadth, with further challenges emerging in the quest to market themselves into clear and desirable career trajectories (Borrego & Newswander, 2010, 2011b; Holley, 2009a, 2009b; Holley, 2018; Millar, 2011; Rhoten & Parker, 2004). With STEM already implicated as a playing field that disadvantages women in their equitable participation and advancement, questions emerge around whether or to what extent interdisciplinary spaces are more welcoming or are serving as “strong entry points” to STEM participation and advancement for women (Rhoten & Pfirman, 2007, p. 72). This present study will begin to untangle this problem by elevating the voices of and examining the socialization experiences of women PhD students engaged in IGERT traineeships.

Purpose and Research Questions

My study investigates how women PhD students’ participation in IGERT programs influences their educational and professional socialization and illuminates the ways in which interdisciplinary socialization contributes to their experience of being a PhD student and informs their personal, academic, and professional growth and future goals. The primary goal of the study is to gain nuanced and rich insights into women PhD students’ everyday experiences, perceptions, and values with respect to their educational and professional socialization as doctoral trainees in interdisciplinary contexts. My investigation is guided by four primary research questions related to the socialization and engagement of STEM women PhD students in interdisciplinary research contexts:

1. In what ways do the socialization dynamics of interdisciplinary traineeships shape the educational and research experiences of women PhD students in IGERT contexts?
2. What opportunities, challenges, and tensions do women PhD students in IGERTs perceive through their interdisciplinary socialization experiences?
3. In what ways do women PhD students in IGERTs make meaning of and negotiate the process of becoming an interdisciplinary science person?
4. In what ways is gender enacted and produced in the context of IGERT traineeships?

In addition to broadening our understanding of women's participation and advancement in STEM education and careers in the context of interdisciplinarity, these questions are also intended to directly investigate and illuminate women's learning and problem-solving practices in the context of interdisciplinary scientific training. Further, the questions address how these learning and problem-solving practices intermingle with the process of solidifying norms, values, and beliefs about the practice of science and the process of becoming an interdisciplinary science actor. My study will seek to specifically explore the nature of women PhD students' participation in IGERT traineeships and attempt to better understand how women view and integrate these experiences with their individual values, disciplinary foci, and career discernment.

The research questions are also designed to explore any special implications that may emerge from an increased understanding of the engagement of women PhD students in interdisciplinarity. For example, my study sought to better understand ways in which participation in interdisciplinary training might be gendered and whether or to what extent participation in interdisciplinary training activity at the PhD level contributes to or detracts from the common marginalization experienced by women in STEM education and careers.

In addition, drawing on the experiences of the diverse sample of women participating in this study with regards to demographic and academic backgrounds, this study contributes to our understanding of the ways in which women's participation in interdisciplinary research training may be similar or different for women across a variety of background characteristics including, but not limited to, PhD focus (including natural vs. social sciences), race/ethnicity, and focus of IGERT. In a slightly different vein, the findings of this study provide insight into the degree to which women's experiences differ across IGERT and institutional contexts. Such insights assist in adding more nuanced dimensions to our understanding of the cultural alienation and "chilly" climate many women researchers experience in the academy and feel toward the overriding male-centric value systems of science (Hall & Sandler, 1982; Ferreira, 2002, 2003a; Fox, 1999, 2001; Rosser, 2004), informing current practices and policies, and opening up new lines of investigation.

CHAPTER 2

LITERATURE OVERVIEW

Examination of Key Literature

The ensuing literature overview will focus on four broad areas of existing research and draw connections among them. The first section will explore the role and function of interdisciplinarity in academe, including how it has been defined and in what ways university organization has supported and challenged interdisciplinary structures and strategies. The discussion of interdisciplinarity will then extend into a second broad area of literature exploring women and science, with a focus on highlighting alignments between interdisciplinary ways of thinking/organizing knowledge and women's epistemologies/ways of knowing. A third section of this chapter will highlight an abundance of literature that underscores how women's participation and advancement in STEM education and careers has been consistently disproportionate to men. Literature that points to interdisciplinary research and workspaces as holding the potential to both welcome and increase women's participation in STEM will also be highlighted in this section. Finally, given this study's focus on the socialization experiences of women doctoral students in interdisciplinary training contexts, the broad literature on doctoral student socialization will be reviewed to highlight what research has documented about its processes, contexts, and outcomes.

Interdisciplinarity in Higher Education

In order to better understand the complex disciplinary and interdisciplinary dimensions of the landscape in which women graduate students are being educated and trained as future scientists and engineers, it is important to understand the ways in which interdisciplinarity is both conceptualized and presented in university structures and strategies. This section focuses on the evolutionary presence of interdisciplinarity in the research university with specific attention to its intersection with STEM disciplines and scientific knowledge production in the university. First, I will outline the conceptualizations and core features of interdisciplinarity, which will include a focus on the strategic and functional purposes and roles of interdisciplinarity in contemporary research universities and how these both co-exist with and produce tensions within university cultures that are largely organized by discipline. From this broad picture of interdisciplinarity in higher education, I will point to the intersection of university interdisciplinarity and the STEM disciplines with a specific focus on the norms, values, and practices that guide science and scientific knowledge production.

Conceptualizations and Typologies of Interdisciplinarity

The conceptualization of interdisciplinarity in higher education has followed an evolutionary path wrought with complexities (Berger, 1972; Klein, 1990, 1996; Lattuca, 2001; Holley, 2009b). Although discussed informally for many years, the first formal definition of interdisciplinarity emerged in the early 1970s, advanced by the Center for Educational Research and Innovation (CERI). This work attempted to define and differentiate several different terms pertaining to interdisciplinarity that are often used interchangeably in common discourse, including *multidisciplinary*, *pluridisciplinary*, *interdisciplinary*, and *transdisciplinary*. From this work, a commonly cited definition for interdisciplinarity emerged, which was articulated on behalf of CERI by Berger (1972). Interdisciplinarity is thus defined as occurring when there is "interaction among two or more different disciplines" that "may range from simple communication of ideas to the mutual integrations of organizing concepts, methodology, procedures, epistemology, terminology, data, and organization of research and education in a fairly large field" (p. 25). Further, Berger offered that "[a]n interdisciplinary group consists of persons trained in different fields of knowledge (disciplines) with different concepts, methods, and data and terms organized into a common effort on a common problem with continuous intercommunication among the participants from the different disciplines" (Berger, 1972, p. 25-26).

In more present-day work, Klein (2010) included a glossary of terms further attempting to promote common understanding and shared language in the arena of interdisciplinary thought and research. In this glossary, she defined and differentiated interdisciplinary research and studies as integrative of "content, data, methods, tools, concepts, and theories from two or more disciplines or bodies of specialized knowledge in order to advance fundamental understanding, answer complex questions, and solve problems that are too broad or complex for a single approach” (p. 181). For Klein (2010), interdisciplinarity in all of its manifestations, was differentiated from multidisciplinary approaches, which she suggested “juxtapose disciplinary perspectives, adding breadth and available knowledge, information, and methods” but “speak as separate voices” (p. 181). She further dissected interdisciplinarity to account for multiple forms. For example, according to Klein (2010), interdisciplinarity can be narrow or broad depending on the degree of compatibility between “methods, paradigms, and epistemologies” (p. 181). It can also take on endogenous or exogenous characteristics based on where research problems originated. Thus, interdisciplinary activity is endogenous when its primary concern is the pursuit of discovery, but takes on exogenous properties when research problems originate from society or from a particular external community. According to Klein (2010), interdisciplinary work can also be instrumental (prioritizing economic, marketplace, or technological needs) or critically question the existing structure of education and knowledge with a goal of social transformation.

Further, Organization for Economic Cooperation and Development (OECD) scholars (1972) and others such as Klein (1990) have focused on the concept of integration as a way to distinguish interdisciplinary activity and scholarship, which has resulted in representations of interdisciplinarity on a continuum (e.g., Berger, 1972; Klein, 1990). On one end of this continuum, interdisciplinary activity is characterized by less integration with a focus on research problems that are more disciplinary in nature, but require some borrowing from other disciplines. A bit further along the interdisciplinary integration continuum, research questions are perhaps more interdisciplinary in nature, requiring more deliberate negotiating and merging of disciplinary perspectives to address. Even further along the continuum, research problems have a far less logical disciplinary home and have been conceived closer to the boundaries of several disciplines.

Finally, researchers pointed to the opposite end of the continuum as a transdisciplinary space, where scholarly teaching and research activities, in effect, transcend the confines of a discipline both in terms of how activities are framed and who takes part. Integration may be as simple as borrowing theories and concepts from one or more disciplines and applying them within another. It may also encompass the merging of disciplines into new inter-disciplines, or may engage two or more disciplines around a common problem or question that may or may not have a disciplinary origin, as well as include actors and networks beyond the university (Etzkowitz & Leydesdorff, 1997, 2000; Gibbons, et al., 1994; Klein, 1996, 2010; Lattuca, 2001). The most integrated interdisciplinary work may assume no disciplinary superiority when addressing an interdisciplinary problem, but spark new understandings, clarify new knowledge connections, and collaboratively negotiate research methodologies, approaches, and dissemination avenues (Klein, 2010; Lattuca, 2001).

Lattuca (2001) departed somewhat from categorizing interdisciplinary activity in terms of its degree of integration, instead attempting to better understand interdisciplinary processes, contexts, and outcomes through in-depth interviews with 38 faculty members who self-reported to have some degree of interdisciplinary scholarship experience. She determined that varying dimensions of faculty interdisciplinarity were expressly tied to the type and genesis of research question being asked and offered a typology of interdisciplinarity which highlighted distinctive interdisciplinary forms, the contexts shaping them, and the processes and outcomes that flow from them. As part of this typology, Lattuca (2001) identified four types of interdisciplinary scholarship: 1) informed disciplinarity, 2) synthetic interdisciplinarity, 3) transdisciplinarity, and 4) conceptual interdisciplinarity. According to Latucca (2001), informed disciplinarity occurs when faculty borrow from other disciplines to ask and answer discipline-based research questions. The second type, synthetic interdisciplinarity, occurs when research questions originate from “the gaps among disciplines” and “not necessarily identified with a single discipline” (p. 82). The next type, transdisciplinarity, was not characterized by borrowing across disciplines, but instead “assumes the interrelatedness of all things and searches for underlying formal structures” (p. 83). In transdisciplinarity, the disciplines “become subordinate to the larger framework” and “provide settings in which to test an interdisciplinary concept, theory, or method” (p. 83) such as when a researcher uses game theory to analyze evolutionary biology and social behavior. Finally, conceptual interdisciplinarity poses research questions without a compelling disciplinary home often motivated by a deliberate critique of the disciplines (as in feminist and cultural studies) and an interest in creating new interdisciplinary spaces and exposing the narrow scope of disciplinary worldviews (Latucca, 2001).

Lattuca’s description of conceptual interdisciplinarity is also underscored in a subset of literature that employed a more critical lens in depicting interdisciplinarity (Minnich, 2005; Salter & Hearn, 1996). For example, Salter and Hearn (1996) pointed to two related but distinct conceptual dimensions of interdisciplinarity that represented “positions in contemporary debates about interdisciplinarity” (p. 8). One position did not challenge the importance of the disciplines or their boundaries, viewing interdisciplinarity as a problem-based or applied mode of research that allows for borrowing of ideas and methods across disciplines in a functional manner. Alternatively, a second position did challenge and critique the disciplines as inadequate for the production of new knowledge and advocated for an interdisciplinarity that results in greater integration between and among the collaborating disciplines in terms of methodology and synthesis of knowledge by breaking down disciplinary silos and producing more holistic, less myopic knowledge. Minnich (2005), too, argued for a poststructural, feminist, or critical interdisciplinarity not necessarily meant to integrate disciplines to any degree but, instead, to move beyond the constraints of disciplinary structure and knowledge to a new way of organizing, constructing, and generating knowledge.

Despite the variety of lenses researchers have employed to explain and categorize interdisciplinarity, strong similarities can be observed in the descriptions and conclusions of what constitutes interdisciplinarity. For example, many of these researchers conceived of an alternate, almost aspirational form of interdisciplinarity, classified as transdisciplinarity, which for Lattuca (2001) occurs when “theories, concepts, methods are not borrowed from one discipline and applied to another, but rather transcend disciplines and are therefore applicable in many fields” (p. 83). An example of this might be an exploration of human behavior via an open systems approach or some other grand framework, as opposed to employing a narrower, disciplinary lens.

Similarly, Berger (1972) depicted *transdisciplinary* teaching and research as something that transcended the disciplines and reorganized knowledge into a system of axioms, for example, by employing a grand theory to examine problems with no apparent disciplinary homes. Separately, Klein (2010) defined transdisciplinary approaches as "comprehensive frameworks that transcend the scope of disciplinary worldviews through an overarching synthesis, such as systems theory, feminist theory, and sustainability" (p. 182). Further, Häberli, Bill, Grossenbacher-Mansuy, Klein, Scholz, and Welti (2001) offered a view of transdisciplinarity that encompassed "a new form of learning and problem solving involving cooperation among different parts of society" and starting "from tangible real-world problems" for which "solutions are devised in collaboration with multiple stakeholders" (p. 7).

Additional parallels in how interdisciplinarity is defined and conceptualized can be extrapolated from these works and extended through contemporary debates about the expanding boundaries, goals, and societal actors in scientific knowledge production. First, although interdisciplinary work can span multiple modes of research including pure and applied forms, it is often discursively linked to a more socially considerate and responsible way of knowledge creation and dissemination. For example, Gibbons et al. (1994) and Gibbons and Nowotny (2001) have referred to bridging disciplines to address complex impending problems as "socially robust" knowledge creation that is not confined to a closed circle of scientific experts and academic departments, or as Haberli et al. (2001) suggested, joint problem solving that has the capacity to move “not just from a problem to a solution but also backward from potential users of results to definition of a problem and design of a research project” (p. 11). Finally, at its most radical, interdisciplinarity can be viewed as a moral imperative, or a way of knowing motivated by social justice, equity, and democratic ideals, concerned with critically analyzing and deconstructing how knowledge is structured and created with the assumption that disciplines are social constructions that result in partial knowledge and perpetuate a system of power and oppression (Haberli et al., 2001; Harding, 1991; Minnich, 2005; Salter & Hearn, 1996).

The ill-defined and complex nature of interdisciplinarity is important to this study in that it demonstrates the reality in higher education—that multiple and varied forms of interdisciplinarity exist in the academy that extend across curricular, co-curricular, and research activities and present diverse organizational contexts through which interdisciplinarity is enacted. The next section illuminates the forces that have been facilitating and legitimizing interdisciplinary research collaborations as part of scientific knowledge production approaches in universities.

Interdisciplinary Strategies and Structures in Research Universities

Despite a lack of standardization with respect to defining and conceptualizing interdisciplinarity, it has become increasingly common for research universities to view facilitating interdisciplinarity as a strategic priority, especially in an age of increased university privatization (Feller, 2002; Holley, 2009c; Klein, 2010; National Academy of

Sciences, 2005; Sá, 2007, 2008a, 2008b). Many universities are leveraging interdisciplinary strategies and structures as a means of differentiating themselves in a competitive, increasingly privatized university marketplace and as a way to capture new sources of revenue from external funding agencies in an era where the NSF, National Institutes of Health (NIH), and other government funding agencies have altered their funding patterns in favor of interdisciplinary proposals (Eckel & Morphew, 2009; Geiger, 1990; Hearn, 2006; Slaughter & Rhoades, 2004). While this "resource dependence" view (Bess & Dee, 2008, p. 148) represents only one lens through which to explain increased university interdisciplinarity, it has, in part, resulted in new institutional structures and planning efforts to facilitate, legitimize, evaluate, and reward interdisciplinary research and teaching (Feller, 2002, 2007; Frost et al., 2003, 2004; Holley, 2009c; Klein, 2010; National Academies of Science, 2005; Sa, 2008a).

Organized research units, centers, or institutes are the most prevalent and visible structures established by universities to house and support interdisciplinary work (Geiger, 1990; Sá, 2008a). These types of centers and institutes often serve as a centralized location for interdisciplinary and other research endeavors that do not fit into the traditional departmental organization of U.S. colleges and universities, and such physical spaces are acknowledged by researchers as a key stepping stone towards creating an interdisciplinary institutional culture (Klein, 1996; Harris & Holley, 2008; Sá, 2007).

However, Sá (2008a) identified three additional interdisciplinary strategies through his examination of institutional documents from 100 universities and site visits to five of these institutions. First, he found that some universities instituted incentive grant programs that worked much like the proposal submission and evaluation processes of state and federal agencies, with seed money funneled to winning research proposals that incorporated interdepartmental and intercollegiate collaborations. Those successful collaborations were poised to receive additional funding and perhaps evolve into permanent research structures (Sá, 2008a). Second, some institutions created steering units that organized, identified, and oversaw a multitude of interdisciplinary promotion activities. For example, these steering structures might assess physical plant needs, facilitate faculty recruitment and appointments, or build research capacity by securing external grants and fundraising gifts devoted to promoting interdisciplinarity. Third, Sá (2008a) found evidence of novel models of faculty recruitment and evaluation. In some cases, institutions underwent changes to policy and practice to accommodate the interdisciplinary endeavors of faculty researchers. For example, evaluation and recognition policies around tenure and promotion were widened to include and value interdisciplinary activity by incorporating interdisciplinary external evaluators into tenure review processes. In addition, several institutions engaged in hiring small groups of faculty in interdisciplinary "clusters," allowing them to generate research agendas together while providing them with respective departmental homes that also co-funded them along with separate institutional funds.

Although a growing number of institutions have attempted to facilitate interdisciplinary programs and encourage interdisciplinary culture, some complex challenges have been documented. First, while interdisciplinarity can be seen as a strategic approach to increased university funding, the environment of financial strain experienced by many colleges and universities may also make it difficult to advance and institutionalize interdisciplinary structures and practices (Feller, 2002; Klein, 1996). For example, the flow of resources in many universities is typically a centralized process that ultimately moves along structural (disciplinary) lines, with budget allocations funneled to schools and departments that serve as core academic operating units (Feller, 2002; Kezar, 2005; Klein, 2010; National Academy of Sciences, 2005). In this model, departments may be reluctant to devote their discretionary funds to supporting interdisciplinary research and teaching if they do not see a clear benefit.

Relatedly, increased privatization also increases expectations for institutional units and departments to become more entrepreneurial and take ownership of generating operating resources. In this common situation, departments may "suboptimize," or retrench and reinforce their existing structures and processes, thereby disengaging from university goals and directives that may encourage interdisciplinary activity (Bess & Dee, 2008, p. 496). Further, the operationalization of organized research units as a primary strategy to support interdisciplinarity has not guaranteed the success or longevity of interdisciplinary initiatives at some colleges and universities (Feller, 2002; Holley, 2009c; Rhoten, 2004). Feller (2002) and Holley (2009c) found that without multiple forms of support, these interdisciplinary initiatives were largely stalled, abandoned, or based in institutional rhetoric without evidence of impact on practice.

Intersection of Interdisciplinarity and STEM

The STEM disciplines offer a compelling landscape for increased understanding of the permeation of interdisciplinary activity and structures in contemporary research universities. As pointed out by Clark (1987), Kuhn (1962), and Becher (1990, 1994), the sciences have historically been at the forefront of innovation that has simultaneously contributed to the explosion of knowledge, the growth of new disciplines, and the migration to deep areas of specialization that push at, blur, and intersect disciplinary boundaries in the name of discovery. For example, the long-standing scientific disciplines of biology and physics evolved highly specialized subfields, including molecular biology, neurobiology, nuclear physics, and particle physics. Importantly, however, bridging and blurring of disciplines was also evident in these subfields. For example, biochemistry draws from both of the traditional disciplines of biology and chemistry. In addition, discipline-bridging subfields like biochemistry and neuroscience have, in many cases, evolved into their own distinct disciplines (Becher, 1994; Becher & Trowler, 2001; Holley, 2006, 2009a; Kuhn, 1962, 1996).

In addition, the STEM disciplines are also considered uniquely collaborative (Becher, 1994; Etzkowitz & Leydesdorff, 1997, 2000; Stokols, Misra, Moser, Hall, & Taylor, 2008), which is also a defining characteristic of interdisciplinarity. For example, the central location of research labs and the collaborative research teams that occupy them are distinct structural features of scientific knowledge production as opposed to more solitary knowledge creation pursuits in the humanities and social science disciplines. Further, as prestigious drivers of university research and knowledge production, the STEM disciplines are highly intertwined with university-wide strategy formation, which has increasingly prioritized the creation of interdisciplinary strategies and structures, especially as funding agencies such as the NSF, NIH, Department of Energy (DOE), and National Aeronautics and Space Administration (NASA), and others have shifted their funding priorities and patterns towards interdisciplinary research pursuits (National Academy of Sciences, 2005).

Novel modes of knowledge production that are highly interdisciplinary in nature and inspired by use and application are increasingly evident in university research. Research modes embodying these characteristics are often more visible in the intersections between and within the sciences and via interdisciplinary fields, such as neuroscience, nanotechnology, or biomedical engineering, especially through formally labeled interdisciplinary centers and organized research units (Geiger, 1990, Gibbons et al., 1994, 2000; Klein, 1996). Through these qualities, the STEM disciplines are perceived as strong incubators for interdisciplinary strategies and structures.

Importantly, the pursuit of specialized funding to support interdisciplinary research often involves the interdisciplinary training of graduate students. Probably the most recognized and well-established interdisciplinary funding initiatives in support of graduate student training, the NSF's Integrative Graduate Education and Research Traineeship (IGERT) program, reported making "278 awards and has provided funding for approximately 6,500 graduate students" since 1998 ("About IGERT," n.d.). IGERT's stated mission is to prepare science and engineering PhD students "to solve large and complex research problems of significant scientific and societal importance at the national and international level" through "[C]ollaborative research that transcends traditional disciplinary boundaries and requires teamwork" ("About IGERT," n.d.). Simultaneously, a concert of voices concerned about the future and adequacy of doctoral education (Golde & Walker, 2006; National Academy of Sciences, 2005; National Science Foundation, 2015, Nerad, 2008, 2014; Nerad & Trznya, 2008; Walker, Golde, Jones, & Hutchings, 2008) has articulated that the doctorate needs to be redesigned to create more interdisciplinary scholars who are "capable of engaging with multiple communities of practice…possess facilities with a range of disciplines, and focus on the integration of knowledge to advance a problem or topic" (Holley, 2010, p. 98). Further, qualitative studies and national surveys of current and former doctoral students have found that many desired exposure to education and training experiences that would provide greater interdisciplinary breadth of knowledge and more interdisciplinary research training (Golde & Dore, 2001; Holley, 2010; Nerad, 2008, 2014; Rhoten & Parker, 2004).

Paradoxically, however, researchers have implicated the STEM disciplines as being highly siloed and specialized organizational structures, possessing deeply ingrained and rigid norms, values, and practices that can confound interdisciplinary strategies, structures, and approaches. For example, the underlying cultural norms of science first identified by Merton (1942/1973, 1957)—universalism, disinterestedness, organized skepticism, and communism—are still widely cited as the basis of the scientific method and linked to what constitutes the practice of "good science." Becher (1994) further dissected the STEM disciplines into “hard-pure” and “hard-applied” categories. According to Becher (1994), hard-pure disciplinary fields share universal and largely quantitative methods and approaches with the goal of discovering and explaining. Culturally, hard-pure fields are underlined by competitiveness, possess an organized structure and process, and boast high rates of publication. In contrast, hard-applied fields such as mechanical engineering are conceived as highly pragmatic and concerned with how to use findings in the physical environment, often resulting in new products and techniques.

In terms of culture, Becher (1994) found it more typical for hard-applied disciplines to engender entrepreneurialism, thereby valuing professional roles and patenting of products and technologies over academic publications. Further, in his study of 20 university physicists in the U.S. and Great Britain, Becher (1990) found deeply ingrained ideas about the elevated status of the hard-pure disciplines compared to hard-applied and soft disciplines. He found not only that the hard-pure sciences were considered more prestigious than the hard-applied sciences, but also that among the hard-pure sciences, physics occupied the hierarchical apex over such counterparts as chemistry, biology, and mathematics.

The cultural differences and prestige hierarchies among distinct disciplines and departments highlighted by Biglan (1973), Becher (1994), and Becher and Trowler (2001) and the guiding norms of science as illuminated by Merton (1942/1973, 1957) have been positioned as perceptual and structural impediments to the organization and pursuit of interdisciplinary research (Klein, 1996, 2010). These same cultural and organizational features of science have been implicated by theorists and researchers as structural impediments to the equitable participation and status of women in the sciences and engineering (DeWelde & Laursen, 2011; Fox, 1999, 2001; Haraway, 1988; Harding, 1991; Hill, Corbett, & St. Rose, 2010; Keller, 1983; Kemelgor & Etzkowitz, 2001; Long & Fox, 1995; Rose, 1983, 1986; Rosser, 2004; Rosser & Lane, 2002; Valian, 1999). As Fox (2001) explained, social and organizational contexts of science "encompass matters of inclusion and exclusion, nuances of training and advising, and evaluative practices as they operate for women and men" (p. 658). The next section will dissect the theoretical and empirical landscape exploring women and the culture of science, including alternate conceptualizations of the values, norms, and practices of science through the lenses of gender and interdisciplinarity.

Women, Science, and Interdisciplinarity

Research that debates and illuminates incongruencies between women and the culture and structure of science offers insights into how alternative modes of interdisciplinary knowledge production may represent the promise of a more heterogeneous and diverse cultural alternative for women and other participants from under-represented backgrounds in STEM. This section focuses broadly on literature that has explored women's thinking about knowledge and science, beginning with a discussion of feminist critiques of the social structure of science, including conceptualizations of "good" and "bad" science, and notions of objectivity and subjectivity as they apply to knowledge production. Parallels between feminist critiques of science and those scholars advocating for and conceptualizing emergent modes of interdisciplinary and heterogeneous knowledge production will concurrently be drawn. Finally, critical and feminist literature exploring epistemologies of women and other non-dominant populations will be explored as another perspective on the complex entanglement between women and modes of scientific knowledge production that draw from multiple disciplines and real-world problems.

Feminist Thinking About Knowledge and Science

A rigorous yet generally overlooked school of feminist thinking about knowledge and science evolving in the literature over the past several decades has interrogated the social structure of science, including the guiding principles that govern science or what constitutes "good science." For example, in her discussions of gender, science, and knowledge, Harding (1991) presented five specific issues that provide a feminist framework around science and scientific knowledge production. She argued that 1) science is inherently political, 2) science has progressive and regressive tendencies, 3) the observer and the observed exist in the same scientific plane and thus are "socially situated," 4) science must decenter privileged White male needs, values, and visions, as well as privileged White feminist critiques to make room for other claims to and critiques of knowledge, and 5) the social sciences provide a framework to help us understand "sciences in society" and "society in sciences" (p. 11-12).

Operating from this framework, Harding (1991) specifically identified the two most common feminist critiques of science. The first, "bad science," suggests that science has failed to rigorously follow its codified methodological and theoretical principles and practices by historically practicing "androcentric" science, ignoring and excluding women by conducting science by men, about men, and for men (p. 54). This critique assumes that the “scientific method was supposed to be powerful enough to eliminate any social biases that may find their way from the social situation of the scientist into hypotheses, concepts, research designs, evidence-gathering, or the interpretation of the results of research” (Harding, 1991, p. 58). Thus, knowledge claims resulting from homogeneously male-directed and male-focused scientific inquiries qualified as “bad” or distorted because they failed to adhere to the scientific ethos— particularly the norm of universalism, which denotes that all scientists can contribute to science irrespective of gender, race, nationality, or culture (Long & Fox, 1995; Merton, 1942; Mitroff, 1974). A second and related critique objects to “science as usual,” which takes aim at the widespread belief that “good science” is synonymous with value-neutrality, including disinterestedness in the object of inquiry and detachment from social, political, and economic forces (Harding, 1991, p. 54). In fact, critics of “science as usual” have asserted that the concept of “good science” is a myth, and argued that an individual is simply not capable of transcending these forces and one’s own social location in a hierarchical society where power and resources are distributed inequitably across class, race, and gender. Thus, a person doing science “can achieve only a partial view of reality from the perspective of his or her own position in the social hierarchy”; therefore, a diverse array of partial views are critical to move beyond the distorted knowledge claims from only the privileged dominant power holders (Harding, 1991, p. 59).

For feminists, misuses and abuses of science arise, in part, when women and other non-dominant members of society are “disembodied” from the practice and interpretation of science. This is a salient issue rooted in the idea that the nature of science itself has historically been organized and directed by a dominant group of largely White and Westernized men (Butler, 1990; Haraway, 1988; Harding, 1991, 1998, 2008; Harstock, 1998; Keller, 1990; Longino, 1990, 1993; Rose, 1983, 1986, 1994; Traweek, 1988). The resulting enterprise essentially has controlled science, who and what science considers, and for whom science is done (Harding, 1991). Further, for Harding (1991, 1998, 2004, 2009b) and others (Collins, 1986, 2009; Haraway, 1988, 1989; Hartsock, 1998; Longino, 1990; Keller, 1990; Rose, 1983, 1994), the notion of rational objectivity, including the idea that science frees itself from sociopolitical context by exercising an immutable set of ethical norms, is a fallacy that obscures recognition of "those powerful forces in society that want to appropriate science and knowledge for their own purposes" (Harding, 1991, p. 148). Or, in other words, rational objectivity does not sufficiently or critically attend to what kind of science is produced by the exclusion of women from science (Rose, 1983).

Harding (1991) and others (e.g. Fausto-Sterling, 1985; Keller, 1990; Gilligan, 1982/1993; Haraway, 1988, 1989, Longino, 1990; Rose, 1994) have pointed to a number of past examples of egregious misuses and abuses of science, specifically race and gender bias in scientific research, that have endangered and harmed non-dominant populations. Two such examples can be found in scientific claims of biological determinism and the eugenics movement, which asserted that individuals were products of their genetic makeup alone and, in turn, fostered the use of sterilization programs and other attempts to cull out those deemed to be genetically unfit, disabled, or inferior (Butler, 1990; Haraway, 1989; Rose, 1994). Other examples of biased scientific knowledge production and promotion have been underlined in the testing of new technologies and the conduct of medical research. For example, the scientific testing that launched the implementation of airbags in automobiles used test dummies reflecting an average-sized man. The failure to design and test airbags for those of smaller stature such as women and children resulted in preventable deaths.

Similarly, the historical exclusion of women and people of different races and cultures in medical research and the corresponding assumption that White male symptoms of disease would look the same in women and in people of other races and ethnicities has been widely cited and attempts to recognize and remedy these partial knowledge bases continue. For example, in September 2014, the NIH announced an initiative to dedicate 10.1 million in funding to research that addresses gender bias in medical studies and clinical trials (Baskin, 2014; Clayton & Collins, 2014; Rabin, 2014), recognizing years of research that has systematically over-relied on testing hypothesizes on male lab animals and male biological systems, tissues, and cells. According to Dr. Janine Austin Clayton, associate director for women's health research at NIH, the initiative is encouraging the fundamental goal "to transform how people think about science and therefore transform how science is done" because much less is known "about every aspect of female biology compared to male biology" (Rabin, 2014).

In essence, when the social power structure of science is homogenous, so is the production of new knowledge (Collins, 2009; Haraway, 1988; Harding, 1991; Minnich, 2005), leading to partial knowledge that ultimately promotes a master narrative that perpetuates dominant social structures and groups and further disenfranchises and disempowers the “other.” In other words, as articulated by Harding (1991), “whoever gets to define what counts as a scientific problem also gets a powerful role in shaping the picture of the world that results from scientific research” (p. 40).

Alternative and Emerging Modes of Knowledge Production

The feminist critiques of “bad science” and “science as usual” are offered as part of a call for better science, an argument and purpose that prominently aligns with those who advocate for more interdisciplinary and heterogeneous modes of scientific knowledge production. Specific similarities between feminist perspectives on scientific knowledge production and interdisciplinary approaches to scientific knowledge production have emerged in the literature in two distinct but related ways. First, both feminist and interdisciplinary approaches encourage wider diversity of participation and perspectives in the construction and production of scientific knowledge. Feminists are concerned with the inclusion of women’s perspectives and research that embodies the people and problems under investigation on the same plane as the researcher, rather than disembodying them as distant and passive objects of investigation. Interdisciplinarians advocate for collaboration among wider and more diverse networks and partners within and external to the university. Second, both reject the idea that science adheres to a universalist approach that assures neutrality from and disinterest in individual, social, and political values and discourses, and according to feminist theorists, individual social location. As a result, many scholars of scientific knowledge production have advocated for approaches that replace attempts at objectivity with rigorous reflexivity and transparent acknowledgement of sociopolitical forces and individual biases. Thus, both feminist and interdisciplinary critiques of the social structure and practices of science have elevated the idea that science and society are fused and increasingly proximal, making it difficult to separate these two “open, interactive systems” (Gibbons, 2000, p. 161). For Gibbons (2000), this “context-sensitive” science is a distinguishing feature of emerging modes of knowledge production that are increasingly interdisciplinary and heterogeneous and have the capacity to produce more “socially robust knowledge…likely to be reliable not only inside but also outside the laboratory” (p. 161).

As part of this argument for why context-sensitivity is important to the production of scientific knowledge, scholars have pointed back in history to examples of how shifts in sociopolitical contexts have effectively mirrored shifts in the goals and practices of science (Kuhn, 1962/1996; Latour, 1987; Nowotny, Scott, & Gibbons, 2001). For example, the fused nature of science and society has been illuminated by the way in which the purpose and structure of federally funded science shifted as World War II came to a close from a military research and development engine to an “endless frontier” of basic science that was the key to technological progress (Bush, 1945). This shift was quickly followed by the formation of the NSF and began to institutionalize a new discourse around scientific research and development accompanied by new patterns and funnels of federal funding for science.

Gibbons (2000) has argued that context-sensitivity in scientific knowledge production and application is increasingly important because the expanded boundaries of science and the connectedness between science and society are more pronounced in the current era where university boundaries have become more open and permeable to forces in society, such as the market, politics, and culture. A number of researchers have begun to identify and conceptualize what emerging modes of scientific knowledge production have been arising from the continually blurring boundaries of science. For example, Gibbons et al. (1994), Gibbons (2000), and Nowotny et al. (2001) described an increasingly heterogeneous and interdisciplinary mode of scientific research, dubbed “mode 2” research, which is characterized by its likeliness to draw from several disciplines and include “a wider, more temporary and heterogeneous set of practitioners” who are “collaborating on a problem defined in a specific and localized context” (Gibbons, 2000, p. 160). These researchers specified that mode 2 research differentiates itself from “mode 1” research, or the more narrow, specialized, and discipline-based knowledge production typified in universities.

Gibbons et al. (1994), in particular, aligned their depiction of mode 2 research with interdisciplinarity because it supports new lines and directions of intellectual dialogue that do not necessarily fit neatly in disciplinary structures or within traditional university boundaries. Instead, they depicted mode 2 as creating a forum that bridges disciplines and moves beyond university walls to other research loci such as government, industry, institutes and centers, and think tanks. They offered this interdisciplinary and boundary-crossing distinction of mode 2 with the acknowledgement that mode 1 is highly valued, greatly historically successful, and still very much required, but that alternative modes that conjoin science, technology, and society in a purposeful way are also required. In this way, mode 2 knowledge production is distinct in its relationship with society and consideration for people, their perspectives, and their problems.

Other theorists and researchers have offered similar schemes showing the expanded and blurred boundaries of science (Ezktowitz & Leydesdorff, 1997, 2000; Gibbons et al., 1994; Gibbons, 2000; Mendoza, 2009; Nowotny et al., 2001; Santos, 2006; Stokes, 1997). Santos (2006), for example, conceptualized an emerging form of “pluriversity” knowledge that is interdisciplinary in nature and linked to societal concerns and technological applications. He argued that pluriversity knowledge has begun to co-exist with long-standing modes of “university” knowledge that are discipline-centric and decontextualized from societal considerations and applications in their focus on pure discovery. Comparable depictions have been offered by Stokes (1997) and Mendoza (2009), who each described scientific knowledge production located in Pasteur’s Quadrant that is “inspired by use,” functioning as a research mode that combines basic research to extend understanding while also considering applications for the public. In other words, mode 2, pluriversity, and use-inspired knowledge involves a much more diverse and expanded network of participants and perspectives which, importantly, increases accountability beyond the walls of the academy and encourages less hierarchical and more egalitarian participation in scientific knowledge production.

It is important to note that mode 2, pluriversity, and use-inspired knowledge is positioned in relation to the capital market and described as being carried out in the “context of application” for and with a knowledge society that demands innovation to ensure global technological and economic competitiveness (Gibbons, 2000, p. 159; Santos, 2006, p. 76). Studies of academic capitalism and “triple-helix” forms of university-industry-government research collaborations, for example, provide plentiful examples of ways in which market forces have permeated and reshaped universities, academic science (Ezkowitz & Leysdendorf, 1997, 2000; Geiger, 2004; Slaughter, & Leslie, 1997; Slaughter & Rhoades, 2004), and doctoral socialization environments (Mars, Bresonis, & Szelényi, 2014; Mendoza, 2007; Szelényi, 2007, 2013; Szelényi & Bresonis, 2014). However, Santos (2006) suggested that "non-mercantile" or "emancipatory" forms of mode 2 or pluriversity knowledge rooted in social responsibility, or guided by a context of social responsibility, also exist.

Similarly, Mendoza (2009) argued that use-inspired science in Pasteur's Quadrant, depending on context, may fall anywhere on a continuum between public good interests and commercial interests. While Slaughter and Rhoades (2004) argued that the ascendance of academic capitalism may have dire implications for scientific inquiry by obscuring the importance of pure discovery and thereby endangering academic freedom and the university's role as a public good, Gibbons (2000), Santos (2006), Mendoza (2009), and Nowotny et al. (2001) acknowledged the need for multiple modes of inquiry, including mode 2, pluriversity, use-inspired, and transdisciplinary knowledge, respectively, that reconnect science with the needs of a global society and seek to solve complex and systemic problems that reach beyond the scope of a single discipline. Although differing standpoints are evident in the arguments of these authors, all point to shifting and emerging modes of scientific research that are highly context-sensitive, more application-driven, and intersect a variety of disciplines in addition to scientific and non-science actors within and outside of academia.

Thus, the relationship and exchange between society and science are central features in feminist and interdisciplinary theorists' views of science.

In part, these increasingly crowded, heterogeneous, and interdisciplinary modes of knowledge production butt against the conventional participants and practices of university science that have focused on the incremental expansion of disciplinary knowledge through pure discovery. Such a shift has been elevated by feminist scholars of science as a necessity to expand the boundaries of knowledge production through diverse participation and to cast a more watchful eye on the inequitable power structures of the scientific enterprise (Benshop & Brouns, 2003; Collins, 2009; Haraway, 1988, 1989; Harding, 1991, 2004).

In their framing of how gender is structured in academic science in Dutch universities, Benschop and Brouns (2003) described university women's experiences in the social structure of academic science through contrasting metaphorical depictions of academic science—the "Olympus" and the "Agora." In the Olympus model, science is depicted as hierarchical and distanced from practical society, invoking an image of the lone male scientist revered for his brilliance atop Mt. Olympus. In this image, "science is primarily targeted at other scientists" because "only science delivers true and objective knowledge" (Benschop & Bruins, 2003, p. 207-208). In contrast, they observed the emergence of an "Agora" mode of science more consistent with those explicated by Gibbons et al. (1994), Gibbons (2000), Nowotny et al. (2001), and Santos (2006), which "implies a strong network and open interaction between universities, research and education organizations and other social institutions of the knowledge society" (Benschop & Brouns, 2003, p. 208). Further, they suggested that Agora-inspired modes of knowledge production were tied to more equitable cultural environments for women due to “less hierarchical structure” and expanded “public accountability” that “creates opportunities for women” by broadening the ownership of scientific problems from an elite “collective of men to a dynamic social phenomenon with diverse participants” (p. 209). This framing presents a powerful example of the common ground being contested by feminist critics of the social structure of science and scholars advocating for increased interdisciplinarity and expanded networks of scientific actors to take ownership of research that addresses the complex real-world problems of a mode 2 society.

Women’s Epistemologies of Science and Knowledge

Studies exploring the knowledge construction practices of women and other non-dominant populations are also useful to consider with respect to epistemological preferences and engagement with science and knowledge production. For instance, as part of their critique of the structures, values, and practices of science, Haraway (1988), Harding (1991, 2004, 2008), and Longino (1990), among others, epistemologically reconceptualized the notion of scientific objectivity from its traditional Mertonian understanding as value-free and disinterested to the idea that women and other marginalized populations actually possess and utilize a form of “strong objectivity” (Harding, 1991, p. 149). These researchers and theorists have depicted strong objectivity as the instrumental core of a unique women’s standpoint born out of being “outsiders within” (Collins, 2009, p. 15), or socially situated apart from dominant power and status structures (Haraway, 1988). This standpoint thus allows women to distinguish patterns of behavior that those immersed in the dominant group culture are unable to recognize.

When applied to the structure and practice of science and the production of scientific knowledge, those possessing strong objectivity critically examine how and to what extent science is situated within political values, desires, and interests as a means of producing more reliable knowledge as opposed to subsuming the ideal that only the disinterested scientist produces reliable and rational knowledge (Harding, 1991). A study by Ferreira (2003a), which focused on women graduate students in the chemistry and biology departments at a single research university, found that a number of women expressed concern with the rigid ideas about objectivity that were conveyed as part of their research training. In addition, some expressed how being expected to detach from their research stood in opposition to the reasons that compelled them to enter their chosen field in the first place. This finding is echoed in first-hand and biographical accounts of established women scientists (Hacker, Smith, & Turner, 1990; Keller, 1983; Traweek, 1988). Such insights are connected to a broader discussion of feminist and critical epistemologies that have illuminated the "ways of knowing" of women and individuals from other marginalized identities (Belenky, Clinchy, Goldberger, & Tarule, 1997; Collins, 2009; Gilligan, 1982/1993; hooks, 1994).

Feminist literature on the learning and development of women also points to tensions between the knowledge claims decided upon and derived from narrow methodologies within traditional disciplinary structures of science and the knowledge construction and production approaches of many individuals who come from historically marginalized populations

(Belenky et al., 1997; Collins, 2009; Gilligan, 1982/1993; hooks, 1994). In this way, women and members of other marginalized groups attach value and credibility to knowledge that arises from "lived experiences" as opposed to knowledge derived from "distant statistics" (Collins, 2009, p. 276). According to Gilligan (1982/1993) and findings from in-depth qualitative interviews with 135 women conducted by Belenky et al. (1997), many women can be described as "connected knowers" who are more apt to advance knowledge claims by using "relational" methods of communication to understand others in context and through shared experiences that recognize and embrace subjectivity between the knower and the known (p. 101). In contrast, "separate knowers" operate by separating information and/or ideas from people and/or societal contexts in order to achieve objective impersonal reason, which has been historically valued as a legitimate avenue to what constitutes good science (Belenky et al., 1997, p. 101). Similarly, Collins (2009) and hooks (1994) suggested that these connected "ways of knowing" (Belenky et al., 1997, p. iv) were simultaneously unique and salient for Black women through an "ethic of caring" that elevates "expressiveness, emotions, and empathy" in the knowledge construction and validation process (Collins, 2009, p. 282).

Ibarra (2001) further conceptualized differences between dominant and marginalized groups with respect to sensibilities, perceptions of time and space, interactions, learning, and knowledge as "low context" versus "high context" approaches (p. 50), originally conceived by Hall (1966, 1977). Underlying his theory of multicontextuality, Ibarra (2001) ascribed low-context approaches to be most salient and ingrained in dominant social groups, characteristics of which include favoring traditional scientific fields that tend to conduct inquiry and use methodology that separates scientific research from social and historical contexts and values prediction and linearity. Conversely, marginalized individuals and groups, which tend toward high-context approaches, do not value information without a critical examination and acknowledgement of historical, social, political, and economic contexts and may favor disciplines that are directly involved with contextual thinking and research about living systems and people. High-context individuals tend to value real-world application of knowledge, interconnected and systems-level thinking, and more open and flexible methodologies.

Interdisciplinary epistemologies have also been advanced by critical and feminist scholars. For example, Salter and Hearn (1996) and Minnich (2005) each suggested that existing knowledge and knowledge creation within the confines of a discipline are inadequate and myopic. Minnich (2005) emphasized two basic errors that result from dominant and durable disciplinary structures and the rarely questioned knowledge and values they encapsulate, including "mystified concepts" and "partial knowledge" (p. 108-109). Comprising mystified concepts are deeply ingrained ideas, notions, and assumptions that are rarely questioned, but from which we may generalize understandings. She contended that without critically examining our ingrained knowledge, we run the risk of too narrowly posing and solving problems, resulting in partial knowledge that is exclusive, privileges dominant voices, and is thus prone to the promotion of misinterpretations.

These findings further complicate the landscape and point to a need to expand our investigations of gender and science to include the interaction of interdisciplinary contexts and varied organizational forms of interdisciplinary collaborations in academe and industry. Ultimately, a multitude of complexities and questions emerge with respect to the nature and degree of the entanglement of gender, science, and interdisciplinarity and the implications of this entanglement for the educational and career decisions of women in the sciences. The next section will continue this line of investigation through a review of recent research that has explored gender differences in the participation and advancement of women in STEM education and careers, including how emerging organizational contexts in the sciences are impacting the success and advancement of women scientists and engineers.

The Participation and Advancement of Women in STEM Education and Careers

Women's preferences for collaborative and open modes of scientific participation over the individualistic, aggressive, and competition-driven approaches that are often culturally supported and valued in science have been considered in more empirical depth across two related threads of literature: 1) differential experiences and outcomes for women across academic and non-academic scientific careers and 2) women's participation and engagement in emerging organizational contexts of science in industry and academe. I will open this discussion with a brief review of "pipeline" and "glass ceiling" metaphors that have been invoked to characterize the problem of differential participation and outcomes for women in STEM and the current statistical and empirical picture for women in STEM education and careers (Blickenstaff, 2005; DeWelde & Laursen, 2011; Rosser, 2004). This will lead to a description of the career trajectories of women scientists and engineers inside and outside of academe. From there, I will shift to a related discussion of the effects of emerging organizational contexts on gender equity in scientific careers in academe and industry, after which I will raise questions and make connections about the participation of women in interdisciplinary organizational structures and research approaches in STEM.

Differential Outcomes of Women in STEM Education and Careers

With respect to the first thread, a number of studies have attempted to empirically identify the key factors that contribute to differential educational and career outcomes among women in STEM. Not surprisingly, many of these studies have focused on the educational experiences and career patterns of women who are pursuing or have earned PhDs in science and engineering fields. These important studies made efforts to better understand such persistent phenomena as the "chilly climate" for women in academe (Hall & Sandler, 1982, p. 2), the "leaky pipeline," or the disproportionate number of men compared to women who enter and remain in STEM majors and careers, and the "glass ceiling" (Rosser, 2004), or the preponderance of women in lower-status roles in STEM academic and industry careers. Such investigations have yielded a great many insights into educational and career barriers and opportunities for women scientists and engineers and hold numerous implications for policy and practice (Fox, 2001, 2010; Fox & Stephan, 2001; Glass, Sassler, Levitte, & Michelmore, 2012; Turk-Bicakci, Berger, & Haxton, 2014; Williams & Ceci, 2012). Several of these studies have examined employment in academia and the differential experiences of women, and several have focused on non-academic employment patterns across race and gender.

In academia, women scientists are more likely than their White male counterparts to hold part-time, contingent, and non-tenure-track positions and less likely to be employed at research universities (Fox, 2001, 2010; Fox & Stephan, 2001; National Science Foundation, 2015; Turk-Bicakci, Berger, & Haxton, 2014). Outside of academia, where the majority of STEM degree holders seek employment, the picture is similarly bleak for women scientists. With the exception of Asian women, women scientists were more likely to work in non-science fields, less likely to work in research and development and private for-profit organizations, and more likely to work in non-profit agencies than White men (Turk-Bicakci, Berger, & Haxton, 2014). Further, these studies found that women scientists with careers in industry science received differential treatment and reduced access to participation in research groups, fewer collaboration and networking opportunities, and a lower level of attainment of leadership and oversight roles in their firms (Fox, 2000, 2010; Fox & Stephan, 2001; Smith-Doerr, 2004b, 2006).

Rosser and Lane (2002) presented a series of key barriers faced by women scientists and engineers. In their analysis of survey data from 389 Professional Opportunities for Women in Research and Education (POWRE) awardees between 1997-2000, they found that issues of work-family balance, low numbers of women and stereotyping, overt discrimination and harassment, and decreased access to social and professional networking opportunities emerged as salient barriers for women scientists and engineers. Similarly, DeWelde and Laursen (2011) observed the confluence of a similar set of “informal and formal” barriers faced by women pursuing science and engineering PhDs, which they dubbed “the glass obstacle course" (p. 571). Through in-depth interviews with 19 women and nine men PhD students at a single research university in the U.S. between 2003-2006, the researchers found that the informal culture of STEM graduate environments created obstacles in the form of the "old boy's club" and sexist stereotyping and harassment, which effectively positioned women as outsiders to their departments, research groups, laboratories, and classrooms. In addition, De Welde and Laursen (2011) found evidence of more formal structural obstacles in the low numbers of women role models and the "inherent conflicts between the timing of academic careers and having children" (p. 585). These studies and a number of others have confirmed the existence and persistence of such obstacles and point toward the importance of policy and practice shifts at the organizational level to produce change (e.g., Kemelgor & Etzkowitz, 2001, Settles, Cortina, Malley, & Stewart, 2006; Sonnert & Holton, 1996; Williams & Ceci, 2012).

Women in Changing and Emerging Organizational Contexts of Science

A developing thread of research related both to the equitable participation of women in STEM careers and to defining characteristics of interdisciplinary modes of scientific research has foregrounded a comparative examination of emerging and established social and organizational contexts of science in which individuals work. Through these studies, researchers have considered ways in which women are marginal to the social structure of science and have identified organizational types within science and scientific research that are more or less hospitable to women. This series of investigations has specifically examined how varying and emerging STEM fields and workplaces may perpetuate or mitigate gender inequities, by exploring the role of hierarchical versus “network” scientific organizations in industries such as biotechnology and oil and gas (Smith-Doerr, 2004ab, 2006; Williams, Muller, & Kilanski, 2012), and in various types of scientific research collaborations in academia (Corley & Gaughan, 2005; McGuire, 2002; Roth & Sonnert, 2011).

On one hand, researchers have found that hierarchical bureaucracies may benefit women because they tend to have clear job descriptions and organizational reporting and communication lines, and formalized and explicit policies and procedures (McGuire, 2002; Roth & Sonnert, 2011). For example, McGuire (2002) noted that anti-bureaucratic organizational structures resulted in an enhanced reliance on informal networks for organizational knowledge and opportunities for advancement, which she asserted could disadvantage women. Similarly, a single case study of one university-based scientific research organization by Roth and Sonnert (2011) concluded that its anti-bureaucratic organizational structures perpetuated gender inequities for women scientists in terms of access to informal networks, in which critical ad hoc decision-making, flows of information, and career advancement opportunities materialized.

Other studies, however, have asserted that gender inequities are both present and often hidden in hierarchical organizations through “shadow structures,” where employees are engaged in coalition building, reputation management, and exchange of organizational resources, thereby perpetuating and reproducing power structures, ideologies, and practices that exclude women’s full participation (Kanter, 1977; McGuire, 2002). Within the context of the life sciences, Smith-Doerr (2003, 2004) hypothesized that flatter and more flexible organizational structures often found in the emerging field of biotechnology presented women with more equitable opportunities for career growth and advancement at the managerial and supervisory levels than hierarchical life sciences organizations such as pharmaceutical firms. In particular, she found that female PhDs in biotech firms were eight times more likely to occupy leadership positions than female PhDs in more hierarchical firms. By comparing career entry and advancement opportunities across both network and hierarchical organizational forms, she identified three main reasons why flexibility in organizational form translated to gender equity: (1) increased transparency in organizations with respect to its wide collaborative networks and accountability to multiple external stakeholders, (2) greater choice in forming collegial relationships across a wide variety of external collaborators and a team-oriented and project-based work process that engenders "fairness and flexibility" in terms of how expertise is utilized and who works with whom on any given project, and (3) collective rather than individualized rewards, due to the aforementioned team/project-based ways of working and more stable research funding that results in a diminished focus on individual achievement and on political jockeying to compete for resources as is common in academe (Smith-Doerr, 2004a, p. 25).

A related quantitative study investigating gender difference in academic scientists' participation in university research centers found that center-affiliated women had relatively equal access to research-supporting funding and graduate students as their center-affiliated male counterparts, and more access to these research-related resources than department-affiliated women scientists (Corley & Gaughan, 2005). Overall, the study concluded that “centers may represent an institutional context in which some aspects of gender equity in science may be achieved” (p. 371). However, Corley and Gaughan (2005) also found that despite men and women scientists being equally likely to be affiliated with interdisciplinary research centers and having otherwise equal opportunities with respect to resources, center-affiliated women were less likely than their male counterparts to have opportunities for paid consulting and research grants or contracts from industry.

Emerging features of new economy workplaces, however, add another layer of complexity to the above findings and underscore the importance of investigating the ways in which organizations are gendered across a wide variety of contexts and industries. For example, Williams, Muller, and Kilanski (2012), through their qualitative inquiry of geoscientists in the oil and gas industry, identified how three features of oil and gas firms in the new economy—teams, networks, and individualized career maps—were gendered. They concluded that these new economy elements of the workplace, which share some characteristics with network forms of organization, actually disadvantaged women in the male-dominated oil and gas industry and resulted in differential access to mentoring, resources, formal and informal professional networks, and credit for individual successes. However, they also observed that women who worked on more gender-balanced teams reported “greater recognition and respect for their contributions” (p. 559).

These rather inconclusive insights on the effects of network versus hierarchical organizations on gender equity in STEM careers point to the importance of context (by firm, field, team diversity, etc.) in such investigations. Further, such explorations are relevant to the study of women STEM doctoral students engaged in interdisciplinary research contexts, as interdisciplinary collaborations in STEM are generally understood as offering more heterogeneous and networked organizational approaches to addressing complex global problems that go beyond the scope of a single discipline (Gibbons, 2000). In addition, team-based collaborations can vary widely with respect to gender balance and other diversity considerations. Further, these investigations of organizational context raise important questions about studies that have found or suggested that women scientists and graduate students exhibited preferences for collaboration and engaging multiple disciplines and stakeholders in the construction and production of scientific knowledge (Sonnert & Holton, 1996; Rhoten & Pfirman, 2007), or tended to look for the broader picture and engaged more often in “more comprehensive and synthetic work” (Sonnert & Holton, 1996, p. 69).

Each of these threads of research is discussed by Rhoten and Pfirman (2007) who, through an analysis of data from three previous studies, including a large-scale survey of scientific researchers in the United Kingdom and two separate mixed methods studies, found preliminary evidence to suggest that a “gendering effect” may be occurring in interdisciplinary science and scientific research in the sense that it is drawing the participation and engagement of more women than men (p. 70). They echoed Harding (1991) and other critics of the social structure of science, noting that “the modern scientific method and most modern disciplines are based on masculine epistemology and knowledge which emphasize the principles of objective rationality, reductive explanation, and dichotomous partitioning between the social and natural worlds” (p. 59).

Rhoten and Pfirman (2007) were careful to note several key limitations to their investigation. From a data analysis standpoint, they pointed out that although these studies were focused on interdisciplinarity, they were not specifically designed to examine gender preferences for interdisciplinarity. In addition, a generational cohort effect was present with respect to the two mixed methods studies since they were comprised largely of post-graduate students (40%) and most women in the sample were in post-graduate student roles, while most men were in senior faculty roles. Finally, they pointed to the increasing legitimacy and high profile of interdisciplinarity as potentially contributing to inflated rates of reported interdisciplinary participation. However, their findings are suggestive of a sociocultural shift in the structure and practice of science that may be resonating with women and likely other populations who have been largely marginalized and alienated from full participation in the scientific enterprise and for whom interdisciplinarity may offer an alternative from the cultural, structural, and "epistemological rules" of traditional science (Rhoten & Pfirman, 2007, p. 59).

Importantly, however, and particularly critical to the present study, Rhoten and Pfirman's (2007) results indicated that the increased participation of women in interdisciplinary research activity was most salient and significant for women graduate students, who the data show were gravitating in greater proportion than their male peers to interdisciplinary research training opportunities and were "more inclined than their male counterparts to engage research that not only draws on multiple disciplines but, in its problem-orientation, also seeks to serve multiple stakeholders inside and outside academe"

(p. 70). Since my study is ultimately focused on the experiences of women PhD students in interdisciplinary scientific training contexts, literature focused exclusively on doctoral student socialization in STEM offers a final layer of insight into the suggestion that women in STEM graduate degree programs may be more inclined toward interdisciplinary activity (Rhoten & Pfirman, 2007). The next section will explore this thread in greater depth.

Doctoral Student Socialization

In order to investigate the speculated entanglement between gender, science, and interdisciplinarity at the graduate level as suggested by Rhoten and Pfirman (2007), the doctoral student socialization literature will be tapped to illuminate the environment in which women PhD students in STEM are engaging and interacting with key socializing contexts, processes, and actors with a specific emphasis on their socialization and training in interdisciplinary research contexts. I will first briefly review what research and theory have elucidated about the broad socialization environment of doctoral students in contemporary research universities. I will then highlight what researchers have found regarding doctoral student socialization within and across the STEM fields as a way to underscore the roles of discipline, department, and institution in the shaping of doctoral socialization experiences and outcomes. Next, I will shift to literature that has explored the effects of academic capitalism, or the increased entrepreneurial approaches and activities of research universities and departments, on doctoral student socialization as a current example of how researchers have expanded their view of socialization to include cultural contexts. In a similar vein, I will review a developing thread of literature that has directly and indirectly focused on doctoral student socialization in the context of interdisciplinarity. Finally, the section will conclude with recent empirical and theoretical insights on the intersection of gender with doctoral training in STEM to help further a discussion on the ways in which interdisciplinarity, gender, and scientific training at the PhD level may interact.

Overview of Doctoral Student Socialization

Higher education researchers commonly agree that existing models and theories of graduate student socialization that depict general processes have been useful frameworks though which to understand common concerns and challenges faced by graduate students as a monolithic group. Such theoretical models and empirical explorations have posited that the doctoral socialization process consists broadly of distinct stages or phases of socialization and development as doctoral students move through their programs of study and related training (Bragg, 1976; Gardner, 2009a; Lovitts, 2001; Weidman, Twale, & Stein, 2001). For example, Weidman, Twale, and Stein (2001) defined graduate student socialization as “the processes through which individuals gain the knowledge, skills, and values necessary for successful entry into a professional career requiring an advanced level of specialized knowledge and skills” (p. iii). They advanced a conceptual model for the socialization of graduate and professional students rooted in the four stages of socialization originally conceived by Thornton and Nardi (1975): anticipatory, formal, informal, and personal. For Weidman et al. (2001), these stages are interactive, overlapping, and non-linear. The researchers also take into account distinct institutional cultures, including academic programs and peer climates; distinct socialization processes, including interaction, integration, and learning; and distinct components of socialization, including knowledge acquisition, investment by identifying with and committing to a professional role, and involvement through interactions that provide opportunities to learn and adopt norms, values, and practices.

In a similar vein, Gardner (2009a) put forth a conceptual framework of doctoral student development, in which she outlined three overlapping and fluid phases of identity development that integrate programmatic, personal, and interpersonal elements associated with developmental change in the individual doctoral student. In her model, each phase includes specific challenges and supports. Phase 1 (Entry) is characterized by the challenges of admission, coursework, and transition from undergraduate- and graduate-level expectations, as well as supports that can include formal and informal orientation experiences and opportunities to build initial faculty and peer relationships. Phase 2 (Integration) is the time when students are negotiating formal course work, exams, and their role as students, while building more specific relationships with peers and faculty advisors. In Phase 3 (Candidacy), students are negotiating dissertation work and job searches, and their roles are again transitioning toward becoming independent researchers with an eye toward desired professional outcomes. Faculty, peer, and other support systems in this third phase are also transitioning. According to Gardner (2009a), while socialization and development occur at each of these phases, program departure is also possible within and across each phase, which can be exacerbated when challenges are not met with requisite support for individual doctoral students.

Paradoxically, scholars also broadly agree that graduate student socialization is quite variable, influenced by institutional, departmental, disciplinary, and other permeating contexts which, in turn, intersect with the background, identity, and perceptions of each individual student to shape each student's socialization experiences and outcomes (Antony, 2002; Austin, 2002; Gardner, 2009a; Golde, 1998, 2005). Scholarly criticism directed at broad graduate student socialization frameworks has argued that these models elevate a perception that students experience socialization in a linear, rational progression and fail to consider deep structural and cultural biases that may systematically advantage some students while disadvantaging and disenfranchising others (Antony, 2002; Gardner, 2008; Sallee, 2011a, 2011b). Thus, as argued by Tierney and Rhoads (1994), socialization, while often treated as a monolithic concept, is known to occur within a variety of cultural settings that influence the processes of socialization and intersect with individual-level background and identity constructs such as race, gender, and class (Antony, 2002; Gardner, 2007, 2009a; Sallee, 2011a, 2011b).

More recent research has begun to take into account how a diverse array of contemporary contexts impacts doctoral student socialization. For example, Gardner (2007) pointed to "at least five distinct, but synergistic cultures" (p. 737) in which doctoral student socialization is situated, including: 1) the overall culture of graduate education, 2) the institutional culture, 3) the disciplinary culture, 4) the departmental culture, and 5) the individual culture embodied in the background, knowledge, and skills of each individual student. My study is informed by the view that doctoral student socialization must be considered though multiple and interacting cultural and individual contexts for a more complete understanding of processes, outcomes, and experiences (Gardner, 2009a). As part of this effort, research that documents socialization differences within and across STEM disciplines and departments is critical to my investigation.

Doctoral Student Socialization in STEM

Within the wide sphere of doctoral education, doctoral programs and training across science and engineering fields have been shown to differ rather substantially from disciplinary counterparts across the humanities, social sciences, arts, business, and education—both in terms of cultural norms, values, and practices and in terms of doctoral socialization and training processes (Anderson, Ronning, DeVries, & Martinson, 2010; Austin, 2002; Becher, 1990; Becher & Trowler, 2001; Borrego et al., 2011; Golde, 2005, 2010; Gardner, 2007, 2008b; Holley, 2006, 2009a, 2010; Merton, 1942; Mendoza, 2007; Mitroff, 1974; Szelényi, 2007, 2013). Thus, cultural variations across and between the fields and subfields that comprise STEM are important to consider in explorations of doctoral socialization and training. Several studies contrasting the socialization experiences of doctoral students across different disciplines and in high- and low-performing departments, have revealed the pivotal role of disciplinary context and departmental culture in doctoral student socialization (Gardner, 2007, 2008ab, 2009b; Golde, 2005). Further, these and other studies have expanded our understanding and picture of socialization within and between the STEM fields with respect to the primacy of research participation, the central role of the research laboratory, and the related processes of choosing a faculty advisor, a laboratory group, and a dissertation project (Gardner, 2007; Golde, 2005).

Both Golde's (2005) exploration of doctoral student attrition and Gardner's (2007, 2008b, 2009b) studies of doctoral student success found that distinct departmental and disciplinary cultures were indeed present and influential in the overall experience and socialization of doctoral students when holding the institution constant. Through interviews with 58 students who departed from doctoral study without degree completion across four departments at one university, Golde (2005) found that attrition could result from "mismatches" between the student and the discipline or the department, inconsistent and inadequate department-level advising on potential career avenues, and to a lesser degree, isolation from the department.

In a similar vein, Gardner's (2007) investigation of 20 doctoral students in the disciplines of chemistry and history at one research university revealed that, although a common set of themes and processes could be extracted from the collective interview data, distinctive disciplinary cultures influenced how students experienced aspects of socialization. She documented specific disciplinary differences around the structure and nature of faculty-advisor relationships and interactions. Chemistry doctoral students typically reported that they expected to operate with a significant degree of independence for the duration of their experience with the understanding that it was required to achieve status as an independent researcher, although they were typically achieving this independence in research groups where they could interact with and learn from a number of faculty, post-docs, and peers.

Further, chemistry doctoral students generally indicated that their enculturation into research experiences was expressly tied to career preparation. In contrast, history students' preparation for future careers was less structured, and they learned less through formalized or collaborative programs and more through informal observation of faculty actions and departmental dynamics. For history doctoral students, comfort with independence and moving towards becoming an independent researcher was a rather solitary process in which they were highly dependent on the nature of their relationship with their faculty advisors, especially the quality of interactions and guidance from them.

Further, researchers have documented socialization differences between STEM and non-STEM disciplines and departments, as well as important differences among STEM-based disciplines and departments. For example, within and across the sciences, Golde (2005) uncovered very different processes of advisor and laboratory selection for doctoral students in the biology department compared to the geology department at one U.S. research university. As part of her findings, she documented the advisor and research lab selection process in each department. In the biology department, first-year PhD students completed several project-based rotations through different laboratories for a defined period of weeks to learn about which research problems were being investigated in which laboratories with which faculty, before they formalized a choice of faculty advisor and lab. Conversely, geology doctoral students entered the program already tied to a specific faculty member and a specific subfield through which they would pursue their field/laboratory training.

Researchers have also determined that doctoral students in the natural sciences and engineering undergo additional distinct socialization processes with respect to intense involvement with technical laboratory experimentation that is often trying (Campbell, 2003; Delamont & Atkinson, 2001). Also, lab teams (especially the post-docs and faculty who supervise and train doctoral students) were found to contribute significantly to doctoral student learning, support, and norm adoption with respect to conducting research, choosing PhD projects, and publishing (Anderson & Lewis, 1994; Campbell, 2003; Delamont & Atkinson, 2001). Specifically, Delamont and Atkinson (2001) pointed to a transition period characterized by uncertainty for doctoral students who were used to undergraduate laboratory or field experiences that were structured for successful outcomes to a new landscape of laboratory experiments rife with failures that required the acquisition of new knowledge and skills. They found that doctoral students who were able to push through these new complexities drew from faculty direction and mutually supportive laboratory groups. These social interactions resulted in doctoral students' acquisition of "tacit" knowledge, including understanding that unpredictable lab experiences were more the norm than the exception, and successful outcomes would eventually result (p.101).

Similarly, in his investigation of the social processes of how faculty manage students in the natural sciences and engineering, Campbell (2003) found that significant tacit learning and training occurred through the social interactions between students and their senior peers and faculty. Thus, the culture of the lab and social interactions with the research group served as an avenue for learning what constitutes successful experimentation approaches and outcomes, and as a support mechanism for achieving independent research success for doctoral students. Both studies, however, underscored that these socialization experiences, while instrumental in training the next generation of scientists, were highly tacit in nature, or not consciously recognized by doctoral students or faculty.

Since my study will focus on the interdisciplinary experiences of women in discipline-based STEM degree programs, awareness of the socialization differences across STEM departments with respect to research training experiences is critical, as is the need to attend to both explicit and tacit processes when attempting to study socialization in any context. Further, it seems that context matters a great deal with respect to discipline, department, and the role of key socializing agents.

Permeating Contexts for Doctoral Student Socialization

In addition to the importance of contextual elements already discussed, researchers have increasingly pointed to the socializing influence of new economy contexts permeating higher education such as the increased globalization and privatization of research universities and the concurrent shifts in funding patterns, faculty roles, and disciplinary knowledge communities (Slaughter & Rhoades, 2004). These permeating contexts are reshaping the academic values, practices, and agency of doctoral students themselves, including their choices and constraints with respect to their research-related training (Mars et al., 2014; Szelényi, 2007, 2013; Szelényi & Bresonis, 2014). Two of these forces, academic capitalism and interdisciplinarity, and their influences on STEM doctoral training environments will be discussed below. Further, gender will be emphasized as another important contextual lens through which STEM-based doctoral student socialization has recently been considered.

Academic Capitalism. Moving beyond the role of disciplinary and departmental contexts in the socialization of doctoral students, several key studies have explored the impact of a well-documented permeating context—academic capitalism—on doctoral student socialization in STEM (Mars et al., 2014; Mendoza, 2007; Szelényi, 2007, 2013; Szelényi & Bresonis, 2014). For instance, Mendoza (2007) examined doctoral student socialization in the science and engineering disciplines within the broader context of academic capitalism. Specifically, her case study sought to understand the impact of industry-sponsored research experiences on the socialization of doctoral students. Through interviews with 20 graduate students at two distinct stages of the doctoral student socialization process in a materials science department with high levels of academic capitalism at a Research I university, she found that differences in doctoral student conceptualizations were based on whether students were in the early or late phase of their degrees, and on their degree of exposure to industry-sponsored research projects. For example, early-phase students viewed the surrounding culture as one heavily involved with industry with emphasized value on application of research findings and related activities such as patenting. In contrast, later-stage students viewed their departments as supporting multiple forms of research and typically associated application-based research with industry collaborations and basic research with the culture of academia, exhibiting deeper understanding of the positive and negative nuances of different sources of funding and modes of research. Although differences emerged based on stage of doctoral student socialization, Mendoza's (2007) findings pointed to doctoral student socialization experiences that were heavily intertwined with and generally supportive of academic capitalism and its entrepreneurial values and practices. These findings underline the role and importance of the broad cultural contexts in which doctoral student socialization occurs and offer expanded insight to developmental models of doctoral socialization by finding differences in perceptions of departmental and disciplinary values and practices between early and later-phase doctoral students.

Similarly, Szelényi (2007, 2013) found evidence of cultural influences in science and engineering doctoral socialization with respect to the permeation of commercial and entrepreneurial values and practices. In her qualitative investigation of 70 students and faculty at three top-tier public research universities in the U.S., she found that a significant percentage of the students and faculty she interviewed worked on a combination of commercial and non-commercial research and had developed "agility in switching between the two realms…often seeing it as a natural, necessary, and increasingly common occurrence in their fields" (p. 217). Importantly, as much as an entrepreneurial and commercially-oriented culture shaped the socialization experiences of the doctoral students in her study, findings by Szelényi (2007) also supported the bidirectional nature of socialization. Specifically, she noted that "students also brought their own perspectives and aspirations to their research and education, sometimes reinforcing their lab's non-commercial focus, accepting or rejecting commercialization, or even playing a crucial role in introducing a specific commercial emphasis that otherwise would not have been at the center of the research process" (p. 220-221).

In addition to studies exploring the influence of academic capitalism on doctoral student socialization in the sciences and engineering, a related and growing branch of inquiry has examined how doctoral students make sense of and negotiate competing and coexisting academic capitalist and public good values, norms, and practices in their journeys toward achieving a STEM PhD and a scientific career. Szelényi and Bresonis (2014), for example, revealed a complex and nuanced set of knowledge production values and practices negotiated, blended, or even resisted by STEM doctoral students and faculty within an expansive organizational space marked by the intersection of academic capitalism and the public good. The authors also found that doctoral students and faculty conceptualized the public good in two distinct ways as it applied to their university knowledge production activities: 1) research that contributed to the public good through a focus on accelerated application to health, technological, or environmental problems or 2) unencumbered basic research with a focus on pure discovery, for which the applications and impacts on the public good would serendipitously emerge over time.

Interdisciplinarity. The overlapping nature of academic capitalist and public good norms, values, and practices in present-day research universities is important to acknowledge in any investigation of STEM-based doctoral training because it represents a current contextual reality in which multiple modes of university knowledge production are operating. One of these knowledge production modes, interdisciplinary research in its multiple iterations, has caught the attention of researchers as a situational and structural context in which STEM doctoral student training and socialization are occurring with more frequency. As a specific mode of knowledge production, interdisciplinarity has garnered increasing attention as a new way of thinking, knowing and, in some cases, organizing the academy (Berger, 1972; Gibbons et al., 1994, 2000; Klein, 1990, 2010; Minnich, 2005). As Holley (2009a) pointed out, the overarching goal of interdisciplinarity can be met with conflict, in part, because "membership in an interdisciplinary community challenges the long-accepted structure of the academy" by discipline and department (p. 242). The multiple organizational, structural, and pedagogical challenges to interdisciplinarity, juxtaposed with a confluence of forces that tout interdisciplinarity as the answer to understanding and addressing complex global issues, have resulted in a cultural context in higher education that is ripe for exploration. In addition, as sites of new and evolutionary modes of knowledge production, the STEM fields offer distinct opportunities for researchers interested in examining doctoral socialization in the broader context of interdisciplinarity (Gibbons et al., 1994, 2000; Holley, 2006, 2009a; Klein, 1990; Nowotny et al., 2007).

While we know more about the general processes of doctoral student socialization and how these processes vary significantly by discipline, Boden et al. (2011) pointed out that "doctoral students and their training programs are recognized as central to increasing interdisciplinary research capacity" (p. 741). To date, several key studies have contributed to a blossoming body of literature on interdisciplinarity and interdisciplinary research training in graduate school. Most of these studies have examined processes and outcomes of specifically labeled interdisciplinary programs that engage doctoral students across a variety of STEM fields. Many of these studies have exclusively focused on the experiences of doctoral students within the context of their participation in NSF-funded IGERT programs at a variety of institutions (Boden et al., 2011; Borrego & Newswander, 2010; Graybill, Dooling, Shandas, Withey, Greve, & Simon, 2006; Moslemi et al., 2009; Rhoten & Parker, 2004), a handful have studied the training and learning experiences of graduate-level students participating in other types of STEM-based interdisciplinary research endeavors (Rhoten & Parker, 2004; Ryser, Halseth, & Thein, 2009), and one has looked at doctoral experiences in the well-established interdiscipline of neuroscience (Holley, 2009b). Of these, only two employed a lens of doctoral student socialization (Boden et al., 2011; Holley, 2006, 2009b).

In an influential study directly pertaining to the learning and socialization experiences of doctoral students in the context of interdisciplinarity, Holley (2006, 2009a) conducted a deep qualitative examination of the experiences of doctoral students in the interdisciplinary field of neuroscience at one private research university in the U.S. Her interviews with 45 doctoral students, faculty, and administrators illuminated a number of findings related to the purpose, organization, and context of an interdisciplinary curriculum and identified important learning and socialization challenges. For example, challenges emerged around depth versus breadth of content in required courses, with students generally reporting lack of depth as an issue. Holley (2009a) also discovered little evidence of focused and collaborative thought among program faculty regarding course content and delivery, or specific strengths or weaknesses of doctoral students in the programs. Difficulty selecting elective coursework was also articulated by doctoral students, even with input from faculty advisors. Ambiguity around required and elective course work was sometimes offset and other times further complicated by a culture that immersed students early and often in laboratory experiences that specifically engaged students in interdisciplinary research.

Overall, Holley's (2009a) study illustrated several challenges for neuroscience doctoral students with respect to their ability to acquire and integrate knowledge across the disciplines from which neuroscience draws. Specifically, Holley (2009a) pointed to a gap between the expectations of neuroscience doctoral students and what they believed they received in terms of curricular and co-curricular experiences. This gap seemed to arise from a general lack of formal attention from program faculty in terms of how to develop interdisciplinary scholars. As such, Holley (2009a) asserted that, in her case study, interdisciplinarity was a "tacit, implied practice, at best, for both students and faculty" (p. 252). Her study also affirmed the importance of the research lab and the experiences it provides in the training and socialization of interdisciplinary doctoral students, both as a means to gain new knowledge and to explore future careers in academia and industry. Based on her findings, she concluded that the curriculum in the case she examined was not being used effectively to assist students in acquiring necessary depth and breadth and that, instead, students were immersed early into the research lab with the informal expectation that interdisciplinary learning would occur.

Using a different approach, Boden et al. (2011) explored how doctoral students negotiated between the disciplinary culture and a culture of interdisciplinarity as a function of their socialization through interviews with 43 students, faculty, and administrators who were engaged in four IGERT programs across two large research institutions. Overall, while noting that general processes of socialization and the key socializing agents of faculty and peers did not differ largely from one context to the other, they observed that disciplinary-based organizational structure, policies, and resource allocation impeded unique features and intents of interdisciplinary programs. They concluded that opportunities for formal and informal interdisciplinary collaboration and the flexibility for interdisciplinary cultural and epistemological development (and thereby related socialization processes) were difficult to foster in such organizational circumstances. Holley (2009a) also found that interdisciplinary programs were often challenged by the disciplinary organization of universities. For example, she noted that even in an interdisciplinary field such as neuroscience, faculty had typically been trained in a specific discipline and the curriculum was similarly delivered as part and parcel of a disciplinary field.

While Holley (2009a) and Boden et al. (2011) were able to illuminate challenges in the interdisciplinary teaching and learning environment for doctoral students and faculty, Ryser et al. (2009) discerned specific forms of learning experiences and outcomes of students in their study, such as increased ability to network with scholars from other institutions and to share research at conferences. Specifically, Ryser et al. (2009) pointed to the importance of specific modes of social interaction with interdisciplinary networks of individuals as a mechanism for learning interdisciplinary research methods, skills, and future career avenues. Their analysis of interviews with 13 students from eight universities in Canada who were employed on a common interdisciplinary research project revealed that faculty mentoring and emotional support from faculty, colleagues, and peers were the facilitating core of students' overall learning experiences. Faculty who welcomed students to the project and who encouraged them to perform varying degrees of research tasks, to make presentations, or to participate in conferences significantly facilitated their understanding of different approaches to research problems, development of research skills, and confidence and ability to produce tangible pieces of scholarship. In addition, faculty encouraged students to cultivate networks of scholars and professionals at conferences and via e-mail outreach to explore research questions and career opportunities. However, only 23% of the 13 participants were at the PhD or post-doctoral level, which presents a limitation in terms of capturing the specific experiences of doctoral students with respect to interdisciplinary research participation.

Graybill et al. (2006), an interdisciplinary team of doctoral students, documented and analyzed their collective and first-hand insights into their experiences as doctoral students participating simultaneously in their disciplinary PhD programs and an interdisciplinary research team as part of the University of Washington's Urban Ecology IGERT Program. Originally initiated by five faculty members, this IGERT operationalized an interdisciplinary research team, which included 25 doctoral students across four cohorts representing the disciplines of anthropology, biology, earth sciences, geography, natural resources policy, urban design, and wildlife science. In addition to their IGERT participation and responsibilities, students were also expected to fulfill requirements for their home disciplines for degree attainment. Graybill et al. (2006) pointed to three key stages—naissance, navigation, and maturation—as characteristic of their experiences moving through the process of becoming “interdisciplinary and disciplinary scholars” (p. 760). Naissance, according to the authors, extended across the first two years when students were in the early phases of negotiating the unfamiliar and negotiating the expectation that students “develop dual intellectual communities” through both connecting with home departments and immersing with their IGERT team (p. 760). The authors reported that a great deal of disorientation and difficulties arose during these years as students attempted to establish these networks and overcome challenges when departmental and IGERT requirements were misaligned, which they suggested was a common occurrence. They implicated the complexities of answering to two intellectual communities as contributing to a much lengthier naissance period than students in a more typical disciplinary PhD program and pointed to the need for students to first gather firm disciplinary grounding, before they were able to situate their own scholarship and consider the possibilities around combining disciplinary and interdisciplinary research and academic identity.

In the next stage, navigation, the authors argued that students typically found a more stable balance between disciplinary and interdisciplinary knowledge bases and pursuits, especially in terms of their academic progress in both areas through effective collaboration with their interdisciplinary teammates and through frequent consultation with faculty from both areas. In addition, students were also negotiating and incorporating other educational and personal demands. At this point, the authors suggested that students were confronting more sophisticated questions about the extent to which they wished to strategically integrate their disciplinary and interdisciplinary research and what potential implications might result in terms of attaining disciplinary legitimacy and depth. Graybill et al. (2006) also pointed to the importance of engaging dissertation committee members who were supportive of interdisciplinary research and “who can respond to students’ interdisciplinary and disciplinary needs” (p. 760). Finally, the authors suggested that the maturation stage occurred around the time when a considerable portion of students’ disciplinary and IGERT requirements were completed. At this point, students were identifying outlets for co-authored publications from their IGERT experience and were generally focused on their job searches. In addition, students in this stage were trying to decide how to best position themselves and articulate the benefits of their dual experience to academic or non-academic employers, especially when one experience may be more or less valued over the other depending on the employment context.

Most of the aforementioned authors focused their investigations of context-based doctoral student socialization in the science and engineering disciplines, which is not surprising given the volume of rationale highlighting these fields as definitively intertwined with academic capitalism and entrepreneurship (Etzkowitz & Leydesdorff, 1997, 2000; Geiger, 1990, 2004; Gibbons et al., 1994; Slaughter & Leslie, 1997; Slaughter & Rhoades, 2004). The collective work of these researchers is important to my study in their focus on doctoral student socialization in science and engineering. These studies are also important in their intersection with broad socioeconomically- and politically-charged contexts that have permeated university science and engineering departments and shaped how doctoral students conceptualized and internalized norms, values, and practices and made sense of future careers within and beyond academia.

My study similarly attempts to understand doctoral student socialization in the broader context of interdisciplinarity, which in itself can be viewed as having socioeconomic and political undertones and intersections with commercial, academic, and socially-focused values and practices. Importantly, several of these studies also concentrated on doctoral students in disciplinary fields and subfields, which is important to my study in an effort to better understand the interdisciplinary socialization of doctoral students who are pursuing discipline-based degree programs that intersect and overlap with their IGERT participation. Unlike these studies, however, my study will also consider the role of gender as both an organizational and individual doctoral student socializing context by exploring the lived experiences of women doctoral students in the sciences, who have been historically underserved but are believed to be engaging in interdisciplinary research experiences in greater proportion than their male counterparts (Rhoten & Pfirman, 2007).

Gender. Recently, Sallee (2010, 2011a) has offered a theory of gendered socialization as a way of introducing gender into existing models of doctoral student socialization. Sallee's theory considers "how gender both influences students' socialization and is simultaneously produced as students progress through their programs" (p. 171). Her theory points to ways that gender differs by context, including disciplinary context, arguing that men and women enact different gender roles and identities within and across the science and engineering disciplines than, for instance, the humanities since “some disciplines are associated with one gender or another” (p. 182).

Sallee’s work adds theoretical and empirical dimension to an evolving yet sparse thread of literature that has focused specifically on women graduate students in STEM with respect to their socialization experiences, barriers to degree attainment, including implicit bias, and differential access to mentoring, professional networks, and resources, as well as differential career outcomes (e.g., Erikson, 2012; Ferreira, 2003b; Long & Fox, 1995, NSF, 2015; Sallee, 2011a). In her study of male graduate students in a department of Aerospace and Mechanical Engineering (a significantly male-dominated discipline), Sallee (2011a) found a number of explicitly and implicitly gendered aspects of the doctoral student socialization process especially across peer and faculty interactions and in the transmission of specific cultural values. For example, she found that students in this department were being socialized into a culture that valued hierarchy, competition, aggressiveness, and egocentrism—qualities and behaviors which are more generally considered masculine and thus privilege values that may discourage or alienate women. In addition, her participants revealed ways in which they engaged in social activities with male faculty and peers that served as a springboard to networking and mentoring that their women counterparts did not, such as through playing sports together.

Sallee’s findings regarding gendered dimensions of doctoral student socialization corroborate previous findings by Ferreira (2003b) who, in her study of graduate student attrition in a biology and a chemistry department at one large research university, found that women largely “felt as outsiders in a culture governed by masculine patterns of behavior” in both their laboratories and their departments as a whole (p. 977). Specifically, she found that women graduate students had different perceptions than their male counterparts of their relationships with and treatment by colleagues, advisors, and their overall department, including feeling welcome, being taken seriously, and having their opinions valued. In addition, many women articulated that they felt uncomfortable with the clear messages that they received from many disciplinary peers and faculty to act aggressively and competitively to succeed. These messages often took the form of encouraging competitive behavior around the hours, nights, and weekends spent in the lab as a symbol of commitment.

Although this pressure was more pronounced in chemistry than biology, in both departments, women and some men saw the lifestyle of a successful scientist and the overall culture of science as incompatible with having a family. Interestingly, disciplinary differences and nuance emerged around the perception that the lifestyle of a scientist was incompatible with the work of caring for a family. For example, since women faculty in chemistry were fewer, biology students were more likely than chemistry students to observe the practices of women faculty or be mentored by women faculty. Further, biology students were often more aware and closer to the topics of sex and gender by nature of their disciplinary focus. Ultimately, these factors resulted in even more assertions from biology than chemistry students that achieving work-family balance was improbable, mostly through observing women role models who they perceived were not achieving balance in their own lives and who, despite having families, seemed to center their whole lives around scientific work.

Other studies have also pointed to ways in which gender interacted with doctoral student experiences and socialization. In a quantitative analysis of survey data from 574 graduate students in science and engineering disciplines exploring the extent to which departmental climate impacted degree progress and career commitment, Litzler, Lange, and Brainard (2005) found evidence of “pervasive gender differences both overall and within science and engineering departments” (p. 13). Specifically, through logistic regression techniques, they determined that women in these departments were more likely to report gender discrimination, feel isolated, and feel negatively about the pace of work and size of workload, and have lower career commitment.

Erickson (2012) lent the most contemporary empirical credence to gendered issues in science and engineering. In her study of 20 women PhD students within four distinct engineering fields including civil, chemical, electrical, and mechanical across two research intensive universities, she found that her participants simultaneously “revealed” and “avoided” gender (Erickson, 2012, p. 355). In other words, they often offered contradicting statements about whether or not gender mattered as part of their experiences in engineering. For example, while most women acknowledged the difficulty of balancing an engineering career and acting as a primary family caregiver, they also suggested that the phenomenon of women choosing care-giving over career was a valid reason for the low number of women in engineering, essentially denying that the discipline, the university, or other social structures of engineering may make it largely impossible to perform both roles simultaneously. As such, the gendered social environment of science and engineering, including its disciplinary values, norms, and practices was offered as a noteworthy reason for the disproportionate participation and outcomes of women and other minorities in STEM. This conclusion echoed a phenomenon outlined by Rose (1983) that “women who manage to get jobs in science have to handle a peculiar contradiction between the demands on them as caring laborers and as abstract mental laborers. Many resolved this by withdrawing or letting themselves be excluded from science; others become essentially honorary men, denying that being a woman creates any problems at all” (p. 86).

Taken together, these studies make important contributions to the literature on doctoral student socialization, expanding its nature and complexity into entrepreneurial and interdisciplinary contexts that are increasingly present in universities. Conceptual models and empirical data about doctoral student socialization continue to be refined with respect to how the discipline intersects with other individual and organizational contexts to shape the experiences and outcomes of each student and to reproduce or reshape the socialization environment.

Importantly, the more recent investigations of gender in the sciences at the doctoral level underscore that, despite attempts at gender-neutral or gender-supportive approaches, the social structures and practices of many scientific disciplines work to discourage and alienate women. Some studies have indicated that established doctoral student socialization processes cross over to interdisciplinary contexts, especially the centrality of interactions with key socializing actors such as dissertation advisors and peers. However, studies have also suggested that interdisciplinarity, as a feature of doctoral training, represents a departure from the discipline-based structure of higher education and the accompanying socialization processes that traditionally seek to achieve mastery of and commitment to disciplinary norms, values, practices, and conceptual underpinnings (Golde & Gallagher, 1999; Holley, 2009b; Rhoten & Parker, 2004). For women PhD students who may be seeking or placed into interdisciplinary scholarship opportunities, the barriers to navigating interdisciplinary training activities may be high, both in terms of tensions between interdisciplinarity and disciplinary structures and norms of science and in the lack of attention to formalized education and socialization for interdisciplinary engagement. Doctoral training within interdisciplinary scientific contexts affixes a new layer of complexity to the socialization patterns of women doctoral students and presents an opportunity to more fully explore how interdisciplinary socialization contributes to women's learning and development as scientists, and how women envision and enact the self as scientist.

Conceptual Framework: Women Doctoral Student Socialization in the Context of Interdisciplinarity

The conceptual framework for my study draws on a set of interrelated theories that, taken together, attempt to illuminate a more contemporary and nuanced view of doctoral student socialization that considers the intersection of disciplinary culture, interdisciplinary culture, and gender. In this section, I use a feminist standpoint lens (Harding, 1991, 2004) to articulate a multi-theory conceptual framework through which to view the lived experiences of women doctoral students participating in interdisciplinary scientific training as part of their overall doctoral training. This framework juxtaposes feminist standpoint theory with a theory of gendered doctoral student socialization (Sallee, 2011b) and a framework depicting four "gendered" modes of interdisciplinary practice (Rhoten & Pfirman, 2007) that, taken together, offer a way of making sense of women PhD students' interdisciplinary socialization experiences, processes, and outcomes. The components from each theory that are important to my study and how these theories fit together to form an exploratory conceptual framework (see Figure 1) to guide an exploration of the socialization of women PhD students in interdisciplinary scientific training contexts are outlined below.

Feminist Standpoint Theory

When applied to the historically male-dominated scientific enterprise and STEM disciplines/fields, feminist standpoint theory considers a woman's outsider-within social location as invoking "strong objectivity," or a perspective that is often invisible or unrealized by dominant groups (Harding, 1991, p. 149). As Gould (1981) underscored, "Science, since people must do it, is a socially embedded activity…Much of its change through time does not record a closer approach to absolute truth, but the alteration of cultural contexts that influence it so strongly" (p. 21-22). Strong objectivity recognizes science in the way described by Gould and as Harding (1991) further explicated, "requires causal analysis not just of the micro processes in the laboratory but also of the macro tendencies in the social order, which shape scientific practices" (p. 149). The social location and "strong objectivity" of the women in my study are important aspects of illuminating their thinking about the purpose and organization of knowledge creation in the sciences and representing their individual agency with respect to their engagement in interdisciplinary scientific training at the doctoral level. Ultimately, feminist standpoint theory through the concept of strong objectivity focuses the lens on how and to what extent women may become interdisciplinary science people and enact interdisciplinarity. Strong objectivity also opens a line of investigation into the ways in which political, economic, and social contexts and values are incorporated into individual women doctoral students' mental models of science, scientific training and careers, and knowledge creation processes and outcomes.

In addition to strong objectivity, a second and related feature of standpoint theory that is important to my investigation is its function to "map the practices of power, the ways the dominant institutions and their conceptual frameworks create and maintain oppressive social relations" (Harding, 2004, p. 31). The mapping of practices of power is facilitated through insights from those who are "outsiders within" (Collins, 2009, p. 15), such as the women in my study who, by virtue of their role as women doctoral students in interdisciplinary STEM-focused training contexts, operate from a social location that allows them to possess distinct knowledge about the workings of a historically male-dominated and hierarchical social structure. It is important to point out, however, that the acquisition and interpretation of these insights can be layered with complexity and nuance due to the phenomenon that "oppressed groups frequently believe the distorted representations of social relations produced by dominant groups" (Harding, 1991, p. 32).

Feminist standpoint theory is an important lens for exploring connections between and among interdisciplinarity, the practice of science, and scientific research, due to its firm grounding in the critique of science and knowledge. This critique acknowledges that science is a social process that is firmly rooted in and influenced by sociopolitical and historical contexts. Importantly, the social processes of science have reinforced the social location of women as "outsiders within" the history and practice of science (Harding, 1991, p. 124).

Overall, standpoint theory is important to my study in the way it advocates for research that starts from the perspectives of women as a way to create a picture of why social life looks as it does, to illuminate the processes that create and reproduce social activity and, importantly, to reveal who benefits from the resulting social order. This approach is critical to the questions my study is asking about the nature of women's participation in and potential preferences for interdisciplinarity, especially with regard to their research training experiences as PhD students and as a bridge to a deeper investigation of power in interdisciplinary scientific training contexts.

Theory of Gendered Socialization

In the present study, which focuses on the lived experiences of women doctoral students in STEM disciplines, Sallee's (2011b) theory of gendered socialization offers a provocative lens through which to examine gendered doctoral socialization within and across the distinct cultural contexts of the STEM disciplines. Sallee (2011b) considered "how gender both influences and is produced" in the doctoral socialization process and how gendered socialization may differ widely from one discipline to the next (p. 170). In doing so, she specifically addressed how gender, disciplinary culture, and doctoral socialization interact to influence doctoral students' experiences (p. 172). While the overriding goal of doctoral socialization is for students to adopt particular discipline-specific knowledge and values, the theory of gendered socialization suggests that different disciplines may be more or less hospitable to men or women. The theory posits that disciplinary cultures are, in fact, gendered environments in which gendered socialization occurs "as students progress through their programs" (p. 170). Thus, she presented a framework through which to understand how doctoral socialization "teaches students not just the skills but the gendered values that are equated with success in a discipline" (Sallee, 2011b, p. 188).

A core feature of Sallee's gendered socialization theory is the concept of gender performance, originally theorized by West and Zimmerman (1987), which she defined as the suggestion that gender is a process and is "not something that exists in isolation but is created in interaction with others" and "occurs everywhere—in the home, in the workplace, and in academia" (p. 175). Importantly, she underscored that the interactive production of gender is not typically evident to those involved in its production. For example, gender is created when a man opens a car door for a woman and in many other types of interactions. In fact, Sallee (2011b) pointed out that socialization and gender performance occur "in response to the same mechanisms" or in response to the same "structures and interactions" (p. 181).

Sallee (2011b) noted that gender is an embedded feature of socialization that influences doctoral students as they anticipate entering a field of study and after they have entered and committed to a discipline, or more technically, during the anticipatory stage and the entry/commitment stage of doctoral study. Each of the components that constitute Sallee's (2011b) conceptual model of gendered socialization—gender dependent on context/structures, gender as a collective creation, and gender accountability—consider how gender is infused into what students learn about a field before and after entering a doctoral program and how gender may be performed as part of doctoral socialization and then reinforced when students and socializing agents hold each other accountable for their performances.

Sallee (2011b) posited that in the anticipatory stage of doctoral socialization, which encompasses years and decades of socialization experiences prior to entering a doctoral program, students have been influenced by gender-breakdowns of undergraduate disciplines and have internalized which characteristics, activities, and interests are considered more feminine or masculine as they consider doctoral degree programs. Prior to entering a doctoral program, student interests have been shaped, in part, by what they have learned about femininity and masculinity as those concepts apply to their own interests and as they apply to a particular discipline/doctoral degree program. In this way, gender has shaped the decision to enter a doctoral degree program regardless of whether a student is male or female and regardless of which doctoral program of study he or she selects.

After entering a doctoral program, or the entry/commitment phase, socialization is gendered in several other ways. Through a contextual or structural lens, Sallee (2011b) argued that gender is embedded in the various features of the discipline and doctoral program, which include overall gender representation of faculty and students, the type of assistantship a student receives, the curriculum, the presence or absence of a financial stipend, and time to degree. Through a lens of collective creation, Sallee pointed to the process by which students are "socialized by their faculty and peers to embrace gendered disciplinary values" (p. 181). Lastly, she called attention to the role of gender accountability in the gendered socialization process by which faculty and students hold one another accountable "for producing and reproducing gender appropriate behavior" (Sallee, 2011b, p. 181).

In her model, Sallee (2011b) not only assumed gender to be an embedded feature of socialization, but also accounted for both "the idiosyncrasies of disciplines" and "how social identity influences an individual's integration into a new department" or field (p. 170). Disciplinary idiosyncrasies, or a discipline's guiding norms, values, and practices, are of critical importance to my study both as a socializing context and as an embedded structural feature. In addition, Sallee points to the importance of recognizing that social identities beyond one's disciplinary identity are at play for doctoral students in becoming full members of a discipline, department, or field. The recognition of multiple facets of identity and how these play into doctoral socialization is important to how my study both values and starts from the lived experiences of women, experiences which have undoubtedly been shaped by each individual's background and identity characteristics that are not static but active and intertwined with the processes and outcomes of doctoral socialization.

Sallee's theory is highly applicable to the present study in its attention to the embedded role of hierarchical and gendered disciplinary norms in doctoral socialization processes and in its recognition of social identity as a feature of socialization. However, the theory does not attempt to conceptualize interdisciplinary contexts or fully account for the nuanced interplay between socialization and social identity in interdisciplinary scientific contexts under investigation in my study.

Four Modes of Interdisciplinary Science Practice

To better guide an investigation of doctoral student socialization and gender in interdisciplinary contexts, my study will incorporate a framework offered by Rhoten and Pfirman (2007) that deals directly with interdisciplinary culture and the ways in which it might be gendered. Rhoten and Pfirman (2007) outlined four modes of interdisciplinary practice, including 1) cross-fertilization, 2) team-collaboration, 3) field-creation, and 4) problem-orientation. The four modes of interdisciplinary practice were offered as a lens through which to "develop an awareness of how intrapersonal, interpersonal, and socio-structural factors may contribute to decisions about interdisciplinary research and how such actions might then affect individual careers and institutional strategies" (Rhoten & Pfirman, 2007, p. 57), which is a strong complement to the other two theories in the conceptual framework presented in this chapter. My study will use this four-mode framework to explore the interdisciplinary socialization experiences of women doctoral students; the framework offers the opportunity to more directly interrogate what we understand to constitute the process of becoming an interdisciplinary science person and to explore ways in which women doctoral students engage and evolve as scientists through participation in interdisciplinary traineeships.

Cross-fertilization, the first mode of practice depicted by Rhoten and Pfirman (2007), was conceptualized as a mode of interdisciplinary practice through which a researcher "adapts tools, concepts, data, methods, or results from different fields and/or disciplines" (p. 71). In this mode, a researcher thinks about how to connect her research problem to both her home discipline and to other disciplines in a highly purposeful way. According to the researchers, cross-fertilization activity at the margins of and across disciplines stands in contrast to the narrow within-discipline research specialization that typifies many STEM disciplinary worlds. While the work of cross-fertilization can be undertaken individually, Rhoten and Pfirman (2007) argued that more often cross-fertilization results through a network of researchers from distinct disciplines working collaboratively, "thereby transforming the structure of scientific practice from autonomous, hierarchical, and competitive to interactive, horizontal, and cooperative" (p. 58). The authors view cross-fertilization as a potentially gendered process where real or perceived gender differences might operate. Although cautioning readers about the dangers of essentialist biological explanations for gender differences, the authors point to research from cognitive psychology and neuroscience that has suggested women's preferences and aptitude for global processing and "assimilating diverse forms of information" as opposed to local processing and compartmentalizing information and explanations (p. 59). They also note that a more accepted and far less essentialist argument for women's connection to field-creation comes from scholars of feminist science who point to women's alternative epistemological framing of science that has developed in response to/alongside the male-centered creation and appropriation of the norms and values that underlie the scientific method. It is through this alternative epistemological view, less bound to the norms of science and the "dichotomous partitioning between the social and natural worlds," that instead imbues women with a focus on "inter-connectedness, and holism, thus allowing for a multiplicity of ideas and truths" to be adapted and valued from different fields and/or disciplines (p. 59).

Flowing from the concept of cross-fertilization, Rhoten and Pfirman (2007) highlighted a second mode of interdisciplinary practice, *team-collaboration*, which they characterize as "collaborative teams or networks that seek to exchange and/or create tools, concepts, data, methods, or results across different fields and/or disciplines" (p. 71). In considering team-collaboration, they pointed out that multiple forms of collaboration occur quite regularly in academic science in researcher-led laboratory groups, in "triple-helix" or university-industry-government research collaborations (Etzkowitz & Leydesdorff, 1997), and in research that intersects closely related disciplines such as biology and chemistry. However, they distinguished these types of scientific collaborations from interdisciplinary team-collaboration, which they depicted as a community who works together to orient to a common problem and share knowledge resources, theories, methodologies, and ideas. The authors suggested that women may be attracted to team-collaboration activities in the context of interdisciplinary research because the culture and structure of science has been implicated in limiting women's access to and involvement in scientific collaboration and networks. If interdisciplinary research, in fact, occurs across a flatter and more equitable organizational structure and across wider and more diverse networks of participants, women may be more inclined to engage and achieve more equitable and welcoming experiences in such scientific collaborations.

The third mode of interdisciplinary practice in Rhoten and Pfirman's (2007) framework, *field-creation,* is reflective of conducting inquiry "in domains that sit at the intersection of or the edges of multiple fields and/or disciplines" (p. 71). Field-creation, which is also described as the "creation of new spheres of inquiry at the intersections of existing disciplines," stands in contrast to the structural and cultural values, norms, and practices of STEM disciplines, especially the research and training emphasis on narrow within-discipline specialization, and the privileging of certain disciplines over others (Rhoten & Pfirman, 2007, p. 58). The authors explore reasons why field creation through interdisciplinary research might align with women's real or perceived preferences. Specifically, they echo findings from Kemelgor and Etzkowitz (2001) and Sonnert and Holton (1995) that "current models of scientific practice and reward put women into unequally competitive positions" resulting in women either choosing to or being pushed to work on the margins of disciplines or specializations "in comparatively un-crowded and niche domains where it could be seen as easier to exercise a sense of autonomy and control" (p. 60).

Lastly, *problem-orientation* was identified as a fourth mode of interdisciplinary practice. According to Rhoten and Pfirman (2007), problem-orientation is a key element that further sets interdisciplinary activity apart from discipline-bound activity in the way it emphasizes "the application of multiple disciplines or sectors to societal concerns, which may not only require an intellectual answer but perhaps a policy action or technological strategy" (p. 58) and also research that "not only draws on multiple fields and/or disciplines but also serves multiple stakeholders and broader missions outside of academe" (p. 71). The authors pointed to feminist research (e.g., Harding, 2001; Keller, 1983), which has suggested that women are often motivated by and concerned for what is wrong in society and how people are impacted by societal issues. These real or perceived gendered preferences, they argued, can impact what type of science men or women enter and what scientific problems they choose to address. For this reason, various agencies and professional organizations have urged K-12 teachers and university faculty to "introduce more real-world problems into science classes as a way to attract and retain women and minorities" (Rhoten & Pfirman, 2007, p. 60).

For the present study, the four-mode framework and its complementary components provide a scaffold on which to build an understanding of how women doctoral students' participation in interdisciplinary traineeships shapes their professional socialization and their development as interdisciplinary scientists. Of prime importance to this study is a nuanced understanding of how women view, learn within, and personally connect to the interdisciplinary training programs and projects of which they are a part. In their descriptions of each of the four features of interdisciplinary practice, the authors pointed to a host of reform efforts aimed at attracting more women to STEM that allude to women's preferences for more cooperative and collaborative, and less competitive and hierarchical models of teaching, learning, and doing science, which includes more framing of science in its social contexts and valuing real-world problem solving with a holistic scope. Examining how and to what extent interdisciplinary socialization experiences engage these four modes of interdisciplinary practice will allow for a deeper exploration of interdisciplinary socialization processes and outcomes for women doctoral students engaged in interdisciplinary training programs.

The framework outlined in Figure 1 (see Figure 1) presents a conceptual approach to examining the socialization experiences of women PhD students who are engaging in interdisciplinary scientific training that incorporates gendered theories of socialization and modes of interdisciplinary practice through a feminist standpoint lens.

Figure 1. Conceptual Framework

Four "Gendered" Modes of Interdisciplinary Practice (Rhoten & Pfirman, 2007)	• *Cross-fertilization* via the adaptation of tools, concepts, data, methods, or results from different fields and/or disciplines and thinking about how to purposefully connect a research problem to home discipline and to other disciplines • *Team-collaboration* by working together to contextualize a common problem by combining and sharing knowledge, theories, and methods • *Field-creation* by working at the intersection of disciplines to push and redraw the boundaries of knowledge • *Problem-orientation* via an emphasis on societal concerns, real-world problems, and impact through accelerated application of discoveries
Gendered Doctoral Socialization in STEM (Sallee, 2011)	• Individual identity and background experiences before entry into a doctoral program • Internalized ideas about characteristics, activities, and interests considered more feminine or masculine in a STEM discipline or program • Various features of the discipline or doctoral program (e.g. proportions of women and men, curriculum, assistantship type, presence/absence/source of financial stipend) • Disciplinary, norms, values, and practices • Key socializing agents (e.g. faculty, peers) • Reproduction of gendered socialization as faculty and students hold one another accountable for reproducing gender appropriate behaviors and appearances

Feminist Standpoint Theory
Interdisciplinary socialization experiences illuminated through the socially situated standpoints of women doctoral students underpinned by strong objectivity and outsider-within status

These related and complementary frameworks align tightly with utilizing a qualitative methodology that is focused on the lived experiences of women doctoral students in the sciences with respect to their engagement in interdisciplinary science. Methodological choices and approaches for the present study will be discussed in detail in the next chapter.

CHAPTER 3

METHODOLOGY

My study is grounded in critical feminist and qualitative approaches to understanding the experiences of women PhD students in interdisciplinary training contexts. In this chapter, I first explain how the methodological approach I employed, narrative inquiry, aligns with the topic under investigation and how it guided the principles and practices of data collection and analysis. I define what narrative inquiry means to the present study and outline the formation and flow of the research design and the core stages it comprised. As part of discussing the processes and stages of narrative inquiry to which this study adhered, I will point to specific ways in which the principles and practices of narrative inquiry are complementary to the feminist orientation of this study and how these guided participant selection, data collection and analysis, and the relationship between researcher and participant. Finally, the discussion will turn to the various dimensions of trustworthiness that my study incorporated.

Narrative Inquiry

In simple terms, narrative inquiry presents a compelling methodological approach when we "want to see how knowledge is constructed in the everyday world through an ordinary communicative act—storytelling" (Reissman, 2008, p. 13-14). This study is designed to examine the storied lives of women doctoral students to better understand their experiences as PhD students engaged in interdisciplinary research contexts. As suggested by Clandinin, Murphy, Huber, and Murray Orr (2010), narrative inquirers "understand experience as a storied phenomenon" (p. 82), which is useful to understanding participants' engagement with interdisciplinary scholarship as part of becoming a PhD-level scientist nested within multiple and intersecting socio-cultural and political contexts.

Further, Chase (2005) has depicted narrative inquiry as highlighting how individuals construct themselves "within specific institutional, organizational, discursive, and local cultural contexts" (p. 658). In this study's focus on women PhD students' lived experiences in STEM-based training, a context in which disproportionate educational and career outcomes for women continue to persist, narrative inquiry allows for several layers of contextual insight and interpretation. Specifically, my study employed a multi-lens focus "not only on individuals' experience but also on the social, cultural, and institutional narratives within which individuals' experiences are constituted, shaped, expressed, and enacted" (Clandinin & Rosiek, 2007, p. 42-43). In doing so, my investigation operated across a "relational three-dimensional space" in which the researcher continuously and simultaneously accounted for three "commonplaces" of temporality, sociality, and place

(Clandinin, 2015, p. 47). Attention to these three commonplaces, or places that need to be explored in undertaking a narrative inquiry according to Clandinin (2015), is what "distinguishes narrative inquiry from other methodologies" (p. 39). Clandinin, Murphy, Huber, and Murray Orr (2010) further explained these commonplaces:

> Thinking narratively, we attend to the commonplaces of narrative inquiry: temporality (past, present, future), sociality (the dialectic between inner and outer, the personal and social), and place (the concrete physicality of the place or places in which experiences are lived out and told) (p. 82).

An exploration guided by these three commonplaces of narrative inquiry suggests a highly relational research practice that Clandinin, Murphy, Huber, and Murray Orr (2010) characterized as "people in relation studying people in relation" or a way of studying the lives of participants as we "come alongside them and become part of their lives and they part of ours" (p. 82).

Narrative inquiry is also specifically attuned to the feminist nature and positioning of this study in its interest in "women as social actors in their own right and in the subjective meanings that women assign to events and conditions in their lives" (Chase, 2005, p. 655). Rooted in feminist standpoint theory, which also plays a role in the conceptual framework of this study, personal narratives and lived experiences are trusted forms of information, highly valued as a point of counternarrative to the elevated and legitimized dominant sociocultural discourse. From a feminist perspective, those who are located in less privileged positions within the social order possess a special perspective due to their social location within and across specific contexts (Chase, 2005; Collins, 2009; Harding, 1991; Hesse-Biber, 2014). The use of narrative inquiry in the present study offers a methodological approach that centers women's issues and lived experiences in the context of becoming a PhD-level interdisciplinary scientist as a basis for knowledge-building (Hesse-Biber, 2014). Further, narrative inquiry recognizes the multiple and overlapping socio-cultural contexts in which the research participant is situated and values the lived experiences of individuals and groups who are "outsiders within" a dominant culture and whose voices and experiences are often marginalized (Chase, 2005; Collins, 2009, p. 15). Collectively, these conceptualizations of a feminist narrative approach open up a discussion of how I designed this narrative inquiry; how my relationship with the participants was structured; how I moved through the experience and process of being in the field and composing field, interim, and final research texts; and how I ensured research trustworthiness.

Research Design

A number of design elements that this section will highlight were important to my exploration of an "individual's experience in the world, an experience that is storied both in the living and telling and that can be studied by listening, observing, living alongside another, and writing, and interpreting texts" (Clandinin & Rosiek, 2007, p. 42-43). I will first describe the narrative inquiry methods of data collection this study employed, including the process and rationale for participant and site selection and ways in which feminist research approaches were integrated into the data collection process. The data analysis process will also be described, especially how data were inductively and deductively coded and interpreted to create individual narratives of each participant and to identify broad thematic findings across the collection of narratives. Finally, I will address how various aspects of research design, such as time in the field and member checking, worked to ensure study trustworthiness.

Data Collection

The data collection process was multifaceted, encompassing strategic participant selection and recruiting and the gathering of field texts through in-depth one-on-one interviewing. As part of the data collection process, a careful focus was maintained on my role as the researcher as it applied to the relationship between researcher and participant and the assumptions and biases brought by the researcher.

Site Selection and Participant Recruitment

Participant selection in qualitative research is typically a purposeful, flexible, and ongoing process (Jones, Torres, & Arminio, 2006; Patton, 2002). I focused my participant recruiting and selection efforts on university-based programs that provided interdisciplinary scientific training to PhD students. Specifically, Integrative Graduate Education and Research Traineeships (IGERTs), funded by the NSF, served as the primary centers of participant recruitment.

I relied on a combination of purposeful sampling strategies (intensity, maximum variation, and snowball) to identify and complete in-person interviews with 19 study participants across three IGERTs located at three universities in the Northeast region of the United States (Creswell, 2009; Lincoln & Guba, 1985; Miles & Huberman, 1994). Intensity sampling, through which participants who reflect the specific phenomenon and the contexts under study are actively sought, was also used. Additionally, because narrative inquiry is interested in representing varied and nuanced stories of individuals, maximum variation techniques were utilized to intentionally achieve the richest possible information from participants who represented differences across a variety of background characteristics. For the present study, degrees of variation were present across STEM and non-STEM major focus, racial and/or ethnic diversity of participants, age of participants, and the content focus of the three IGERTs and the unique university contexts in which these were operating. Finally, snowball sampling, in which participants recommend other potential participants who similarly reflect the phenomenological and contextual parameters of the study, was also utilized to help further diversify demographic variables and increase the range of individual experiences captured by the study.

To identify specific sites for participant recruitment, I relied on data from recent descriptions of NSF IGERT programs from NSF, IGERT, and university websites, including a database of currently funded IGERTs at research universities in the United States. An analysis of these data sources revealed a total of 152 currently funded IGERTs across the United States that were engaging graduate-level STEM students in interdisciplinary training. Due to the intensive and relational nature of narrative work, this list was further narrowed to research universities with currently funded IGERTs in the Northeast region of the United States, a geographic location with an abundant and varied array of colleges and universities, a diverse and global student population, and numerous STEM-focused academic programs, departments, and industries. This geographic narrowing resulted in a total of nine funded IGERTs across seven universities that were still accepting traineeship applications. From these data, the nine IGERT programs at seven distinct institutions still accepting traineeship applications were further narrowed down to three IGERTs and three universities as key sites of recruitment of women PhD students. The programs were determined to be the most recently funded new IGERT sites in the Northeast region in the United States. It is important to reiterate that no new IGERT programs were funded after October 2015; thus, including sites that were in the earliest phases of their 5-year programs was important to the timing of my study. These sites would be enrolling and funding new cohorts of doctoral student trainees for a period of years between 2015 and 2020, which aligned with the timeline for my study and guaranteed that data collection could be completed during a final window of opportunity to conduct research in the IGERT context. Consistent with the funding timelines of the three included IGERT sites, data collection took place over a period of approximately five months starting in March 2017 and closing in early August 2017.

I sent personalized e-mail invitations to each woman identified as a potential study participant, which included information about the study goals and importance as well as provided details about the relative time commitment study participants could expect and what financial participation incentives were included. I followed up as needed via e-mail and phone outreach (see Appendix A). Ultimately, I conducted in-depth interviews with a total of 19 women across three IGERT programs located at three different universities. Select participant data are highlighted below (see Table 1).

Table 1. Participant Data

Participant Pseudonym	PhD Focus/Major	Self-reported Race/Ethnicity	Country of Origin	Age
Coastal University				
Martha	Global Policy Studies	Latina/Brazilian	Brazil	31
Lily	Global Policy Studies	Caucasian	US	29
Chelsea	Environmental Biology	Caucasian	US	22
Megan	Business Administration	Caucasian/Jewish	US	25
Maggie	Environmental Science	Caucasian	US	25
Abby	Environmental Science	Caucasian	US	30
Keelin	Marine Science & Technology	Caucasian	US	23
Emily	Marine Science &Technology	AAPI/Native Hawaiian	US	24
Valley University				
Meera	Industrial Engineering	African American	US	25
Julia	Mech./Indust. Engineering	White/Chinese Amer.	US	26
Hannah	Environmental Conservation	Caucasian	US	26
Karina	Environmental Conservation	Caucasian	US	39
Alison	Industrial Engineering	Caucasian	US	31
Suburban University				
Amaia	Biomedical Engineering	White/Cuban/Chinese	US	26
Menaka	Chemical Engineering	White/Chinese	US	22
Caroline	Biology	Caucasian	US	26
Erica	Mechanical Engineering	Caucasian	US	27
Alysa	Biology	Caucasian	US	23
Brittany	Biomedical Engineering	Caucasian	US	24

Gathering Field Texts

Field texts "are the records, including, for example fields notes, transcripts of conversations, and artifacts such as photographs and writings by participants and researchers" (Clandinin, 2015, p. 46). To gain insights into the worlds of the women at the heart of my study, field texts were generated through 1) in-depth one-on-one interviews and 2) my field and reflexive notes and memos. In combination, these data collection approaches attempted a holistic and relational way of focusing on the lived experience of each participant and honoring and elevating the participant's voice in the creation of her own narrative while rigorously and transparently examining researcher experiences, assumptions, and biases.

In-depth Interviews. Feminist researchers view the in-depth interview process as a form of "co-creation of meaning" in which the researcher takes a role of active listener and should be prepared to sacrifice her agenda in order to follow the pace and path of the interview participant (Hesse-Biber, 2014, p. 203).

I conducted a total of 19 in-person one-on-one semi-structured interviews at a place convenient or meaningful to the participant. A single follow up interview with one participant was also conducted to gain additional understanding of certain aspects of her lived experience. One of the 19 interviews lasted 45 minutes. Another 16 interviews lasted about an hour and 30 minutes each, and two of the 19 interviews extended beyond two hours in length. Interviews were digitally recorded and transcribed verbatim at which point they operated as field texts (Clandinin & Connolly, 2000). A researcher-created interview protocol consisting of topical areas, questions, and possible probes guided the line of inquiry for the one-on-one interviews with 19 study participants (see Appendix B). In addition to collecting some basic demographic information to monitor and continually strive for maximum variation, the interview protocol was guided by a narrative inquiry framework and included broad open-ended questions intended to encourage each participant to engage in storytelling about her own lived experiences. In addition to designing questions to elicit narrative responses from participants, the interview protocol included questions and probes that explored potentially gendered features of both doctoral socialization and interdisciplinary research training suggested by the Sallee (2011b) and Rhoten and Pfirman (2007) models outlined in my conceptual framework. Thus, the interview protocol was constructed in loose categories which included one or two broad main questions (and a small number of subquestions that could be used as probes) focused on eliciting narrative accounts about early and present experiences with science, interdisciplinarity, and gender. These questions were not intended to overly direct or structure the interview experience. Rather, they were intended to elevate the voice of the participant so she may be free to tell her story in the sequence and form she chooses while allowing space for organic pauses, silences, and other important verbal and non-verbal expressions of her story.

Field and Reflexive Notes. A self-aware and reflexive approach towards my own role as researcher was an important component to the research process because my study required me to use myself as an inquiry tool of data gathering, analysis, and interpretation. Relatedly, how I see the world through my own standpoint and biases was important because the participating women’s stories were ultimately filtered through me and required that I “recognize that people from different backgrounds might understand and organize the world in radically different ways” (Bach & Staller, 2014, p. 108). Thus, I engaged in rigorous self-consideration and reflection on my own identity, social location, and presence in the research as an acknowledgement that these aspects would affect how I collected and interpreted evidence, how I related to and interacted with others, and how they related to and interacted with me. As Jones, Torres, and Arminio (2006) suggested, I regularly reflected on several questions, including 1) what about me and my experiences led me to the study, 2) what personal biases and assumptions do I bring to the study, and 3) what is my relationship with those participating in the study.

Gaining Access and Building Rapport. For the narrative inquiry I carried out, gaining access to and building rapport with the women PhD students whose lived experiences informed and guided my inquiry was critical. I approached the recruitment of women PhD students participating in currently funded and active IGERT traineeships through a two-tiered approach. Initial outreach was conducted via e-mail directly to the women PhD IGERT trainees using the contact information provided at the project site housed on igert.org and, depending on the institution, on a university-based IGERT program page (see Appendix A). For one institution, I also reached out to an IGERT PI gatekeeper who provided a list of potential study recruits.

This two-tiered method of recruiting was meant to carefully attend to the benefits and drawbacks of recruiting women IGERT trainees directly or using IGERT PIs or other faculty persons as points of access to women doctoral students. Specifically, I wished to acknowledge and mitigate power issues that would privilege the roles of others, including my own role as researcher, over the women on whom the study would focus and who I envisioned as participants, not passive objects or transient and generic information sources (Harding, 1991; Hesse-Biber, 2014). Thus, as part of structuring and engaging in various participant recruitment approaches, I paid close attention to power and hierarchy tensions that had the potential to emerge, especially in regard to accessing women IGERT trainees via PI or other gatekeepers of any gender.

As part of the recruiting process, I offered a modest monetary incentive to women who agreed to participate in the study. An incentive was important to my recruitment process in two distinct ways. First, the pool from which I recruited included a finite number of women who could be study participants. Second, PhD students are known to be very busy with academic life, which includes (but is not limited to) working long hours in the lab. Specifically, a cash incentive in the amount of 75 dollars was given to each woman who participated in an in-depth interview.

In terms of building trust and rapport, I discussed the process of informed consent with each study participant prior to each individual interview. As part of this process, I clearly articulated the purpose of the study and underscored that participation was voluntary in the sense that participants could freely choose whether or not to answer any or all interview questions, could stop the interview at any time, and should feel free to ask questions at any time. At the same time, I furnished each participant with informed consent documents (see Appendices C and D), which included study details and key contact information in the event they had questions, ideas, or concerns over the course of their participation or in the future. The informed consent process was one critical avenue through which initial rapport and trust were developed between researcher and participant (Hesse-Bieber, 2014). Importantly, during this time, I was introducing the narrative nature of the study to the women who participated, letting them know that it was their stories as told by them in their own voice that I was most interested in hearing. I shared some information about myself with each of them to build trust and to underscore that their stories, the way they chose to tell them, were of the utmost value.

Being in the Field and "Living Alongside." As discussed by Clandinin, Murphy, Huber, and Murray Orr (2010), narrative researchers inquire into "lives in the midst" which is a highly relational process in the sense that "we do not stand outside the lives of participants but see ourselves as part of the phenomenon under study" (p. 82). In the process of gathering data and composing field texts, the researcher-participant relationship is brought to the foreground. As the researcher, I was uncovering knowledge by participating in social interactions with those whose lives interested me and informed my study. Thus, who I am in the narrative inquiry, how I built rapport and related to the participants and their stories, and how power and control differentials were negotiated were critical and ethical aspects of coming "alongside" the participant.

Recognizing that issues of power and hierarchy may not be able to be completely broken down in the researcher-participant relationship, I sought to both minimize and acknowledge power differentials in the research process through transparent interactions that endeavored to elevate the role and status of the women whose lived experiences would guide my study and without whom, my study would not be possible. Feminist researchers have sought and developed more egalitarian research approaches that reframe the role of the participant as an active and "embodied" subject and social actor engaged in shaping the conditions of her own life as a departure from traditional scientific inquiry that investigates and analyzes passive and "disembodied" objects (Acker, 1990; Butler, 1990; Haraway, 1991; Harding 1991). My study drew from this approach and consciously recognized data gathering and analysis as a relational process of knowledge co-creation. Transparently framing and articulating the knowledge co-creation aspect of this study with my participants was a key part of my interactions with the women who participated in the study. Specifically, I engaged them in key knowledge co-creation activities, including 1) inviting them to story-tell about themselves and their experiences through a one-on-one interview with me and 2) involving them in member checking, or reviewing my written depictions and interpretations of their lived experiences for accuracy (Creswell, 2009; Mertens, 2015). Importantly, since this research is meant to be transformative, sharing narratives and general study findings was employed as a critical step in the research process so that participants were able to gain new insights and avenues they might use to actively shape the conditions of their own lives.

Throughout the data collection process, I reflexively examined and documented my own experiences and assumptions related to the process of living alongside participants through an "outsider-within" framework, which Collins (1986, 2009) explained as a location that "can foster new angles of vision on oppression" (2009, p. 14). Hesse-Biber (2014) depicted insider/outsider status as an integral methodological component of feminist inquiry in terms of interacting with participants to gather data both as a consideration when analyzing and representing data, and as a framework to guide researcher reflexivity. I identified both insider and outsider aspects of my role as researcher and co-creator of knowledge with respect to my own background. For example, I found the need to acknowledge feeling a kinship to the participants based on hearing their stories of gender bias and discrimination within and outside of academe that were similar to my own experiences of discrimination. I also interrogated my strong sense of empathy when hearing participants wrestle with the prospect of work life balance/integration, especially in terms of having a family while balancing a career and how women struggled to envision a successful pathway to achieving both simultaneously. Being a new mother at the time of data collection magnified these elements of women's narratives for me, so it was important for me to acknowledge these as potential biases that could influence data analysis and interpretation.

These insights, including how my role and presence evolved in my interactions with the participants and how my relationship and insider/outsider status evolved with each participant during the research process, were important components of my methodology and played a role in my approaches to data analysis and representation of findings. I recorded many of these reflexive notes and memos in the data analysis phase, using tools built into Dedoose (www.dedoose.com), the online qualitative data analysis platform I used to code and analyze narrative data and engage in reflexive activity.

Data Analysis, Interpretation, and Representation

Data analysis in this narrative inquiry was a lengthy process and comprised a complex and rigorous progression of moving from field text to interim text to a final research text and included a combination of deductive approaches (guided by the conceptual framework and literature) and inductive approaches (appropriate for the open-ended and exploratory nature of the study). In all, the data analysis process occurred over a period of nine to 12 months, starting in December of 2017 and moving forward in a constant comparative way until about December 2018 when it was clear that data saturation was observed.

As mentioned in the preceding section, I used the online qualitative data analysis platform, Dedoose, to organize, code, and analyze field texts (including approximately 1000 pages of interview transcripts and researcher reflexivity notes and memos). With the assistance of the data analysis software package, I used both open and axial coding techniques in a constant comparative way to both develop cohesive narratives of each participant and to illuminate broad thematic findings that emerged across the collection of narratives (Corbin & Strauss, 2008; Glaser & Strauss, 1967). As summarized by Clandinin (2015), "Field texts are co-compositions that are reflective of the experiences of researchers and participants…whether narrative inquirers are listening to participants' told stories or living alongside participants as their lives unfold in particular places, there is ongoing interpretation of the stories lived and told" (p. 46).

Composing Texts: From Field, to Interim, to Research

Narrative researchers negotiate the construction of a variety of field and narrative texts, which are always embedded in the relationship between researcher and participant. As noted above, field texts were generated from in-depth interviewing, observation of interview participants, and note-taking processes. During and after the primary data analysis phase, I began a process of shaping field texts into interim research texts, which drew from the “relational three-dimensional narrative inquiry space” of temporality, sociality, and place (Clandinin, 2015, p. 47). Through this iteration of analysis and interpretation, I moved away from the direct and intensive contact with participants that characterized the process of creating field texts and, as suggested by Holley and Colyar (2009), engaged in creating a narrative sequence from the field texts. In this process, “the researcher is cast as a storyteller, the participants become the characters, and the plot orders the reader’s comprehension of significant events” becoming the “weight-bearing walls for research texts” (Holley & Colyar, 2009, p. 681).

By thinking narratively throughout the analysis process and using the three-dimensional space to compose and re-compose texts, I drew from and adapted several analysis and coding strategies and concepts. For example, through a constant comparative process, I began data analysis from the very start of data collection (Corbin & Strauss, 2008; Glaser & Strauss, 1967). In this way, sampling, data collection, and data analysis occurred continuously and in relation to one another and narrative twists, turns, and tensions revealed themselves in a way that could be probed further as the research unfolded (Jones, Torres, & Arminio, 2006, p. 43).

I relied most heavily on constant comparative analysis through both open and axial coding that was tightly aligned with the practice of thinking narratively and looking for a cohesive way to retell an individual story. In the process of constructing individual narratives of each participant, I used open coding techniques to break data apart and delineate concepts that "stand for blocks of raw data" and hint at emerging "properties and dimensions" of data blocks (Corbin & Strauss, 2008, p. 195). Since narratives are not typically imparted to us by participants in sequence, nor adhere to narrative form or cohesiveness, open coding was used to assist the process of deconstructing field texts as a way to begin to identify how a story might be constructed from its respective parts. I also used axial coding, or "relating of concepts to each other" to assist in marking and sequencing the narrative threads conveyed by the participant, providing an avenue for reconnecting seemingly disparate parts of texts into cohesive narratives (Corbin & Strauss, 2008, p. 195). Together these coding processes helped reveal narrative elements in the form of plot, character, and significant events around which a cohesive narrative could be constructed on behalf of each participant (Corbin & Strauss, 2008; Glaser & Strauss, 1967).

Using Dedoose, codes were created through a combination of inductive and deductive approaches. Deductively, for example, codes representing the four modes of interdisciplinary practice (Rhoten & Pfirman, 2007), known features of the IGERT programs (e.g., IGERT program design elements), and doctoral student socialization (e.g., peer socializing agents, faculty socializing agents) were created to capture and aggregate pertinent data. Through this process, new codes were also developed more inductively as data began to illuminate other variations of women's lived experiences and tensions in women's narrative accounts. As constant comparative analysis continued and additional gradations of interdisciplinary socialization emerged from the express standpoints of the participants, additional codes were created, capturing new and more nuanced data points. For instance, deductive codes created to capture data on the cross-fertilization, team-collaboration, problem-orientation, and field-creation modes of interdisciplinary practice gave way to the inductive creation of finer-grain codes to capture more nuanced ways in which Rhoten and Pfirman's (2007) four modes of interdisciplinary practice operated within interdisciplinary doctoral student socialization environments. In another example, a general deductive code attempting to capture women's expressions of marginalizing or harassing experiences resulted in inductive creation of codes to capture women's expressions of tensions around disciplinary marginalization and prestige and ways in which women were able to actively shape their own interdisciplinary socialization experiences. Overall, combining deductive and inductive coding methods was important in both teasing apart interdisciplinary experiences from disciplinary ones and in identifying important nuance in women's interdisciplinary socialization experiences.

The coding process also aligned with how Clandinin, Murphy, Huber, and Murray Orr (2010) stressed the importance of identifying important "tensions," or moments in living alongside participants when "they told stories that seemed tension filled" as a critical part of making sense of moments between researcher and participant. They suggested that these identified tension points may become “the cracks or openings for co-composing inquiry spaces as well as co-composing field texts and research texts…and a way to inquire into the dangers of learning to live and tell different stories as counterstories to the dominant institutional, cultural and social narratives that shape the landscape” (p. 83-84). Through coding techniques, I was able to systematically attach keywords or thematic tags to segments of text and link together relevant data segments to each other to sequence, interpret, and represent a cohesive narrative and provide a data roadmap against which to confirm findings and test conclusions (Hesse-Beiber, 2014). I used deductive and inductive approaches to open and axial coding in these ways to trace and identify such tensions or cracks and to capture and depict the nuance of words, pauses, and gaps.

Clandinin, Murphy, Huber, and Murray Orr (2010) described the process of shaping field texts into interim narrative texts as critical to illuminating their inherent incompleteness, thereby opening up new points of contact with participants through member-checking and clarification interviews and activities. More directly, the authors defined interim texts as “intentionally written as tentative, open texts…to be read and negotiated with participants…inviting participants to say more when plotlines seem incoherent, where there are gaps and silences in those in-between spaces” (p. 84). Member checking, through which three of 19 participants responded and confirmed accuracy of their in-progress individual narratives, and a follow-up one-on-one semi-structured interview with one participant resulted in the generation of new and extended field texts and allowed me to further the degree of coherence and completeness in constructing and finalizing individual narratives. In depicting the study findings, I often incorporated longer narrative excerpts to ensure that the full voice and intent of participants was authentically represented with a special focus on representing the true essence of how women narratively depicted key moments, or turning points in their interdisciplinary socialization.

As a whole, the process of moving from field text to interim text to final research text generated nuanced and rich description and opened the reader up to the world of the participant "in such a way that we can understand the phenomenon studied and draw our own interpretations about meanings and significance" (Patton, 2002, p. 438). During the composition of interim and final research texts, I paid close attention to how I changed in relation to the research and the participants' stories throughout the inquiry as a way to further envision the multiplicities of a storied life and how attending to these multiplicities in the lives of individuals allowed for "wondering about and imagining alternate possibilities" (Clandinin, 2015, p. 52), which are documented specifically in the conclusion, discussion, and implications to follow in chapter six. Ultimately, the generation of "rich description" (Geertz, 1973, p. 5) attained through a combined process of moving from field text to interim text to final research text and engaging in rigorous researcher reflexivity documented through a variety of notes, memos, and journals was important to enhancing the credibility and trustworthiness of my qualitative investigation. For my study, this was particularly important as a way to more intensively examine how gender operated in interdisciplinary socialization and training contexts for women PhD students.

Ensuring Trustworthiness of Research

The present study built a series of transparent trustworthiness strategies into the data collection and analysis phases of the research design. Specifically, my study attended to aspects of credibility, transferability, confirmability, and dependability. These four elements of trustworthiness are well-documented measures of evaluating the "goodness" of research that is qualitative in nature (Guba & Lincoln, 1989; Mertens, 2015).

Credibility. My study addressed credibility in several ways. Importantly, one of the design features of my study, member checking, occurred with study participants as texts were composed, recomposed, and finalized. Further, I spent a prolonged time in the field both gathering and interacting with field texts over a three-year period between 2016 and 2019. This time period for data collection and analysis included 1) approximately six months of interviewing, 2) one additional month for reviewing and cataloging initial interview transcriptions, 3) several months constructing stand-alone narratives for a majority of the 19 participants and member checking these interim texts with the participants, and 4) approximately one additional year of data analysis to move forward in constructing final research texts. These measures assured the research was not closed prematurely before a comprehensive analysis and presentation of the data was achieved. Strategies such as peer review/debrief and intense researcher reflexivity through ongoing note-taking and journaling acted as additional credibility approaches that provided insight on whether and when data saturation had occurred (Mertens, 2015).

Transferability. Due to the prolonged and interactive engagement with participants and field texts and the intense focus on the three commonplaces of temporality, sociality, and place, my study encompassed very detailed and thick description (Geertz, 1973) or "extensive and careful description of the time, place, context, and culture" (Mertens, 2015, p. 271). In qualitative research, the onus of judging goodness of research rests with the reader (Mertens, 2015). When these elements are present, readers can then make judgments regarding the ways in which the results of the study are transferrable to their own situations, experiences, or lives.

Confirmability and Dependability. These interrelated indicators of research trustworthiness are rooted in the process of establishing a complete and transparent chain of evidence that details each step of the research process (Mertens, 2015; Yin, 2009). The chain of evidence for the present study made data collection processes and procedures transparent and traceable to original sources (while protecting participant confidentiality). I engaged in confirmability and dependability audits at critical points along the data collection and analysis phases. In the case of the present study, regular and rigorous review and debriefing activities were inherently present as part of the structured interactions and feedback loops between my three dissertation committee members and me, with a special emphasis on the committee chair as an ongoing primary source of feedback and guidance. In addition, the member checking process engaged study participants as confirmability and dependability auditors in their review of my process of moving from field text to interim text to final text, including reviewing my data conclusions.

The use of a narrative methodology to approach a social study of women in STEM doctoral programs takes on added significance when juxtaposed against the scientific method that frames the research in STEM fields that has historically valued and legitimized largely quantitative, linear, and rational approaches. Rational objectivity, which includes distancing the researcher from the subject or object under study, as well as from the broader local and cultural context, sits in contrast to narrative inquiry. Narrative inquiry embraces subjectivity by recognizing the political dimensions of research that are inherent in 1) researchers who, as co-constructors of knowledge with their participants, bring biases that require reflexivity and 2) the broader local and cultural contexts in which the research, researcher, and participants are situated as part of the knowledge creation and interpretation process (Chase, 2005; Riessman, 2008). In response to literature-based suggestions that women PhD students are more frequently working at the intersection of STEM disciplinary social structures and emerging interdisciplinary scholarly spaces, the use of narrative inquiry to explore this phenomenon was intended to increase understanding through the creation of holistic and storied accounts from each individual participant—women whose voices are typically marginalized or muted within the masculine enterprise and master narrative of science. Ultimately, the goal of using narrative approaches in the present study was to illuminate rich storied accounts and nuances of how each participant individually navigated the interdisciplinary socialization process and the extent to which women were actively shaping their own pathways to becoming interdisciplinary science people.

CHAPTER 4

IGERT LEARNING OPPORTUNITIES TO SUPPORT INTERDISCIPLINARY MODES OF PRACTICE: THROUGH THE EXPERIENCES OF WOMEN DOCTORAL STUDENTS

The findings described in this chapter underscore this study's focus on interdisciplinary doctoral socialization by linking Rhoten and Pfirman's (2007) four modes of interdisciplinary practice to doctoral student socialization in the interdisciplinary training context of IGERT programs. Specifically, findings in this chapter will: 1) depict ways in which IGERT learning opportunities distinctly supported three of the four modes of interdisciplinary practice, including cross-fertilization, team-collaboration, and problem-orientation and 2) highlight how the fourth mode of interdisciplinary practice, field-creation, took a different form in supporting participants' learning and socialization in interdisciplinary training contexts. The modified role of the field-creation mode of interdisciplinary practice from the experiences of the participants will be addressed in the latter part of this chapter and a reframed definition of field-creation for interdisciplinary doctoral socialization will be presented. In addition, this chapter will consider the role of overarching contextual forces, including IGERT and university contexts, in women's depictions of their interdisciplinary socialization experiences. As a holistic illustration of one woman's lived experience, this chapter will begin with a segment of Keelin's story, a Coastal University IGERT fellow.

Keelin's Story

Keelin, at Coastal University, was initially somewhat apprehensive at her advisor's suggestion that she apply to the IGERT program. She was unsure how it would fit into her goal of completing her PhD in marine science and technology, but aware that since her entire post-secondary educational experience leading up to her PhD was in chemistry, IGERT might offer a challenge outside her comfort zone and complement her PhD degree focus. She explained:

> I came from chemistry, which is like the most silo-esque, you know, it's very much -- I just took chemistry. I didn't even take a biology class in my undergrad. So, it was very much just chemistry and so I was like, man, I don't have -- I didn't write a single essay in college. All I did was science. I was like, this would be a really interesting learning opportunity for me.

Keelin also saw IGERT as a program that might help her envision the applicability of her previous and future research, which she noted was a perspective she felt had been lacking from her previous chemistry-heavy educational and research experiences:

> The reason I wanted to leave chemistry was because I didn't see the application of my work. I did, you know, I worked with aqueous film foaming foams, looking at their -- you know, what the concentration was, but I had no idea what that actually meant for human impact or animal. I just didn't know that and I'd ask and no one cared because that wasn't what we were researching. IGERT just sounded like that sort of next step, even above what I -- I wasn't comfortable with the idea but I was like, I need to do something like that, like that's what I'm looking for. So, that's why I decided to apply for IGERT… and I can't believe they accepted me from just chemistry.

Keelin was still early in her IGERT experience at the time of her interview; however, she was already finding that the actual experience was much more profound than she had originally anticipated. For Keelin, IGERT simultaneously presented challenges and unexpected learning opportunities that resulted in new knowledge and skills that she had not considered as critical to the practice of science or to her future career pathway. In characterizations of her IGERT experiences, she offered nuanced insights into how IGERT was instrumental in giving her formal and informal learning opportunities that intersected and reflected three of the four modes of interdisciplinary practice conceptualized by Rhoten and Pfirman (2007), specifically cross-fertilization, team-collaboration, and problem-orientation. She discussed how IGERT and, especially, her peers encouraged and supported her to move out of her comfort zone to take on project/research-based responsibilities that called for a skill set that she had only just begun to practice related to interviewing and engaging stakeholders. Reflecting on what she believed she was gaining from her IGERT experience to date, Keelin described navigating new research approaches and communication expectations:

> I was lacking a lot of skills in anything but lab work… and the team that I'm on is really supportive of that and knows that I don't have the experience and so they throw me into situations that are safe but also that I don't want to do, like go to meet with people. I'm meeting -- I've met with people by myself before. They're like, "Oh, you can do it," and I'm like, "Can I? Are you sure you trust me with this?" But, they've been great.

Engaging in new learning opportunities and challenges allowed Keelin to consider her strengths and past experiences in the context of conducting interdisciplinary, team-oriented inquiry into highly complex and multi-dimensional problems and to see avenues for personal and professional growth. As she explained:

> I am the kind of person who sits in the back of the room and takes notes -- but, you know, when you're talking to someone, you have to ask questions, and I have to actually analyze things on the spot to get the right answers that I need, as well as to critically think about a social issue. I can't just go and take samples. There's no finite -- there's no solution to this. To be able to analyze like that, I'm not sure I'm good at it yet, but I think I've gained skills to be able to be good at it someday and learning from my teammates how to present in front of people. I've never really done that before.

Some of Keelin's learning gains were important in helping her connect her scientific interests with human concerns, and she noted the significant impact of knowledge exchange and support between and among IGERT peers, especially those from policy and business departments:

> So, it's just like they're kind of teaching you to be really critical and, I mean, and trying to teach a mix of -- I mean, I come from chemistry so I don't know anything about people and so sitting through a lecture on how to conduct risk analysis, I'm like, I don't know anything about this. But, there are people who are experts in it, like my colleagues, not even professors. So, that's been really cool and working on group projects, it's really challenging, but I think it's been great.

The exposure to IGERT-based scientific problems that involve multiple stakeholders and are concerned with broader societal impact was influencing Keelin to start considering how to envision the human impact potential of her more pure than applied PhD research and how more practical framing might be incorporated into her dissertation research:

> My research so far has been very much chemical-based. So, I'm doing research -- looking at carbon flexes during storms -- it has a human impact, you know, kind of like deep far down, but it's definitely more chemistry than -- and I've been working with my advisor to try and figure out how to make it more transdisciplinary because it's very much single right now. I mean, I think I need more experience to do anything that's not just taking water samples and running them in a lab. I think, you know, one of my chapters will hopefully be transdisciplinary if I can make it that way

> and my advisor is 100 percent on board. So, I think it will happen. I just don't know how that will look yet.

Keelin's in-progress story, while unique to her, was thematically similar to the other participants in my study in the way it underscored the role of IGERT experiences in supporting learning opportunities that facilitated and provided practice in cross-fertilization, team collaboration, and problem-orientation.

Keelin and the other 18 women doctoral students who participated in this study were anchored in three distinct IGERTs at three separate universities. Across all three IGERTs, women described structured programmatic elements that were instrumental in their interdisciplinary doctoral student socialization. These programmatic elements, which typically included common coursework/team research projects, course-based and conference travel, seminars, and "innovation clinics," provided clear learning opportunities that supported and encouraged women to engage in interdisciplinary activity. Embedded in these programmatic activities were clear illustrations of learning opportunities that activated three of the four modes of interdisciplinary practice outlined by Rhoten and Pfirman (2007), including cross-fertilization, team-collaboration, and problem-orientation. The fourth mode, field-creation, was not central to the participants' interdisciplinary socialization experiences perhaps due to the fact that they were still PhD students, and thus, did not have enough experience to enact "field-creation" in the immediate term (see Table 2).

Table 2. Rhoten and Pfirman's (2007) Four Modes of Interdisciplinary Practice

Mode of Interdisciplinary Practice	Description
Cross-fertilization	• adapting "tools, concepts, data, methods, or results from different fields and/or disciplines" (p.71)
Team-collaboration	• collaborating in "teams or networks that seek to exchange and/or create tools, concepts, data, methods, or results across different fields and/or disciplines" (p. 71)
Problem-orientation	• emphasizing "the application of multiple disciplines or sectors to societal concerns, which may not only require an intellectual answer but perhaps a policy action or technological strategy" (p. 58) • research that "not only draws on multiple fields and/or disciplines but also serves multiple stakeholders and broader missions outside of academe" (p. 71)
Field-creation	• the "creation of new spheres of inquiry at the intersections of existing disciplines" (p. 58) • conducting inquiry "in domains that sit at the intersection of or the edges of multiple fields and/or disciplines" (p.71)

This study is intended to glean nuanced understanding of women's interdisciplinary doctoral socialization experiences through narrative inquiry. It is not designed to offer a comparison of the different IGERTs included in this study as, for example, a case study might. However, because each individual IGERT was so strikingly different in its thematic emphasis, structural elements, and scope of participation, the first set of findings in the section below will be presented in the context of the IGERT in which participants' experiences occurred. In addition, it is important to stress that my study's findings are derived from the perspectives of women only and do not intend to include the experiences of men. Men very well may experience and express interdisciplinarity in similar ways, but this study intentionally focused on women's experiences only and is reinforced by literature that clearly links my findings to women's lives.

Interdisciplinary Socialization and Modes of Practice at the Coastal University IGERT

Coastal University is a large public research institution in the Northeast that espouses a commitment to transdisciplinary research and community engagement. The Coastal University IGERT, in which just over a third of the women in my study participated, was focused on interdisciplinary problem-solving in local coastal communities by bringing together biology, chemistry, environmental sciences, policy, and business disciplines and through engaging external and community-based stakeholders. The design and focus area of this IGERT was very much in line with the University's mission of transdisciplinary knowledge creation and community engagement.

A number of common IGERT-supported learning opportunities were cited by Coastal women as instrumental to their interdisciplinary socialization, including retreats, common coursework, weekly seminars, and certain travel opportunities. In describing and citing the importance of various programmatic elements, participants highlighted the ways in which Rhoten and Pfirman's (2007) modes of interdisciplinary practice were embedded and activated in the IGERT at Coastal. For example, every entering cohort participated in a weekend-long retreat at a coastal island field station, where they were introduced to each other, met faculty and administrators, and participated in a cross-section of discussions and activities intended to break down personal and disciplinary barriers. Descriptions of this activity illuminated the significance of cross-disciplinary perspective-sharing as a facilitator of cross-fertilization and team-collaboration.

Abby, an environmental science PhD student and member of the first Coastal IGERT cohort, described the socialization impact that the opening retreat experience had on her. She depicted an experience where students, faculty, and NSF representatives engaged in activities to break down disciplinary barriers through sharing personal and academic background information and research interests. In particular, the activities created cross-fertilization opportunities about perspectives, norms, and practices of different disciplines that tied into elements of problem-orientation and team-collaboration in considering how individuals from different disciplines might work as a team on a central interdisciplinary research problem:

> What was nice is we had a crash course meeting thing on [a local island]. They brought us out there and had us out there the whole weekend. It's the only time I've ever been out there. We have a field station, and so they just let us all stay in the field station, and we really got to know each other. I think our experiences would have been much different had we not been forced to talk to each other and really break down those barriers of, oh, who are you? Why do I care who you are? We had everyone from our cohort.

According to Abby, the cross-sections of individuals present at the opening retreat included funded fellows, unfunded associate fellows, and faculty from all of the disciplinary departments participating in the IGERT experience as well as the NSF coordinator "responsible for being the external person to review some of our feedback." She elaborated further on the activities in which the group engaged:

> We were talking about what the IGERT is, what does it mean, what is our mission statement? Then it was a lot of splitting us into small groups and trying to describe our research to one another, when -- I mean, we're not in the same discipline. We don't have the same vocabulary, which we learned pretty quickly. (laughter) There was a lot of trying to break down those barriers just by getting people to talk to each other and maybe not sound super academic all the time... So that was really good.

A second programmatic experience, a semester-long "innovation clinic" course, was cited by Coastal women as a significant contributor to interdisciplinary socialization. The particular significance of the innovation clinic was its focus on engaging doctoral students from different natural, life, and social science backgrounds in collaborative research projects situated in local coastal communities and including a wide variety of external community-based stakeholders. In doing so, the cross-fertilization, team-collaboration, and problem-orientation modes of practice were illuminated in women's depictions of this experience and its impact on each individual's interdisciplinary socialization. As part of the innovation clinic course experience, Coastal women recounted the process of working as interdisciplinary teams on multi-stakeholder problems embedded within coastal communities that cross-cut a variety of intersecting environmental, economic, technological, and human concerns.

In this vein, Chelsea, an environmental biology PhD student, described how she and her peers were introduced to the innovation clinic through a coastal travel experience that engaged them with a variety of problems and community stakeholders:

> So we went on this three-day kind of crazy trip in January visiting basically a ton of different places up and down the coast line. So coastal communities… So it was non-stop meetings and travel. It was a great experience…And we got to be introduced to all these different places and problems they're having, and different things that people in those communities really need. Yeah, it was awesome and crazy.

Chelsea also described how this travel experience was revisited in their corresponding innovation clinic course:

> The first day of class…we already kind of had a rough idea of who these different clients were from these communities that had problems they needed us to address as the class. They had these ideas and they basically presented them to our class as a whole and said, "Okay, these are all of the potential projects. You guys need to organically find groups of people you want to work with and pick a project. We'll pick a project and the group will form.

Through their descriptions of their innovation clinic experiences, Coastal women depicted the processes through which their interdisciplinary socialization was occurring. Interdisciplinary socialization was particularly visible as women engaged in learning experiences that clearly supported three of the four modes of interdisciplinary practice, especially cross-fertilization, problem-orientation, and team-collaboration with peers. As they engaged in these interdisciplinary practices to advance/address their innovation clinic problem, Coastal women actively distinguished how such research differentiated from prior disciplinary and other IGERT-based programmatic experiences, describing the work as “transdisciplinary,” “political,” “challenging,” and a “learning curve.” These descriptions were especially underscored in reference to the strong emphasis on stakeholder engagement, which is both included in Rhoten and Pfirman’s (2007) definition of problem-orientation and was also viewed as an expanded notion of team-collaboration that presented challenges and rewards with respect to collaborating with peers from different disciplinary backgrounds and with external constituents.

Megan, one of the IGERT fellows pursuing a business PhD, experienced the innovation clinic project in a way that challenged her to consider more conceptual notions of interdisciplinarity. In this case, she was conceptually debating whether research could exist in a form that transcended discipline and exploring ways in which the innovation clinic was nearing that category for her and what that might look like:

> I think Innovation Clinic is probably the most transdisciplinary thing we’ve done, but maybe -- but in the opposite direction, where everything else we’ve done has been dominantly science with maybe social sciences in there somewhere, and this is all working with people, working with clients, working with their needs. For my group’s project, we’re working with someone who’s trying to bring an ocean cluster. He

> wants startups and entrepreneurs who work around water to all work in the same space in order to revive [our city] as an ocean economy. Does that sound like science? No. I just used the word "economy," you know?

Similarly for Keelin, who comes from a chemistry and environmental toxicology background, this more people-oriented and community-based research included collaborative approaches that were very different from her prior experiences. When Keelin described her first experience conducting research by talking to people, compared to the lab-based research with which she was more familiar, she discussed processes related to cross-fertilization, problem-orientation, and team-collaboration in her description of the intricacies of the project:

> Well, we have a client…and he's trying to start an ocean cluster…like a group of marine-based industries all collaboratively working together and maybe eventually in a shared space and it will help start-ups and stuff start….It's kind of hard to do because [coastal city] is very old-fashioned and they're a fishing-based industry and so trying to bring something new and innovative into that city is not going well for him, and companies in the past that have come in have just failed immediately because of lack of community support. So, we're just trying to help our client not make the community super-mad at him when he says this and he's somewhat of a newbie to the town. He's only been there for 30 years, which in my mind that's more than my lifetime so I'm like, that's forever, but, you know, in that city, it's not.

Keelin spoke more about the process of engaging with stakeholders and how she was finding her footing with this unfamiliar process:

> So, we've been setting up one-on-one interviews with people and talking to a lot of the community leaders, fishermen. We have a meeting with the mayor next week and so we're just -- a lot of other groups are doing stakeholder meetings, but we chose to do ours one-on-one just because I think we get a better feel for individual points of view. We're unsure still what our product sounds like because we've kind of learned what we already thought we knew from these people and so we still have to come up with an idea to help our client better facilitate this ocean cluster into the city. So, that's been really fun and challenging. I've never had to talk to people before.

Embedded in Keelin's description of the project was a strong cross-fertilization element through which her individual perspective and knowledge base were expanding beyond the scope of her disciplinary experience to date. Further, Keelin's account of her experiences illustrates team-collaboration and problem-orientation practices as she worked as part of a collaborative team, also including external stakeholders, to make sense of a central problem and the context that surrounds it.

The challenging political landscape inherent in a research project that engaged many community stakeholders was central to Chelsea's IGERT experience. She discussed the high value she placed on the different knowledge contributions of her peers and the knowledge she has gleaned from required IGERT courses that explored economic, policy, and governance concepts and approaches, such as risk calculation, negotiation skills, and stakeholder/community engagement. Chelsea illustrated how cross-fertilization, team-collaboration, and problem-orientation were interacting and instrumental in how she and her teammates made sense of and navigated a complex and sensitive interdisciplinary research problem:

> Right now, we are working in a very political environment, which is not something that every natural scientist gets to do. And my group is composed of people -- I think we all pretty much have natural science backgrounds though it's totally differing areas across the natural sciences. We talk about different theories of how to engage with people and how to engage with stakeholders, and how people perceive risk versus the actual calculated risk. So, I've been able to pull in a lot of that, too, and kind of use that in trying to figure out how to get these people to actually agree with us and want to work on this actively. Basically trying to figure out what really is in this for them and how can we help them achieve that part while also getting what we need. So that's been really helpful as far as the coursework that's helped with a lot of the technical things in the class.

Martha, an IGERT fellow pursuing a global policy studies PhD at Coastal, described a peer interaction that combined elements of cross-fertilization, team-collaboration, and problem-orientation in negotiating individual and disciplinary values while trying to move the innovation clinic project forward:

> We're doing the innovation clinic now. And there is one person in our group who is a deep-hearted environmentalist. All he wants is just to the see the environment to be

protected and respected and restored. And we were talking with all these stakeholders that are -- and our project is on a site that's heavily industrialist, so we have all kinds of industry and pollution and debris, and everything. And he was getting very frustrated over the project, because as we started talking with policymakers and regulatory agencies and companies that work there, he saw that just restoring the area wouldn't just really fly. And he says, "Oh, you know, it's just not possible, you know? If they want to have all these industrial things here, then we should probably just bring the restoration project somewhere else." And I was like, "Wait. Is there any way that we can have both at the same place? Is there any way that we could restore part of this so that people could have some access to the area, and the area would no longer impose an environmental hazard to people who are there?" "And can we compromise that with some kind of industry, maybe not the industry activities that's there now, but maybe with other kinds of businesses that could do a more friendly use of the natural resources, and then we could have both?" And he is, like, "Oh, yes. I guess."

Lily, a global policy studies PhD student, described an instance during her innovation clinic experience where cross-fertilization, team-collaboration, and problem-orientation elements illuminated disciplinary strengths and differences among peers, including a debate on what types of activities and methodologies constitute research:

We have a team of a fish biologist, whatever the heck I am, a girl who has done business in water security, and a guy who does divinity and environmental issues, and a girl who does biogeochemistry. We’re all going to sit together, and we’re going to go to [coastal city] and figure out how to implement this ocean cluster idea, and how do we get the people who in [coastal city], who like to get up in arms about everything, to appreciate it. That was awesome. It was a great challenge. I’m very biased, because it fit exactly in what I want to do for my dissertation research, to go out and talk to people who are resistant to what you’re talking about. But that didn’t jive for everybody. Somebody said, “Well, wait a minute. We’re just going to go talk to people? We can’t just do that; that’s not...” I said, “No, that’s research.” That’s qualitative research. That does count for something important.

Maggie, an environmental science PhD student, also described some of the important contextual and political elements she and her team were recognizing as they attempted to merge and share their expertise in considering their innovation clinic problem. Maggie noted ways in which she was simultaneously considering her own personal strengths and opportunities as both a team contributor and as a learner:

The goal of that class to my understanding is to solve a problem of using all of our different approaches, right? So, we’re supposed to be in groups of like three or four and you’re supposed to mingle with the 2015 cohort as well and you’re not all supposed to have the same background. Obviously, there’s some limitations just based on numbers and all of that. So, my group, unfortunately, doesn’t have any of the business and policy students. But that’s really where I can come in and offer some

> insight, because of my background and just at least understanding basic laws and just those things.

Maggie elaborated further on how the innovation clinic experience reflected the complexities of real world interdisciplinary problem-solving and the learning that results from it:

> So, what I've liked so much about having to take that innovation class is -- for me, I feel like I'm back in the real world. I feel like I am really doing something, taking something out of the classroom and really trying to do something. And we're working on a shellfish initiative for [the state]. And again, that's not going to be something that is just going to come down to one discipline. It's not just going to be the science that gets something like that passed. The nature of [the state's] shellfish initiative is in a sense to come down from the state. So, policies are involved. Laws are involved. So, it required us to understand those things and see where the limitations are. We can propose all these recommendations, but if they don't fit within the framework of the state and how they're structured, then it's not useful. I think we're learning about it. Because, clearly, that's not my background, so I'm still even just learning, "What are shellfish?" Just this simple, simple like, "Let me go to a Wikipedia for a minute and just get all of that information." So, we're still in the process of learning.

In all, these and other key activities and interactions supported by IGERT structures were highlighted by Coastal women as instrumental in their interdisciplinary socialization experiences. Coastal women's depictions of the innovation clinic and complementary programmatic elements of IGERT highlighted the immense complexity and general messiness of this work and ways in which the women valued, learned from, and assimilated particular disciplinary tools and perspectives each individual teammate brought to the table. As part of this process, the women were simultaneously engaging several interdisciplinary modes of practice. For example, a cross-fertilization process, or expansion of each woman's breadth of knowledge beyond her home discipline and assimilation of new perspectives and approaches, was clearly unfolding. Instrumental in facilitating cross-fertilization was a powerful team-collaboration design that resulted in team-based assimilation of new methods and approaches via perspective sharing among peers and, importantly, with external stakeholders in the coastal communities. The women also described the process of gleaning and assimilating the perspectives of a variety of external, often non-STEM, community-based stakeholders. These community perspectives emphasized problems that were rooted in real-life issues that were often immersed in key policy and human impact questions involving marine life and the environment. As the women integrated these community perspectives into the framing of their research, their work in the IGERT innovation clinic became aligned with how problem-orientation was depicted by Rhoten and Pfirman (2007).

The strong stakeholder engagement focus of the Coastal women's innovation clinic experiences also interacted with and furthered the process of cross-fertilization for each individual woman and expanded the notion of team-collaboration beyond the walls of the university to include community member perspectives and participation. As part of the continual interaction between and among cross-fertilization, team-collaboration, and problem-orientation modes, Coastal women often reconsidered, individually and in collaboration, how to use multiple lenses to diplomatically debate and advance the research problem within a multi-stakeholder population, especially when stakeholders were coming from different and sometimes incompatible or conflicting perspectives. How women at Valley University depicted their IGERT and interdisciplinary socialization experiences will be explored next.

Interdisciplinary Socialization and Modes of Practice at the Valley University IGERT

Just under one third of the participants in my study were affiliated with an IGERT focused on interdisciplinary aspects of off-shore wind energy creation and usage. Housed at Valley University, the flagship campus of a state university system in the Northeast known for strong academic programs and very high research activity, the Valley IGERT broadly combined environmental/natural science, engineering, management and social/behavioral science departments and sponsored graduate students from a variety of STEM and some non-STEM majors. Many of the ecology and environmental science doctoral students sponsored by IGERT held math, science, or engineering undergraduate degrees and some also came with engineering, environmental sciences, policy, and psychology master's degrees. Women at Valley highlighted particular experiences unique to their IGERT, including shared coursework, course/research-related travel, weekly seminars, and annual poster sessions as key programmatic and structural aspects of their traineeship that engendered ways of working consistent with the same three of Rhoten and Pfirman's (2007) four modes of interdisciplinary practice—cross-fertilization, team-collaboration, and problem-orientation.

As Karina, who was pursuing a PhD focused on environmental conservation and marine science, noted:

> There's a framework for it, right? You have to take classes in each of the different departments. We had weekly seminars where we came together and listened to the other research, and we took trips together to get to know each other better, and to explore the industry that we were researching.

Common IGERT coursework, most of which included learning opportunities through travel and interactions with wind energy stakeholders and experts at a variety of travel sites, was richly described as supporting and facilitating cross-fertilization, team-collaboration, and problem-orientation. In these experiences, Valley women depicted the ways in which their disciplinary lenses were expanded through perspective-sharing with peers and through interactions with government and non-government organizations with an interest in wind energy. Alison, a May 2017 PhD graduate in industrial engineering and former IGERT fellow, described some features of her IGERT travel experiences, including how they engaged her with interdisciplinary knowledge and skills beyond her discipline and beyond the walls of her doctoral program:

> So, there were the three classes that we had to take, so one was an engineering course. That was a course that already existed and didn't have a trip attached to it. The first trip, maybe, that I went on was part of the planning class where we took a trip to DC….so we set up a bunch of meetings with different wind energy stakeholders in DC, so we met with some legislators, and we met with AWEA [American Wind

> Energy Association] and stuff like that. We met with some folks at the DOE [Department of Energy]…that was the first one, and then…the following year was the trip that we took to the Bahamas, and we did a case study of wind on Eleuthera, so that was the eco class for the IGERT.

The impact of her IGERT travel experiences to Washington, DC and what she gleaned through meetings with stakeholders were also central to Meera's experience and instrumental in expanding her perspective, which was grounded in her PhD focus on industrial engineering. Meera noted that the trip to Washington, DC helped her see the importance of strategically communicating scientific research findings to policymakers in a way that could facilitate policies that protect the environment:

> That trip opened my eyes further to the importance of being able to translate science into policy. It's like, yes, the bench science I do is important, but maybe more important is being able to talk about it in a way policymakers can digest and then write policy that uses scientific understandings to protect the environment.

Hannah, who was part of a later IGERT cohort than Alison and was pursuing an environmental conservation PhD, recounted the importance of these course-based travel experiences to her interdisciplinary socialization, and how the experience created a forum for cross-fertilization, problem-orientation, and team collaboration modes of interdisciplinary practice:

> The engineering course is one of them that we're all required to take. The other one is -- oh, what was it? It's like the environmental assessment of offshore winds. So,

looking at what an environmental impact assessment report actually looks like and what goes into that. And, you know, with considerations of ecological environment. So, everybody takes that, which is great because that was last semester. We got to go to the US Virgin Islands….It was actually really cool going down there because we were essentially looking at the feasibility of offshore wind there. So is it a potential area where it could happen, just like looking at it as a case study. But we got to talk to a bunch of stakeholders on the island and like, the utility and some energy group that specifically helps people with their energy use. And then also some ecological stuff….

Underscoring the collaborative nature of the project, Hannah described the culminating assignment:

> We ended up writing this white paper all together about offshore wind there. But I mean, that it's probably not a good idea because it's in like, hurricane zone. Like, major hurricane zone, so that wouldn't work, and a bunch of other reasons too. Like, there's a lot of corals there that are endangered and whatnot, but yeah. It was a really, really cool experience to have.

Outside of the course-based travel, students described important field trip experiences that also supported interdisciplinary learning and networking with different groups of industry, government, and university stakeholders, as Alison described:

> We had a field trip in the fall. The first year that I was there, we went to the blade test facility in [a coastal city]. And then, we went out to [a nearby coastal town] to take a

look at their wind turbine. So that was the field trip the first year, and then the second year -- it might have been the last time we did that -- we took a trip up to Maine, and we visited the University of Maine because they had a prototype of a floating turbine. So we went to see that, and I think there was an optional second portion of the trip where some of us went and met with some of the fish and wildlife people that are up there off the coast of Maine.

Valley IGERT fellow peers were an important source of cross-fertilization for each individual participant and a group with whom to practice interdisciplinary team-collaboration and problem-orientation. Wind energy experts and stakeholders at a variety of travel sites were also highly instrumental in facilitating interdisciplinary learning opportunities that promoted aspects of cross-fertilization and problem-orientation, where women were actively assimilating new knowledge about other disciplines and using new knowledge to work as a member of an interdisciplinary team to further a research project. As the only IGERT member with a psychology background, Hannah described how she was able to activate her psychological perspective and knowledge as part of a team of IGERT peers looking at a wind energy research problem and interacting with experts and stakeholders, and where certain disciplinary differences and successes emerged for her and her teammates:

> The one course in the US Virgin Islands was actually really helpful. I really learned a lot with that, and I was definitely the only behavioral kind of social scientist on the team. And so when I was speaking with stakeholders, I totally just had different views of -- different questions to ask them. Like, one person was specifically

> interested in the grid. I really wanted to know about the people and what they might have thought about it, so that's also been helpful. Just coming in with different lenses and, asking different questions… it was helpful to see people's different perspectives of things, and going down as a group, the end of every day was like, "All right. What did you guys learn today?" And we were all on the same page about potentially offshore wind in that area, so…. It was a good experience.

A variety of weekly seminars also facilitated interdisciplinary socialization by creating a forum that especially engaged cross-fertilization and problem-orientation modes of practice. As Meera noted, "The interdisciplinary part comes in kind of like when we have these IGERT seminars and we get to hear about different research areas. They bring in different people to talk." Karina further described the seminar experience as a forum where she was able to engage in cross-fertilization and use her expanding interdisciplinary perspective to discern differences in science communication effectiveness. She concluded that IGERT-affiliated faculty and students were particularly more adept at presenting their topics in an accessible and thoughtful way to an interdisciplinary audience compared to many presenters from outside the IGERT. In making this evaluation of how the seminars contributed to her interdisciplinary learning and socialization, she also considered her own disciplinary biases:

> I found that outside industry people who come in, most of them -- not all of them -- the engineering ones, especially, were very topic-specific and lost everybody else. They didn't understand their audience and they were just talking about this fine

> electrical transformer and how we need to optimize it. Great if you have three electrical engineers in the room, not so great for the others. Some people from industry or from trade groups did a better job of staying above it and giving a better sense. And maybe because I identify with that style of talk better, I could understand it. Most of the [Valley University] professors I thought were fine. I think they had a good understanding of their audience and kept it at a cross-disciplinary level. And then the students, for the most part, were very good as well. And so, I really appreciated that perspective, and just to finally get to know their research.

Unique to the Valley IGERT was an annual poster session that brought in visitors from state government agencies, institutes, and organizations and provided IGERT fellows exposure to the work of their peers and to a variety of external networks, as Alison explained:

> We'll have a poster session every year. Then, they invite a bunch of people from all over the state to come and attend that. So, there is usually somebody from the state's Clean Energy Center that's there, and there's a few other people from outside the university and outside the IGERT that attend that.

Meera and an IGERT fellow peer had taken on the task of coordinating one of the annual IGERT poster sessions at Valley. She described the interdisciplinary learning that transpired for her, both in terms of coordinating such an event and her exposure to the research ideas of peers. Meera's description of coordinating the poster session revealed aspects of cross-fertilization though perspective- and knowledge-sharing that resulted in Meera's expanded understanding of the research problems around wind energy, and fostered the potential for future interdisciplinary team-based collaborations:

> You get to see everybody else's posters, and I remember one girl was doing sharks' interactions with cables. And the underground cables have an effect on the sharks and then I learned about floating turbines from [IGERT peer] and how they would actually anchor them, and she just works on anchors, and then people get to learn about me, because I do power grid and actually looking at the integration of a large amount of offshore wind and so people get to kind of see that type of thing, and another person is doing carbon emissions and how much carbon emissions will be reduced through offshore wind. And there's a bunch of others. There's one political science guy who was doing research in Denmark. And that's how you find out about other people's interests and topics and then when you're talking to a lot of people, then some people come up to you and say, "oh, have you ever thought about this?" So that's kind of how you get to do those interdisciplinary projects for people. Because then people are like, "oh, I didn't know that you did that. I do this. Maybe we should collaborate."

As illustrated by women's narrative depictions, IGERT programmatic structures supported interdisciplinary socialization at Valley through which the interdisciplinary practice modes of cross-fertilization, team-collaboration, and problem-orientation were in constant interaction. The interaction between and among these three modes was especially apparent in the course-based travel experiences that required team-based problem-solving activities and team-based case studies that fostered connection and discussion with a wide-variety of university, industry, association, and government wind energy experts and stakeholders. External stakeholder interactions at Valley emphasized information gathering, learning from other wind energy experts and advocates outside the university, and networking. IGERT program learning opportunities put cross-fertilization, team-collaboration, and problem-orientation in constant interaction. The interdisciplinary socialization experiences in the context of the Suburban University IGERT will be highlighted in the next section.

Interdisciplinary Socialization and Modes of Practice at the Suburban University IGERT

Suburban University, a moderately-sized private research university in the suburbs of a major metropolitan area in the Northeast, is known for combining liberal arts and research sciences to engender creativity and innovation. The Suburban IGERT, with which just under a third of the women in my study were affiliated, focused on an overarching interdisciplinary quest to advance the field of soft robotics and brought together biology and a wide variety of engineering departments. Doctoral students outside of more traditionally recognized STEM fields, such as business or policy, were not represented. Further, opportunities to engage with external stakeholders beyond academe were limited. Women at Suburban described similar types of IGERT programmatic experiences, including culminating experiences/orientations, shared coursework, seminars, and research-related travel, all of which underlined and facilitated the same three of the four modes of interdisciplinary practice as at Coastal and

Valley, namely cross-fertilization, team-collaboration, and problem-orientation, but specific to the Suburban IGERT context. Caroline, a biology PhD student, described the general focus and loose organizational structure of her Suburban University IGERT:

> Our program is definitely a "what you make of it" IGERT, I'd say. We have another IGERT…that one is super different. They have courses they have to take, and they have a separate quals for that IGERT. Whereas the soft robots one is more like, "Here's a group of people that you can work with. Occasionally we'll get together and discuss things." We used to do more -- once a year we get together, at the very least…to do more business management and technology transfer seminars. Stuff like that. But there really are not that many scheduled meetings within the IGERT. It's more just like now you have a list of faculty and students that are in this group that you can contact for whatever you need in a different discipline. So, I've taken advantage of it, but not everyone has. I know people whose names are in the IGERT that I've never met since we're from all different departments and mostly we're just in our departments….

Reflecting on her own lab, however, Caroline added:

> My lab is lucky enough that it's like a central lab,…so I just happen to be in a space where there are a lot of IGERT people… There are mechanical engineers, biological engineers, and a bunch of them are in IGERT. So, it is just helpful…But there are others like on the other side of the world over in engineering land nobody knows or sees.

Despite working on a fairly narrowly defined interdisciplinary problem research problem, women at Suburban described the ways in which their interdisciplinary socialization was facilitated though IGERT learning opportunities that activated the cross-fertilization, problem-orientation, and team-collaboration modes of interdisciplinary practice. These modes of practice were particularly evident through women's depictions of their participation in IGERT-funded conference travel, individual- and team-based IGERT and international competitions, and informal discussions occurring in the central IGERT lab to which Caroline referred in the preceding quotation.

Menaka, a chemical engineering PhD student, described the role of a "boot camp" orientation experience as influential to her interdisciplinary socialization at Suburban:

> Before we started school in the fall, we had a boot camp where a bunch of professors…from various departments come and present on their work and how their work can be applied to soft robotics. But just to give a little bit of background, the program has to have a professor in each of the engineering departments and then the sciences department. And then they gave us some projects to do over the week, like we fabricated some robots and did some control stuff. And then we had to do something that we wouldn't have had to do for a normal funding situation… That was a week long. We were there from 8:00 to 8:00 p.m., pretty intensive. But, it was a lot of fun though.

Caroline described the interdisciplinary socialization value of a similar boot camp experience:

> So, they do the opening experience. It's called the IGERT boot camp. For me -- they changed it -- there were three of them and it was different every time. So, basically it's a week of where you get together with your cohort and you just do a bunch of stuff. Like we learned about robotics, I learned about biology, we built a small robot, we dissected things. Just for a week before the start of classes. So, it was full days like nine to five for what they call a boot camp. So, that was the opening experience. We met everybody, met all the faculty, got an idea of the different tools around us. They showed us all the different technologies, we had the nano lab with 3-D printers, and the manufacturing stuff. So, without that, it would've been so difficult. They know that, so they give that experience at the beginning of every year. And after your first year, you go back to that and give talks about your research, introduce yourself to the new cohort.

Suburban women also pointed to IGERT-sponsored "innovation challenges," in which individual trainees (and to a lesser degree, small teams of trainees) competed for monetary awards, as a common feature in the landscape of their interdisciplinary socialization experience. Erica, a mechanical engineering PhD student, described what these challenges looked like over the years in which she was involved with the IGERT and how, during the most recent competition, she was able to network with one of the competition judges who ended up serving on her dissertation committee:

> I've also done the innovation challenge. It's, again, evolved as the years went by. The first year that we did it, I think I won two thousand dollars from it for my

> research. That year, the organization was a little interesting, but we essentially had our idea, and then we came up with other applications for it. I think we helped divide up the money that time, but they wouldn't let us give it all to one person, which is what we wanted to do, and so me and a couple other people also got money.

Erica talked more about the structure and outcomes of different innovation challenges in subsequent years that fostered collaborative approaches to problem-solving, one of which brought in judges from outside the university, which supported additional forms of cross-fertilization for her through networking:

> And then the next year, we were given a design problem, and we split up into teams. I came in second place with my team, so we each got -- what did we win at that one? Ten thousand? So, we each got 3,300. That one we were trying to design a robot that could go from land to water to air, any order. We came up with this idea and presented it. Then this year, we gave a business pitch. I think we had five minutes to give a little TED talk about a project. It didn't have to be our own personal research project. It could be something that we've come up with and want to explore with the other people in the program. You could do it by yourself, or you could be in a team. I presented on my PhD research, and me and another girl both won 15,000, which pretty much funded all the materials. I've been using pretty much that money over the past four years for materials, which has been great. At the last one, there were two judges, and they asked some questions, and I think people from the audience could ask questions. Then I met with -- one of the judges was a mechanical engineer who

> ended up serving on my dissertation committee, but I met with him afterward just to talk about stuff more. It was really nice.

In addition to boot camps and internal innovation competitions, several participants discussed the importance of IGERT sponsoring them to attend national and international conferences to participate in design competitions, connect to new networks of researchers, and to gain exposure to research topics and approaches outside of their PhD and IGERT experiences. At Suburban, these conference travel experiences emerged from the narratives as the most powerful and impactful way of engaging in the cross-fertilization, team-collaboration, and problem-orientation modes of interdisciplinary practice. Erica summarized how IGERT-sponsored conference/research travel particularly influenced her interdisciplinary socialization and access to networks:

> I think it kind of evolved over the course of the program, but when I started, you got eight weeks of travel, so I did three my first year in Switzerland, and then five last year in Italy. The first three in Switzerland, I went to a workshop for a week. It was the second soft robotics workshop in Ascona, which was beautiful, near Italy. It was awesome. It felt like vacation, almost. It was actually a really great conference, and everyone kept telling me that it was going to spoil all other conferences for me. I would say like 75 to 80 percent of the talks were very high quality, which I now know is kind of an anomaly. There was just a great group of people there. Pretty much most of the people in the field, and pretty small, though, so you could really interact with all of these different people, which was really nice, especially being only a year into

> grad school and not having any connections. I then spent two weeks at ETH in Zurich, modeling soft robots, one of the ones that we had in the lab. And that was cool.

In addition to her time in Switzerland, by working in the BioRobotics Institute at the University of Pisa, Erica was able to more fully engage in interdisciplinary learning and modes of practice under the umbrella of soft robotics. This work at the University of Pisa had a stronger team-collaboration component and a wider problem-orientation lens than her Suburban-based IGERT experience. Working at the BioRobotics Institute facilitated cross-fertilization in terms of her incorporation of an expanded definition of soft robotics:

> Then in Italy last year, it was kind of similar. The first week was a conference and robotics competition, with some of the same people at the one a few years ago. I had two IGERT teammates, and then there were two other [Suburban] teams that went. Yeah, it was really fun. People have some different definitions of what a soft robot is, so the competition was a little frustrating for us. We generally take it as soft materials, and not like -- some people define it as robots that act soft, so like hard materials with a lot of joints, but then there was also just one group that had an RC car with a kind of soft hand on it, and that was a little frustrating. But it was still a really great experience.

The second part of Erica's travel experience as she described below presented a significant learning experience through strong cross-fertilization of ideas and approaches with new networks with whom she was able to collaborate. Her enthusiasm for what she was able to learn and ideas she was able to generate for her own design projects, especially in applying origami principles to soft robotics, is very evident in her depiction of the experience:

> And then I spent a month working at the BioRobotics Institute, it's part of the University of Pisa, and they're one of the big groups doing soft robotics over there. So, I worked on some of my own stuff, but then also they were doing some stuff with origami robots, so it's taking the principles of folding paper and applying it to robots. One of the robots at the competition had wheels that changed shape in kind of an origami way, so being able to fold everything in, but then blow up everything and come up with suddenly bigger wheels, which was pretty cool. They had this actuator that's a little bit like a tube that expands, but when it expands, it turns and unfolds so you can rotate a wrist and get this soft motion -- they were doing it with pneumatics, so they don't have any motors or anything. It was pretty cool. They wanted to relate force to distance traveled, so it was a lot of geometry to figure that out. And then also learning from them how they fabricated some of their soft robots, that I wanted to build an arm similar to. It was a really great experience.

Another key learning opportunity Erica noted from her international travel experience was the opportunity to better understand how labs and doctoral education worked in a different country and build new international collegial networks:

> Also it's, I think, good to see how other labs function. Everyone's a little bit different, and their degree is a little different, too. They have a six-month study abroad -- like a mandatory study abroad period at another lab, which is -- I don't know, really cool,

> and if you're going into academia, I think, fairly important to experience different ways that different people are doing things. It's been nice. I know that there are people who I can email if I have a problem, and I know what they're working on.

Caroline, a member of the final and most recent IGERT cohort at Suburban, had engaged in shorter travel experiences mainly centered on competing with teammates in various national and international design competitions. Caroline provided insight into how cross-fertilization, problem-orientation, and team-collaboration were activated and worked as interdisciplinary socialization experiences for her through the process of competing individually and as part of a team in international robotics design competitions:

> There's a big portion of our IGERT that's international travel -- thus me traveling….My second year I did an IGERT project -- like a soft gripper. So, very simple -- a thing that gripped onto different surfaces. But I got to present that at a conference in Germany. The next year in April we built the current robot that I'm working on. So, it's a soft foam caterpillar-inspired robot that inches along. We got to bring that to Italy for a robot competition. Yes! We competed. Our robot competed…Yes, it was awesome. With that same robot we tried a few other competitions, and so we kept adding to it and modifying it. So, we were accepted to the conductive motion of animals in machines conference this June, so this month, and that's in Japan. And we also applied -- we'll hear back in a few weeks -- we applied to another conference in Vancouver for October…So, that's all IGERT funding and IGERT robot projects.

Caroline described more about how her competition experiences morphed from competing solo at first to collaborating with a team of IGERT and non-IGERT graduate students as well as undergraduate students in subsequent competitions. As part of engaging in these competitions, she also illuminated how she negotiated her multiple faculty advisors and competing demands:

> So, for the first thing it was just me -- like the gripper. And then there was this competition that [faculty member] was like, "We should get involved in this!" So, we made a team. Eventually I became like the leader of this team….against my other advisor's will (laughter), because I told him, "I'm just working on it. I'm just helping a little bit." And he's like, "Caroline, it's not going to work like that. You know it." I'm like, "No! I promise. I'm doing one thing." But, so -- suddenly became the team leader and that's -- yeah. He was like, "I knew that would happen." So, he wasn't surprised at all. He's good like that. He was just like, "Yeah, I know. I can't control anything you do." (laughter) So, I've been pushing that forward, and I want to get as much out of it as we can. So, it was like after the competition I'm like, "OK. We're writing a paper. We're making a demo." So, that's why we're going to Japan and Vancouver. We're going to keep on this until I burn you all out and you leave (laughter)!...

In her account, Caroline also described student collaborations that included both IGERT and non-IGERT graduate and undergraduate students:

> So there are six graduate students, four of them are IGERT, two of them are just other graduate students, and we have two undergraduates who work on the project with us. They got to come to Italy with us. One of them did. Which was amazing, I'm sure.

As the above narratives illustrate, the Suburban IGERT was focused on organizing primarily biology and engineering disciplinary perspectives around the shared topic of soft robotics. However, structured curricular or seminar experiences, as a way of fostering common interdisciplinary socialization experiences, were not particularly abundant, and Suburban women depicted their IGERT experience as somewhat more of an individualistic and competition-centric pursuit. However, learning opportunities that facilitated the cross-fertilization, team-collaboration, and problem-orientation modes of interdisciplinary practice were activated for women through international travel opportunities that connected women to other soft robotics researchers, labs, and approaches or offered opportunities for participation in individual- and team-based design competitions where knowledge and perspectives around soft robotics innovations could be integrated.

In some ways, Suburban IGERT women were able to explore and connect to a highly diverse array of global research networks and alternative methodologies through IGERT-sponsored international travel to attend conferences, enter design competitions, and visit other universities, labs, and institutes as graduate student researchers. However, the loose, individualistic structure of the Suburban IGERT resulted in minimal consistency regarding the utilization of travel funding and in the depth of travel experiences of the Suburban women. Less central to Suburban women's accounts was a perspective-sharing process that included community or governmental stakeholders as teammates and knowledge-sharing agents or engaging in learning and research opportunities that emphasized societal concerns, which Rhoten and Pfirman (2007) consider a feature of problem-orientation. However, as the next chapter will illustrate, women across all three IGERTs aspired to connect their future research and careers more directly to community, health, and/or environmental concerns.

Field-Creation Mode of Practice as a Goal of Interdisciplinary Doctoral Education and Training

Overall, participants described interdisciplinary socialization experiences that supported cross-fertilization, team-collaboration, and problem-orientation, underscoring Rhoten and Pfirman's (2007) descriptions and extending them to include the specific experiences of the women doctoral students in this study. The remaining mode of interdisciplinary practice, field-creation, was not present in the participants' interdisciplinary socialization experiences in the way it was originally outlined by Rhoten and Pfirman (2007) as engaging "research in domains that sit at the intersection of or the edges of multiple fields and/or disciplines" (p.71) and actively creating "new spheres of inquiry at the intersections of existing disciplines" (p. 58). The absence of field-creation practices may simply reflect the early-career status of the study participants; field-creation practices may be more relevant to the work of more established scholars. Instead, the study participants were experiencing what I refer to as *anticipatory field-creation*.

Revisiting Keelin's story, highlighted at the start of this chapter, presents an opportunity to see an example of anticipatory field-creation, particularly how her IGERT learning opportunities were assisting her in considering the impact she could potentially make to the field of climate change. In the near term, she was thinking about how to diversify her PhD research to incorporate an interdisciplinary lens. In the longer term, she was in the process of considering how her intersecting interests in chemistry and climate change and expanded perspective in these areas could be realized in future work that would provide opportunities for more clear and direct human impact potential, possibly within the context of creating a novel field.

In a similar vein, Menaka at Suburban depicted aspects of field-creation as a future goal for herself in terms of doing novel work somewhere at the margins of disciplines. It is clear from her quote that she was in the very early stages of envisioning field-creation opportunities, including the benefits of drawing from interdisciplinary perspectives, underscoring its anticipatory nature in her role as a doctoral student:

> I think that… so far in research in academia in general, people are very focused on the attributes of each discipline…the focus has been so narrow. If you think about, for example, chemical engineering. Normally, when you think about chemical engineering, you think of the huge process plants…or something like that. There are newer applications for chemical engineering in the material sciences that are being explored but they are so heavily researched, they're kind of…maxing out, and there's less of an opportunity to really get your foot in the door there. Whereas, taking it from an interdisciplinary approach, you could kind of find that niche of where you can

> contribute to the research community. I've really been thinking a lot about what niche area I might be able to find.

In another illustration of anticipatory field-creation, Hannah at Valley was envisioning ways to create new spheres of inquiry at the intersection of wind energy and psychology. The potential to explore wind energy though a psychological perspective was illuminated through her connection to the IGERT, and she had begun to explore project and publication potential of this idea with an eye toward future research and career pathways. A strong public good orientation was also embedded in her depiction of anticipatory field-creation through her desire to elevate the perspectives and experiences of low-income residents in wind energy research:

> IGERT has definitely informed my interest in the offshore wind and renewable energy-related work, which I would have never considered before if it wasn't for IGERT, for sure. Just in reading the literature on offshore wind, I realized, like, not very many psychologists have kind of come in and said, "Hey, why don't you guys think about these things?" So, there's really not much research on these underlying, psychological kind of things that go into opinion information. So I was like, "Oh, social norms. That needs to be talked about." At the same time, I'm planning on writing a paper that's looking at low-income residents and their energy use and all these energy programs that haven't really engaged with them at all. But, I don't know how or if I'm going to pull this work into my dissertation yet.

On one hand, women were working at the intersection of fields/disciplines under the umbrella of their IGERT focus areas, all of which could be characterized as emerging interdisciplinary fields at the intersection of or on the margins of multiple disciplines. On the other hand, the women were generally not creating novel spheres of inquiry as part of their IGERT experiences. More accurately, women's narratives suggested that field-creation operated less as a mode of interdisciplinary practice, and more as the overarching goal of learning to become an interdisciplinary science person. Consequently, the learning opportunities the women were having across the other three modes of practice were laying the groundwork for future field-creation as they considered how to continue to develop and incorporate their broadened interdisciplinary perspectives and skills into innovative future research and career directions with a strong theme of facilitating interdisciplinary research application.

Findings presented in the next chapter will illustrate a connection between participants' interdisciplinary socialization experiences, which include the cross-fertilization, team-collaboration, and problem-orientation modes of practice, as well as the anticipatory goal of field-creation, to bring into focus a human dimension of the interdisciplinary socialization process visible in the ways in which participants negotiated and refined the process of becoming an interdisciplinary science person on a more experiential and epistemological level.

CHAPTER 5

THE EXPERIENTIAL-EPISTEMOLOGICAL DIMENSION OF INTERDISCIPLINARY SOCIALIZATION

Experiential-Epistemological Dimension of Interdisciplinary Socialization from the Express Standpoints of Women PhD Students

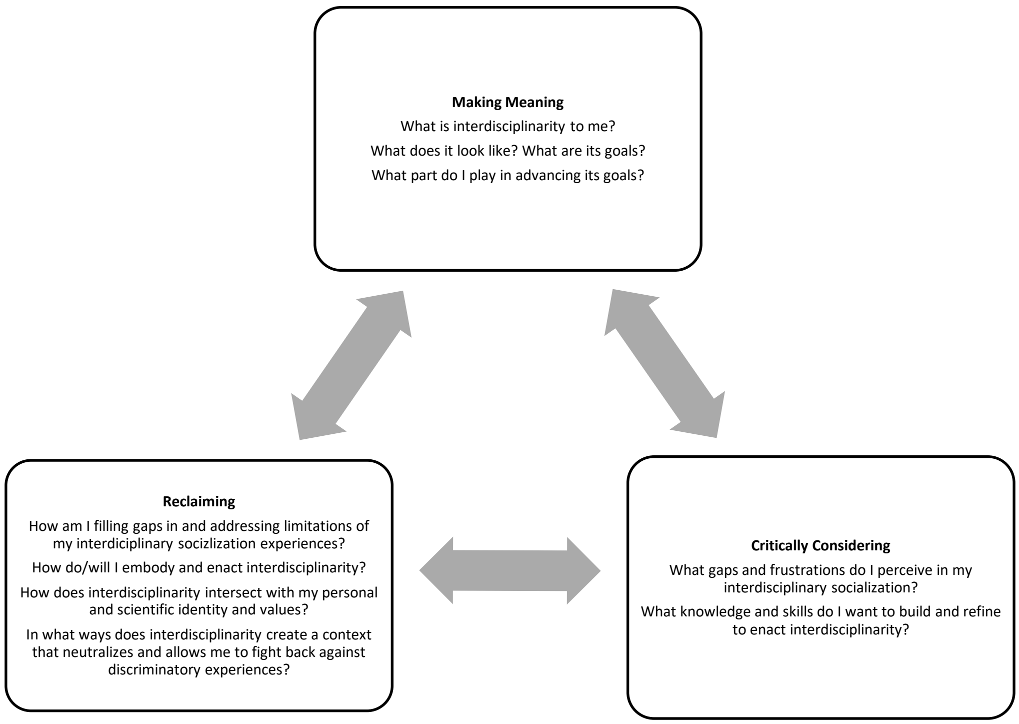
While Rhoten and Pfirman's (2007) modes of interdisciplinary practice framework is a valuable lens through which to better understand and categorize women doctoral students' interdisciplinary socialization experiences, the participants also described their interdisciplinary socialization experiences in more personal and human terms that overlapped with, but could not be fully captured by the framework. This chapter presents findings that point to another dimension of processing interdisciplinary socialization experiences that was prominently featured in the collection of narratives in this study. This other dimension of processing, which I refer to as the Experiential-Epistemological (EE) Dimension, operated as a dynamic, bi-directional space in which participants filtered their interdisciplinary socialization experiences through other aspects of self, identity, values, and aspirations.

The E-E Dimension was named such to illuminate a process through which women incorporated a set of interdisciplinary values and beliefs which, in addition to practices, comprise important components of socialization theory. For the women in my study, the E-E Dimension illuminated how norms, values, and beliefs about interdisciplinarity were gleaned, in part, through practice, or learning opportunities that allowed for women to practice cross-fertilization, team-collaboration, and problem-orientation and to envision field-creation opportunities. The influence of practice as a facilitator of women's formation and integration of interdisciplinary norms and values provides part of the rationale for the *experiential* aspect of the E-E Dimension. At the same time, women's processing of interdisciplinary socialization experiences through the E-E Dimension was highly *epistemological,* which was incorporated into its designation to reflect a very specific phenomenon: that women's processing of interdisciplinary socialization experiences in the E-E Dimension was causing them to reconsider *how they know what they know*.

The E-E Dimension represents the ways through which women processed and reflected upon new interdisciplinary contexts and experiences. This process of reflection resulted in epistemological growth as women transformed their epistemic views to include interdisciplinary justifications for what knowledge is and how it is acquired and produced. Experiential-epistemological dimension activity was also evident in the way interdisciplinarity extended to and encouraged an information exchange platform that raised awareness about discriminatory experiences. In this way, interdisciplinarity gave rise to novel understandings of women's own and others' experiences and provided women tools to take up the fight against discrimination. In addition, women's epistemological views of interdisciplinarity were expanded beyond their IGERT training contexts to incorporate a more critical awareness of deeply engrained structural and cultural forces instrumental in pushing women and people of color to the margins of disciplines, fields, and society.

The presence of the E-E Dimension illuminates the overarching question central to the experiences of the women in my study: What does it mean to be an interdisciplinary science person from the standpoint of women doctoral students? In the E-E Dimension, women were actively addressing this question by analyzing, interpreting, and integrating their interdisciplinary socialization experiences in a personal and epistemological way. The E-E Dimension also operated as a space through which women not only could process and assimilate, but also could reshape their interdisciplinary socialization in directions that made sense to them personally. The E-E Dimension was marked by three key and overlapping components: making meaning of interdisciplinary socialization, critically considering interdisciplinary socialization, and reclaiming interdisciplinary socialization (see Figure 2).

Figure 2. The Experiential-Epistemological Dimension in Interdisciplinary Doctoral Socialization



In the *meaning-making* process, women focused primarily on sorting through and making sense of pluralistic and complex conceptualizations of interdisciplinarity as they determined their own definitions of what interdisciplinarity - and the goals of interdisciplinarity - should be, both conceptually and personally. The process of *critically considering* was comprised of an ongoing evaluation of the quality of their formal interdisciplinary socialization experiences through which women identified frustrations and gaps. Finally, the collection of narratives highlighted a *reclaiming* process through which women actively bridged gaps in their interdisciplinary socialization in a variety of ways, and they explored and refined how they wished to embody and enact interdisciplinarity. In doing so, they considered epistemological questions such as: Who am I as a scientist, engineer, researcher? How does interdisciplinarity shift what I know about knowledge? How do I want to enact my interdisciplinary self and beliefs? Which parts of my background experiences and personal identity are important for me to incorporate into my interdisciplinary science perspective? In what ways does interdisciplinarity create a context that neutralizes and allows me to fight back against discriminatory experiences?

As women filtered their interdisciplinary socialization experiences through the E-E Dimension, expressions of interdisciplinary norms, values, and beliefs were significantly more visible than in the findings presented in chapter four, which focused more on illuminating interdisciplinary socialization practices as opposed to interdisciplinary norms, values, and beliefs. Specific interdisciplinary norms, values, and beliefs expressed by women in the E-E Dimension included:

- Communication – with each other and with audiences beyond academe,
- Collaboration – with each other and with audiences beyond academe,
- Application – through more traditional approaches of product/technology creation and by facilitating application through less traditional means of policy and public outreach/education,
- Working on problems deeply contextualized in societal concerns,
- Actively working to raise visibility about and fight back against multiple forms of discrimination, and

- Fusing self, identity, values, and "social location" with the practice of science.

These interdisciplinary norms, values, and beliefs will be illustrated through the findings presented throughout Chapter 5 and framed within the context of the E-E Dimension in the sections to follow.

Making Meaning of Interdisciplinarity

As women made meaning of interdisciplinarity as a concept and a practice through their interdisciplinary socialization experiences, their broader views of interdisciplinarity were coming into focus. In developing a broadened and personalized view of interdisciplinarity, the participants described an explosion of learning through which they made meaning of interdisciplinarity, clarified features and goals of interdisciplinary work, and identified knowledge and skills they desired to develop in order to become more interdisciplinary. Consistently, throughout the meaning-making process, study participants placed a high value on communicating with people from different disciplinary backgrounds and communities, within and outside of academe as the cornerstone of interdisciplinary learning, collaboration, problem-solving, and knowledge application. Through this process, communication became both the center of interdisciplinarity and the means to a broader understanding of interdisciplinarity. In addition, the women participating in this study defined application as the main goal of interdisciplinarity, describing their desires to leave lasting impact on society through their work.

Communicating as a Cornerstone of Interdisciplinarity

As part of making sense of interdisciplinarity, participants depicted a significant explosion of learning frequently facilitated through formal and informal interactions and perspective-sharing with peers, and to a lesser degree, with faculty and stakeholders from different disciplinary backgrounds and communities. This learning explosion resulted, in part, from opportunities for interdisciplinary socialization grounded in the cross-fertilization, problem-solving, and team-collaboration learning opportunities discussed in chapter four. However, study participants were also actively defining and, in some cases, thinking quite radically, about different ways of being an interdisciplinary science person and personally discerning what knowledge they wanted to build and refine to advance interdisciplinary knowledge and aspects of their personal identity.

The participants valued acts of communication that helped them formulate a broad view and personal vision for interdisciplinarity by expanding their interdisciplinary lenses and knowledge bases. They also valued communicating as part of an interdisciplinary skill set that they desired to build, nurture, and use to facilitate interdisciplinary knowledge production and application through both traditional and non-traditional routes. To the majority of the participants, communicating with individuals from other disciplines and communities was a major contributor to the learning explosions they described as they made sense of interdisciplinarity in the E-E Dimension. Lily from Coastal, for example, suggested the importance of communication as the “essence” of interdisciplinarity:

And interdisciplinary could be something as simple as bringing in people from different fields, but still operating individually. And some people would say that's multidisciplinary. There's like a whole spectrum…. But I think the essence of it is what's much more important. And that's the dialogue… perspective sharing, or perspective integration, or challenging and discomfort.

In a similar vein, several women described how interdisciplinary communication had sparked specific insights and behaviors that they were assimilating into their broadened visions for interdisciplinarity and how they desired to behave and communicate with others as interdisciplinary science people. Alysa from Suburban, a biology PhD student, described how informally communicating with peers from different disciplines in a shared IGERT office space enhanced her capacity to consider research ideas from new interdisciplinary angles, which was shaping her vision of future ways of working:

> Having the mixed office for us is probably the most profound part of my experience so far. I know on the fourth floor of the building where some of the other biology labs are, it's pretty much just biology. And now I can't even imagine working in that environment. Like I find it maddening, because even, like I'll talk to people and I know they're working on like superhydrophobic surfaces or something that's way over my head. I'm like, "Could I grow cells on that?" And then we'll have a really interesting conversation that I could never have had with just biologists.

As a result of communicating with peers across disciplines, Caroline from Suburban University referenced how she had become increasingly aware of differences between and among disciplinary cultures, including some unique methodological and language preferences. Especially interesting to her was recognizing the detached nature of communication in engineering compared to the more personal and inclusive communication approaches used in biology. Through these insights, she was also able to consider what these distinct disciplinary communication styles signaled to her as an interdisciplinary scientist in terms of her own scientific communication preferences:

> Engineers and biologists talk so differently. It's wild. I had no idea. Because when I first started doing biology, I'm like, "Wow. I can talk like a person?" Engineering is the toughest -- I don't know, they like to use big words that no one else really knows (laughter). And they also talk -- in their papers they write them in the, I guess, passive. Like, "The study was performed." Is the way that engineers like to write. And biologists say, "We did the study." It's very interesting to like switch between those. It almost feels like two different languages. I would never say, "I did this" in an engineering paper. But biologists now -- moving on to talking like that -- like a person.

Communicating in such ways was highlighted by participants as a cornerstone to ultimately viewing a complex problem widely and deeply enough to be able to organize an interdisciplinary research initiative around it and envision traditional and non-traditional pathways to interdisciplinary knowledge application. Women's focus on communication also underscored a more human element of interdisciplinary learning and problem-solving that could emerge from simply talking and listening to one another. Meera, from Valley, illuminated the importance of communication with interdisciplinary peers in gaining an expanded scope of a complex research problem as she recounted how dialogues and discussions have played out as part of her interdisciplinary socialization experiences and opened possibilities for interdisciplinary learning and future collaborations:

> We have to come up with a bunch of steps to get to that solution and when I don't know the step, I have to go ask somebody if they know the step. And then I have to go ask somebody else, and I have to ask somebody else, and then knowing a bunch of people will help me find all these steps. And I think that's like probably the good part about the interdisciplinary part of IGERT because seeing other people's research, I was really able to see how different people work together to make it all work.

Expanding on how her interdisciplinary perspective was broadened through presenting in poster sessions, Meera also was recognizing potential future interdisciplinary collaborations:

> Because before, you're just like, "Okay, to get offshore wind, we just need to look at how to integrate it." Like, that's how I felt. We just need to look at how to integrate it so that the power grid can work, but then that wouldn't necessarily work because then the eco people get upset that the birds are getting killed. And you're just like…Yeah, and the bats, yeah. And then you're like, okay. So then you need people working on that, and then you need people working on the policy side, and with all the people doing the policy and making sure the grid's okay, making sure the birds are okay, and the sharks are okay, and the seals are okay, then it will work. And so I just love working with people and talking to people about it.

Keelin, a chemistry doctoral student from Coastal, also depicted the value of engaging in disciplinary knowledge exchange through communication with peers and faculty in her interdisciplinary training and how this increased learning, engendered empathy, and ultimately eased the path to successful collaboration:

> I think the idea here is that they're trying to train people to not compete with your colleagues but to actually understand where they're coming from. It's like if you're from biochemistry, you would understand biology as well. You may not be an expert in it but at least you'd understand what the biologist is feeling and thinking and so I think that's been interesting because I didn't know that I would be trained in thinking like a social scientist, I -- you know, my one psych was Psych 101. So, I think that's been new. It doesn't by any means make me an expert in any of the fields or make any of us experts in anyone else's field, but I think it gives us the ability to realize where other people are coming from and I think it just makes us good collaborators…like, you don't have to get over the hurdles of understanding the core of a discipline.

Furthering Knowledge Application as a Goal of Interdisciplinarity

Through the E-E Dimension, participants were filtering their interdisciplinary socialization experiences in a way that helped them make meaning of interdisciplinarity with respect to clarifying its goals. In this view, women envisioned the goals of interdisciplinarity as facilitating interdisciplinary applications through traditional pathways of product and technology creation, but they also envisioned various non-traditional pathways of interdisciplinary knowledge application through policy and public outreach work**.** As an example of the former, Amaia, a biomedical engineering PhD student from Suburban University, was envisioning how interdisciplinary approaches, perspectives, and skills could facilitate multiple pathways for application of interdisciplinary knowledge in more than one field:

> I feel like interdisciplinary, to me, it has to be more than just combining knowledge of the fields, it has to be combining application as well. Because a lot of projects, I would call them interdisciplinary. Like you're making a robot, you have the robotics aspect, you have the coding aspect, if you're making it for a biological caterpillar then you have the bio aspect, and I get how that's interdisciplinary, like foundationally and knowledge base-wise. But for something to be interdisciplinary for me, I think it has to be able to apply to a bunch of different fields. You have that robot, you can apply it to understanding how animals move, that's a biology aspect. You can apply it to enhancing artificial intelligence code, that's a totally different thing, or you can create some sort of new mechanical apparatus that changes the way movement is described or something like that. I would say, for something to be interdisciplinary of value, you have to be able to envision it in multiple ways, not just gather information from multiple areas, I think. And that is what can make something from being a base product to being something that's paradigm-shifting, or something that you can really envision in lots of different fields.

Women specifically underscored policy work and educational outreach work as important and intersecting avenues to facilitate interdisciplinary applications and as desired enactments of their interdisciplinary knowledge and skill-building. In doing so, they often assigned significant value to gaining fluency in theories and skills situated in predominantly social science fields that would help them reach across disciplines and communicate with a wide swath of academic and non-academic stakeholders to achieve a variety of interdisciplinary goals. Maggie from Coastal University described both her desire to do interdisciplinary research and be the one to apply it. To achieve this goal, she articulated her desire to expand her scope of knowledge and skills beyond her core discipline in a way that allowed her to become more interdisciplinary as a scientist and to use her expanded interdisciplinary knowledge and skills to collaborate with the broader community and to foster interdisciplinary discoveries through policy:

> So, there might be times when I have to wait years and years and years for anything to be done with my data and…depending on what you're working on, that's just how that would go. But at the end of the day, I want my data to be applied. And I want to be the one to understand how it can be applied. Because one thing that I think is that it's often left out of the literature, especially in the topic that I'm investigating is they call for policies and they call for economic analysis, but that never happens in the same space in the same dialogue as that particular research and that particular question. And I think that it would be so much more beneficial if even it could just be

> explored a little bit. And so, I want to be able to understand that, but also understand my own limitations, right?

Maggie underscored the importance of interdisciplinarity in the way she envisioned herself as a multi-faceted researcher, stakeholder communicator, and facilitator of applications:

> So, if it comes down to where this could be really effective for generating a policy even at a municipal level, then knowing that I need to reach out to municipal leaders and then they take it from there, right? Just knowing that that connection needs to happen and me being able to make that connection is where I want to be. I want to be able to have those intelligent conversations with the lawyers, with the economists, and all stemming from the Excel spreadsheet that has my data in it, you know? So, I see myself within that space.

Maggie, like other women in my study, was making meaning of interdisciplinarity in ways that allowed her to envision both traditional and non-traditional ways of facilitating the application of interdisciplinary knowledge through policy work, scientific communication, and public education/outreach, while she actively considered what future role she could play in such work. In a similar way, Karina at Valley University was making meaning about how she might like to inspire interdisciplinary applications by placing herself at the "nexus between science and policy":

> I really like that nexus between science and policy, and I like the fact that I can understand science and I can read something and distill it and give a policy recommendation.….I still have this idealistic goal of having some sort of practical

outcome to my dissertation that can be applied in the regulatory process, so that there is some incremental improvement in it. So, I think always striving to make a small change, just a small, little one. If even to raise the questions amongst people and saying, “Hey, is how we’re doing it really the right way and can we think about doing it a different way?” So, even if…through going to workshops and conferences so that we can bring that question up, and challenge people to start thinking about it in a different way, then that’s my goal.

Similarly, as Alysa from Suburban made meaning of the goals of interdisciplinarity, she illuminated the dual importance of building an interdisciplinary knowledge base and using that perspective to communicate more pure scientific research in ways that could make science more accessible to the broader public and break down trust barriers between science and society:

> I feel like both that kind of fundamental search for understanding is my personal abstract goal for the science I do. But I also think it’s really important that it informs the society at large. So, it’s kind of a double bind for me because I’m most interested in really basic research, which isn’t inherently or immediately applicable to something like medicine. But I also feel like it’s important that we take those basic science findings and communicate them in whatever ways we can so that people feel less scared of science. Because my feeling, at least with the groups that I’ve interacted with outside of academia, is that even where findings aren’t... wouldn’t

> have the capability to immediately damage anyone, people feel very skeptical and very nervous about them. And I would like to see that communication gap lessened.

Alysa elaborated further on how interdisciplinarity, for her, included gaining systems-level fluency in how disciplines work together on complex problems, so that she can increase public understanding of how science considers and addresses interdisciplinary problems for the good of society:

> I feel like the breadth of skills that it makes available to me is one of the most important things…because, I mean, it's wonderful to be a good biologist, but good biologists don't perform useful outreach. I feel like the more fields that you have even basic understanding of, the better you can draw connections for people, the more interesting and engaging you can make it. Because if you're not a scientist, I mean, you certainly don't want to hear about trinucleotide repeats and why that research is important. You want to hear about why different fields are interesting as wholes, or like how they can connect to one another to help society at large.

Emily, a marine science and technology PhD student from Coastal University, also described how communicating science to the public is beneficial and personally important to her as a way of being an interdisciplinary scientist and engaging in interdisciplinary knowledge creation:

> And so when it comes for me to what kind of ideals and values I have, it's, man, wanting to make sure that I can share what I'm doing to most any audience I encounter…because people tell you all the time, if you can't explain to your grandma,

> you're not doing it right….So, like, that is such an important part about science to me, the passion and curiosity when you're on the water or engaging with code and being creative is so important. But, I think one of those higher values I have is just making sure I can share it.

Julia, a mechanical engineering PhD student from Valley University, similarly articulated a desire to expand and activate her interdisciplinary knowledge base in a way that assisted in contextualizing, interpreting, and communicating the technical aspects of alternative energy to broader academic and non-academic audiences in an effort to facilitate adoption and application of scientific advancements in this interdisciplinary field:

> …really the conversations I want to be having about wind energy are the interdisciplinary aspects of it, in that I enjoy math and I just spent five years writing math lab code to get a piece of paper that says I can do math. But really, I want to be engaging in the political, sociopolitical sides of that dialogue, and I think those are far more important actually than making a wind turbine a little bit lighter, a little bit cheaper, or whatever. Like the things we think about in strictly the technical realm.

By making meaning in the E-E Dimension, Amaia from Suburban was envisioning interdisciplinary career avenues that can influence science policy and foster the inclusion and advancement of more people of color in the sciences:

> I was a little bit interested in forming how laws are made…But I don't know if that's going to be a next step. That's kind of like a long-term career goal that I think I'd be remiss if I didn't at least try to get my foot in. But maybe like influencing government

> from the inside, with the scientific perspective…And then on the same side of that, like NGOs, one of my friends is doing a diversified scholar initiative, trying to involve minorities in the sciences and things like that. He's a professor but he's also doing that on the side, that I think is really a good thing to do. I'd be interested in something like that. About "Yeah, I have a career," but you have a tangible way of giving back and helping other people into the pipeline. Interested in that.

Critically Considering Interdisciplinary Socialization

As part of the E-E Dimension, participants also engaged in a process of critically considering their own interdisciplinary socialization experiences. By critically considering, women were identifying gaps and frustrations in their interdisciplinary socialization experiences and weighing their own strengths and weaknesses in the context of interdisciplinarity. Women's narratives highlighted a number of specific, and sometimes overlapping, issues and dynamics that they identified as incongruent with their training expectations and personal conceptualizations of interdisciplinarity. While the frustrations and gaps depicted were specific to each individual woman's experience and shaped by the unique IGERT context in which the women operated, many similar themes were present across the categories of frustrations articulated. In most cases, women's frustrations were directly tied to instances where they believed their opportunities for interdisciplinary learning and communication were minimized or obstructed. More specifically, these forms of learning and communication were hindered at times by issues of program design and administration. They also addressed frustrations arising as a result of biases or uneven representation of disciplines in the overall interdisciplinary socialization experience. Interdisciplinary socialization frustrations around access to and clarity about IGERT and entrepreneurial funding initiatives were also described by participants.

Program Design and Administration

A variety of the gaps and frustrations expressed by the participants could be categorized as issues of program design and administration. In one set of examples, Coastal women criticized their IGERT program's focus on distinguishing between interdisciplinary and transdisciplinary research, a process that they believe took time away from valuable peer- and course-based knowledge exchange. In their view, oversaturation in this theoretical debate and quibbling about terminology was counterproductive to moving ahead with the immediate needs of the interdisciplinary research projects in which they were involved and the multi-stakeholder collaboration, diplomacy, and problem-solving these required. Chelsea acknowledged this frustration as unique to Coastal, specifically noting how it detracted from the problem-orientation and team-collaboration modes of interdisciplinary practice:

> I know everyone gets very frustrated by it, and I kind of do too in a certain extent. But I just think we waste too much time trying to define it and not realizing that each person might have a slightly different definition associated with it. But when I think of transdisciplinary, I think of it more in terms of solving a problem. When I think of transdisciplinarity, it's, I look at it problem-based and not just like an overarching definition, I guess.

Megan, one of the few Coastal social sciences IGERT fellows, further documented the common frustration with these recurring, circular, and time-consuming debates, characterizing them as both a program design issue and counterproductive to fostering real-world interdisciplinary communication and collaboration:

> Literally, they gave out a worksheet during -- right after boot camp, there was a little getaway just for the 2016 cohort, and they gave out a worksheet about what transdisciplinary was with all these definitions from science-y places…And then, the first day of class, the professor takes out the same worksheet, and we do the same exact activity, like, talking in groups of three, and I'm just like, "Oh, my goodness." So from my perspective, you know, academia is great for some things, but my personal approach is, "I think we need to spend less time talking about the same things over and over and more time pursuing and doing things." So, I mean, I think the general consensus among my cohort is, "Let's stop trying to define 'transdisciplinary' and just do it." Let's all just work together instead of being like, "What's the difference between 'transdisciplinary' and 'interdisciplinary' and 'multidisciplinary?'" And now I'm like, "Oh, interdisciplinary," and I'm like, "Oh, let me correct myself: transdisciplinary." And people are like, "Is there a difference?" And I'm like, "No, there's no difference."

Megan concluded with describing her own take on what she considered the key part of the definition: "Oh, my goodness, why does it matter? You're trying to get people from a bunch of different fields to collaborate. Great. That should be the end of the definition. And I think this semester we've kind of buried it because we don't want to talk about it anymore."

At Valley, women pointed to a lack of formal and informal opportunities to meet and interact with peers, especially from cohorts other than their own, as a program design and administration gap. Karina depicted how her frustration in this vein overlapped with her perceptions of shortcomings in IGERT program design and administration:

> I thought that would look like, not only having the weekly seminar talks, but maybe having more informal discussion groups. Maybe having a little bit more guidance from professors on where they saw overlaps happening, because the program is like a five or six or seven year program. And so, you tend to only get to know the people in your own year group. They have the oversight on pulling these people from the different year cohorts, and seeing those different research questions and things. And so, I thought there would just be a little bit more central guidance coming from there.

Hannah at Valley expressed similar regret when opportunities to meet fellows in other cohorts for comradery and potential research collaboration were lost which, as a member of the final IGERT cohort, was particularly salient for her:

> …it's hard when people are starting to graduate too. It's like, "Oh. I would have loved to do something with them, but they're gone now. They're, you know, not even in the program." So, it's kind of a weird dynamic for now, but I don't know.

Karina described program design and focus issues that negatively impacted problem-orientation and team-collaboration learning opportunities. For her, this was tied specifically to a mismatch with how she expected the IGERT program to orient to a vast interdisciplinary research problem like wind energy and collaborate to address the problem:

> I was really hopeful that this IGERT would produce collaboration in the PhD program that I hoped I'd had before, so. It turns out it was like my master's…at least in my case, it was quite, again, self-motivated….I had really thought with this group of 25, we were going to have this one core question and we were each going to come at it from a different direction to find an answer. And it really wasn't that. It was some students did hook onto a professor's research, and some students were just like, flailing and trying to find their own path. Still, and I think my expectations with IGERT, with that interdisciplinary type of research, really weren't met. Especially coming from an interdisciplinary background. I have an engineering undergrad, I have a policy master's, and I was trying to get an ecology PhD so that I would feel well-rounded when I wanted to present myself to the workforce.

Karina reiterated more specifically how she thought she would be interacting with the interdisciplinary wind problem and collaborating with others in the IGERT:

> Yes, the expectation, I had thought, again, that we would have this common problem. But that from different backgrounds we would have different ways of approaching it, and maybe not just solve the exact same question, but the overriding question. Maybe in our case, why isn't offshore wind energy more advanced in the US? Europe has had it for 25 years. The US just installed their first five turbines this year. Why? What are the engineering challenges? What are the financial challenges? What are the environmental challenges, and how can we chip away at those challenges to accelerate the program? And that's how I had thought it would be.

Abby at Coastal who was a member of the inaugural IGERT cohort, expressed frustration about general lack of clarity around program elements and expectations:

> The caveat for this whole thing is that I was the first cohort, so there is a lot of stumbling and stammering around, and a lot of people not knowing what they expected, people not knowing how to structure this in a great way. I would say I didn't receive a lot of training specifically, and I think most of my cohort members would agree with that, during our structured training time. It's additional -- let's see. What were the requirements? It's courses over the first two years, and you are put together, I guess.

Similarly, Menaka from Suburban was frustrated by her program's lack of attention to cross-fertilization learning opportunities from outsiders who could facilitate an exploration of future career possibilities in her IGERT seminar series, although she attempted to glean this on her own:

> We haven't really had any events where we get to meet industry professionals or professors besides the boot camp. So, we had two visiting lecturers come from MIT and Harvard, and they explained their research and stuff. But we were only talking about their research, we weren't talking about their experience as a professor or a post-doc. And so, yeah, they haven't really put on any events to kind of push that in either way…. I think the IGERT program, the nature of it is so broad. So, the people that organize it can kind of pick the pieces that they want and develop it in their own way. But I think that would have been a good experience, to not just talk about

research but talk about how they feel about their careers and stuff like that. So, I try to ask when I interact with the industry professionals that come or any new post-docs that I meet, I try to have some sort of conversation to see how they feel about things. Because, I mean, I think that for the most part everyone convinces you that what they've done is the best way to do things.

Biased and Inconsistent Representation of Disciplines

A number of women described significant frustration around the marginalization and inconsistent representation of certain disciplines over others as a problematic feature of the IGERT experience. Lily from Coastal, an IGERT trainee coming from a social science disciplinary background, was consistently frustrated by a lack of depth and myopic representation of the social sciences by IGERT faculty, which she believed greatly hindered both her and her peers' opportunity for interdisciplinary knowledge acquisition and placed a unique burden on her to act as a disciplinary voice on behalf of the social sciences in an effort to bridge the interdisciplinary learning gap:

> …there was this kind of big social science-shaped gap in the teaching of the coasts and communities classes -- those four of us, at least in my year, who had social science training…would speak up when something was being said that didn't really resonate or didn't really fit that…The problem is the perspective of the primary instructor, was that social science is policy. And really, it's just about persuading people to think what you want to do. It's like, how do you get somebody to think like you? And we really resented being just lumped into, these are the policy people.

> Yeah. And definitely listening to people and having a social science like qualitative conversation is not about, how can I hear what you have to say so that I can then persuade you? That wasn't quite understood.

Lily further explained her frustration around feeling that she and the social sciences disciplinary perspective were marginalized in the IGERT experience and steps she and her social sciences peers felt compelled to take to combat disciplinary tensions within the IGERT space:

> And because there is that faculty gap, we felt like we had to fill that gap so that -- me, I'm speaking for myself. I felt like what I started doing in that class was when I would ask questions, it was not because I didn't know the answer. It was because I want the question to be out there for everybody else in that class, to hear like, oh. Because I knew the background that they were coming from, and I knew that that type of question was not normally asked in those spaces. So I started asking questions that I knew the answers to, just to fill that gap. And that created really weird power tension, where the student would have more knowledge in certain areas than the professor. And that is an essence of interdisciplinarity, but if you don't -- that's why I saw power sharing as so important. If you don't fill that knowledge gap with other faculty, the students that have that knowledge have to kind of feel, feel like they have to fill that gap. And then that messes up the whole classroom dynamic of teacher student. And if you don't have a teacher that is comfortable with that kind of power sharing...That's what I guess has been really disappointing.

Martha, a social sciences PhD student and IGERT fellow at Coastal, described similar frustrations. In doing so, she underscored the immense value of interacting and learning from other IGERT fellows, while articulating other instances of disappointment with program design and faculty interactions especially related to the presentation of social science perspectives:

> I think that the IGERT experience has been way below expectations, from what they have promised. And I think because I focused on what they promised, I've been so disappointed because they really have not provided us with the education that they promised. But what I think that I didn't focus too much in the beginning, and which turned out to be the best part of the IGERT is, the interaction with the other fellows. So, for me, the biggest part of being an IGERT fellow is that I interact with other fellows. The professors don't add much to my education. The classes don't add much. The courses, the assignments, all the crap that we need to do for the program -- that's just a filler. So, one of the biggest problems is that the professors think that they understand social sciences, but they really don't. They really don't. And how can you tell somebody that they don't know something, if they tell you that they do, and they want to teach it to you, you know?

Similar to Lily, Martha also expressed deeper and more specific frustrations with the disciplinary marginalization she was experiencing in the IGERT, but underscored a highly positive interdisciplinary socialization experience happening among IGERT peers, despite perceived faculty and course shortcomings:

> So those of us who understand social sciences and understand how problems are conceptualized differently and how we can frame one problem in different ways, and the way we frame it matters, we understand that. And we feel completely voiceless and powerless, because…Believe me, we tried. We've tried to get the professors to understand the way that we've viewed the world, but they don't understand that we view it differently. They think that we view it wrong. And that's problematic, you know? The other students, they agree. They know. They understand what we're doing. There's many other peers stationed in the hard sciences, if you will -- biologists, and marine ocean scientists, and they come to us and they say, "How do you work? What does your research look like? What's research to you?" And working with them has been the most powerful, transformational, inspirational thing. The fellows. But this is like -- it's a side thing. It's like a consequence of the program. The program is like the classes and the assignments, and the projects and the clinic. And it's all garbage. It's completely BS. The students are great. So I've been learning a lot by working with them, and I think that they are learning from us who are not scientists. But the professors -- they're hopeless.

In a similar vein, Karina from Valley described her frustration with interdisciplinary perspective tensions between "the engineers and the ecologists" in her IGERT, especially regarding how two engineering professors interacted with ecology faculty and students around wind energy topics and discussions, which also highlighted some gender tensions:

> Two of the professors in mechanical engineering are kind of older gentlemen who founded the wind energy center at [Valley]. Which is founded in a terrestrial realm back in the ‘70s, and they’re kind of -- they’re just, they’re old engineers. And we, when the ecologists would present on, say, hotspots for ecology where wind turbines shouldn’t be, they would just give all these excuses and theories of, “Well if it’s a hotspot, then you should actually build there so that you can protect.” Like, just these wacky counter arguments that we would shake our heads as we’d walk out of the seminar. The last time it happened, thankfully, was with a male ecology student who presented. I say thankfully because they were rather, I don’t want to say sexist, but they were, they were from an old school…

Funding

Several women pointed to lack of clarity about or access to opportunities for funding to support individual and collaborative research and conference travel. For example, Hannah from Valley University described times where expectations were not clear regarding her IGERT involvement, research outcomes, and funding:

> I’ve heard from other students, like, interdisciplinarity is supposed to be a required part of your dissertation. I’m like, “Oh. I don’t think I was informed about that.” There’s a lot of stuff coming at the end that people just did not tell me about. They’re like, “We told everybody else, therefore you should know by association,” yeah. I’m like, figuring out all these -- like, getting funding was totally difficult because nobody told me I had to push a certain button in a certain program to make my funds go

through. So I was sitting there for like two months, "Am I going to get paid?" Like, I need a paycheck, please. Yeah. So just stuff like that where I'm like, "All right." I don't think people care as much about talking to each other about you know -- at least administratively, that's been an issue.

Lily at Coastal expressly pointed to a lack of transparency and communication from IGERT administrators regarding funding for conference and research travel:

> The whole first year…in IGERT, especially [IGERT peer name deleted], kept asking, can we get in writing what is available for us to do these things, to do work, to go to conferences? What is available? It was not really explicitly described until the end of last year. So, we finally found out, that funds are available. And if you frame it properly that shows it's transdisciplinary and if you're presenting in a conference, there's some money available to do that. If you're trying to work on a project, there's some money available. So, I might try to use some of that to do a pilot study in West Africa or something like that. Now that they finally explained it, it's very well. The problem is, it was not fully available to us, because we didn't have the details on it.

Receiving monetary prizes by winning IGERT-based design competitions, a unique feature of the Suburban IGERT, disadvantaged students in the earlier phases of their doctoral programs and IGERT experiences, which Menaka underscored in describing her first encounter with these competitions:

> Every year they have an innovation competition which is, I believe, the prize is $30K and it's only eligible for IGERT students. So, it's a very small pool with a fairly large

> prize award…I wasn't able to do it this time because I didn't have an idea and they were fairly far along in the process by the time I came, but hopefully, they'll have it in the years to come. Then I'll try and capitalize on that. Yeah, that would be really cool.

Alysa also exhibited some lack of clarity about how these competitions at the Suburban IGERT contributed to her overall funding opportunity as an IGERT fellow:

> I know that the theory, at least this year, was that they were giving you money that you could invest into your research or into actually starting a business idea. I have no idea if it was earmarked in any particular way.

In a slightly different view of funding concerns, the Suburban IGERT focused a portion of the weekly seminar series and innovation clinics on entrepreneurship, technology transfer, and creating a business, which Amaia considered a point of frustration related to the realities of funding such initiatives:

> We had meetings on how to create a business from zero. I remember that meeting because I think I had a low opinion of the guy, because he was just explaining how you get your foot off the ground, and your network and stuff like that. To start your business, you needed a few million and blah blah blah, and I'm like, "Okay, but how do you get the few million?" And he was like, "Oh you just, you know, your network and your parents and your friends," and I'm like, "I come from the middle of nowhere, I struggled to go to university, I put myself through loans, I put myself in debt, who is everyone around me that could pay for that out of their pocket?" And the

> answer is a lot of people, and they have people that they know, that have money to give to you. Like, oh my God. I don't have that network, that I feel like really blocks people from starting. Because you have all these people that maybe do have that, and then they can get started and they can play around with your friends' millions of dollars, and I'm like, "Okay, I just," I block out from listening because I can't relate, and I just don't see myself being like that.

Reclaiming Interdisciplinary Socialization

Reclaiming interdisciplinary socialization was another clear element of the E-E Dimension for my study participants. In the reclaiming process, women were formulating goals for their interdisciplinary socialization and incorporating new or reaffirming existing pathways to expand and enhance it in ways that made the most personal and epistemological sense for each individual. Several women in my study reclaimed interdisciplinary socialization by connecting to experiences that offered varied and deep interdisciplinary knowledge- and skill-building opportunities that the IGERT did not. In some cases, these were outside activities in which women were already involved despite messages to focus solely on the PhD experience. In other cases, reclaiming resulted in women orchestrating new participation in both university-based and outside activities to fill perceived socialization gaps and support their own personal vision for their holistic interdisciplinary socialization. As part of the reclaiming process, many participants found it important to connect how they wished to behave as interdisciplinary science people with work that supported the participation and advancement of women and, to some extent, people of color in STEM and society.

Reclaiming by Adapting IGERT Structures

A number of women discussed instances in which they, individually and with peers, were able to adapt formal structures and experiences within their IGERT to address interdisciplinary socialization gaps they had identified. For example, Coastal women recounted a number of ways they took initiative in bringing interdisciplinary topics and experiences to the weekly seminar series. In fact, they played a significant role in choosing and often fully coordinating seminar formats, topics, and visiting presenters. Abby, who was a member of the inaugural IGERT cohort at Coastal, explained how she and her cohort peers took charge of their seminar experience after a period of time and how reclaiming this structure both addressed knowledge gaps and enhanced their interdisciplinary socialization:

> At some point, we kind of hijacked the seminar a couple semesters in and turned it into a place to workshop our dissertations to one another. That was super valuable. I would, for example, during that time -- you'd rotate, and I would make a five to ten minute presentation about the theory behind my work, what I'm trying to do, how I'm trying to do it, and just try to present it to a room full of people who maybe don't know anything about biology, maybe. Maybe they haven't had it in a long time. And trying to communicate with them and express to them that I'm still doing something academic and valuable -- I think that was super helpful, to be able to change your language a little bit. So we did that. And then to get feedback from people based on

how they heard you, how they understood what you were doing, something they might suggest that's an interesting idea that goes with your research, something that you might look into a little bit more. That was the basis of us learning how to talk to one another.

Abby talked more about other types of collaborations and initiatives that resulted from students' driving a change in the seminar experience and the overall sense of trust that was engendered among IGERT peers:

> Then after that, I think there have been a few people who've written grants together, grant proposals, and stuff like that, and I think that beginning conversation that I had during the seminars was really instrumental in -- I guess kind of establishing like, okay, well, I know science stuff, so you can trust me. It helped us trust each other. I know the science stuff, and you know this business stuff, so let's see if we can just spitball some ideas and come up with something that would be a cool idea. I think several people did write grant proposals to pursue that. I know our lab did. We're not funded, but we wrote a proposal with two of the other students in biology. Our advisors did, so we didn't spend a ton of time on the actual meat, but it was IGERT that brought us together and said, oh, we have some similar stuff that we're interested in, and I think this would be interesting to explore.

Several cohorts later, Lily from Coastal described a similar student-led seminar experience she and her IGERT peer, Martha, designed to actively identify and value the disciplinary and personal skills each individual IGERT peer brought to the table, because they felt the disciplinary knowledge and experiences of IGERT students were often ignored or devalued by program faculty:

> So, Martha and I actually -- this last year -- took the initiative to have a seminar program where we mapped the skills of the peers in the room, because this is a program about interdisciplinarity. We all bring something. And we did that. We just created like, what do you want to know, and what do you bring to the table? And how can we match these, these skills sets? Like if somebody really wants to know how to do R, we have an expert in R. There we go. And that would also help us steer the goals for that IGERT, if we know, what do you people really want to get out of this? What do you want to know? But we did that on our own…And we were able to, to actually operationalize some of that. But it just tells me something like -- that we had to do that on our own initiative. We invited our professors in to talk about it. And it was supported by the faculty….with minor resistance…but that's how we tried to fill the gaps.

Martha, from Coastal, described another time when she and her IGERT peer, Lily, helped bring in an outside professor for a seminar talk about transdisciplinary research methods:

> A lot of people were like, well, no, what is this, what is this transdisciplinary? What is this? Lily and I actually took a transdisciplinary methods class outside of this, and we brought the professor in to speak to everybody. Because we're like, hey, there's somebody who actually does this stuff. Let's put you in here. We've actively tried to

> bring in as much as we could to people…we started trying to take our own initiative to fill those gaps in different ways through workshops and things like that.

At Valley, one IGERT cohort collaborated to adapt the common coursework by creating an online course option that would be more accessible to IGERT students who wished for an alternative to the common engineering course and to provide coursework options for students across all IGERT cohorts, including IGERT-affiliated students who might be traveling for research purposes or otherwise not physically present on campus. Karina described how she perceived the benefits of this as an IGERT student who was also a mother to several young children and had relocated to a different state with her spouse and children:

> I don't know if this is unique to my situation. But my cohort, they decided to make the engineering class optional -- and we created an online fundamentals of wind energy alternative. It was then later taught to other people as an extension course. So we didn't have to sit in with the engineering class, with all of those people….I appreciated the flexibility, and I think it was wonderful for me at the time, given my life situation.

Reclaiming by Engaging in Outside Interdisciplinary Experiences

Some participants elected to maintain former or seek new involvement in interdisciplinary knowledge- and skill- building initiatives outside of the IGERT experience in response to gaps they perceived in their interdisciplinary socialization and in spite of both overt and subtle messages to abandon such initiatives during their PhD years. Maggie from

Coastal adamantly chose to keep working in a scaled-back version of her full-time job several states away from her PhD institution and explained how it factored into a more comprehensive interdisciplinary socialization experience:

> I currently coordinate and lead a working group throughout Region 2 for EPA. And that's, again, specific to micro plastics, but involves NGOs, politicians, business-minded folks, academics. All of them are part of this dialogue and I have to understand "Why is this important to you and how can I get you to participate? Because you're interested in this. We need to make you even more interested to do something," right? So, just working with stakeholders is something I enjoy doing. It's challenging, though, right? And it can get very monotonous at times. I think why I've been successful in that most recent thing [innovation clinic] that I was describing is that I take the time every maybe six months or so to individually email every single person and be like, "Hey. How are you doing? And what are you looking to get out of this working group?" How can we frame these types of things so that I can learn a little bit more about what their interests are and go from there.

Several other women described ways in which they took on additional roles at their PhD institutions and how these roles integrated with their interdisciplinary perspective and ongoing socialization. Julia at Valley felt it was important to take on an advocacy role as the organizer of Valley's Graduate Union with a specific emphasis on supporting women in STEM. Some of her impetus for doing this stemmed from her rocky and isolating first year as a PhD student at Valley, when she seriously considered quitting her program. Becoming an IGERT fellow in her second year offered community and inclusivity and gave her a reason to stay. Based on her experience and her identity of “not being like a super cisgender straight presenting person,” she felt she had something to give back to other graduate students:

> Getting the IGERT funding for my second year helped me stay at a point where I was really split about staying in or leaving graduate school. And my first year, I was sort of like on the periphery of the IGERT, and then I was -- it was the first year of the program. I saw that this community thing existed, but I was sort of on the periphery of it. And I would go to a lot of events and stuff because a lot of that stuff was open to the public, but getting invited into that community in a more explicit way was really important to me staying -- probably the main reason I stayed. And so I have built some community within the IGERT, and for the first time, I was talking to other women scientists for example. And so for the first time, that was happening a little bit more. And the IGERT community -- part of it being cross-disciplinary and part of it just being across different lab groups.

Julia talked more about how her feelings of not belonging or having community in her early pre-IGERT PhD experience made her consider the gendered aspects of her experience and impacted how she wished to behave as an interdisciplinary science person in terms of being welcoming and inclusive:

> Some sort of honest dialogue with somebody who is in my position now as I was entering first year probably would’ve been helpful for grounding perspective about

what it was even going to be like. You know, if one of the guys in my lab that's sort of more in the in crowd had said, "You can come to this thing if you want" once, that would've made such a big difference to me, I think. So, I try to be more conscious of inviting people in whatever way. That doesn't always look like "Come to this party," but inviting people in in sort of a broad sense. I think women in particular -- we do -- it's sort of this like, "Well, something's not going right. I'm clearly doing something wrong." I hear so many -- I mean, especially in my organizing role with GU, I'm doing a lot of advocacy work. I'm just having a lot of conversations with women. So, maybe it's something particular to women in STEM? I don't know. But when we have experiences of gender, there's so much self-blame that happens in that. In so many ways, I want to say, "This is not your fault." I also want to sort of say, "This is not your fault…your first year is really hard. It's not because of something you're doing or not doing. It's just because it's hard and that's how this goes."

In a similar vein, Caroline at Suburban talked about how her involvement in the graduate student government expanded her understanding of how graduate programs across different disciplines operate and how graduate student experiences and funding across STEM and non-STEM disciplines differ:

Like the graduate government is actually pretty useful…it makes you meet people not in your department, which if you're not in IGERT is impossible to do. Like there's no way you can meet people that aren't in your department unless you are in IGERT or the graduate government. They don't make it easy. So, I would recommend that, because it shows that your world is not just your tiny lab. There's other people out there. Yeah, even if you're doing an interdisciplinary project, there's no way you're also meeting -- if you're in STEM -- there's no way you're meeting an English major or history major. But if you get involved in the government you meet everybody and realize, "Wow. There are other majors here? Like there are other issues that they have that I don't have that we should be worried about?" You hear people in my department, I guess complaining a lot about, "Oh, we don't make a lot of money." And, "Oh, our benefits aren't that good." Have you met someone from the English department? Because they're not even guaranteed funding on a yearly basis. I never complained about money since meeting people who are actually having trouble. People in my department say, "Oh, I'm so broke." I'm like, "No, you're not." (laughter) "Sit on down. You're fine." "Stop going out drinking every night."

Reclaiming by Highlighting Discrimination in STEM and Society

In many instances, women's reclaiming processes were intertwined with using interdisciplinarity and the IGERT context as a lens through which to recognize and interpret past and current acts of gender discrimination, and to fight against gender-based and other forms of discrimination. A significant proportion of women in my study reclaimed and expanded their interdisciplinary socialization experience by engaging in activities that specifically addressed the advancement and participation of women in STEM and society. A number of these initiatives were specifically attuned to mentoring and outreach to support participation and advancement of women and, to some extent, people of color in STEM education and careers. Highly encouraged by the supportive and authentic dynamic that she was experiencing with her IGERT peers and recognizing powerful intersections with her cultural background, Emily from Coastal had recognized a growing desire to share her scientific knowledge in expanded communities beyond academe and involved herself with a program to support and encourage girls in STEM:

> I'm the Regional Director of [a non-profit organization that helps advance girls in computer science] so I think a lot about women and how do you support women in tech, how do we get more environments to want to support these women, and I still have no idea (laughter), but…It's just like you need to be able to really share whatever you're doing to people around you or else it doesn't matter how much you know, and I kind of see that across my cohort. They really care about that aspect and like really reaching out and making meaningful connections that aren't superficial.

Emily further commented on the importance of reclaiming ways of sharing knowledge as rooted in her indigenous and interdisciplinary perspectives:

> …who I am as an indigenous woman, the point of view, I'm very passionate about fish and navigation and basically not using more technology to navigate on the ocean and things like that. So, I've spent a lot of time thinking about that and doing that, and the whole point in the navigator system is you don't become the lead navigator of a canoe sailing from Hawaiʻi to Tahiti by knowing all the stars, by knowing every way. You don't ever become that person. It's only if you're able to teach some people under you. That's the only way you ever become a lead navigator and like that's just

such an important part of who I am…You need to go and be active in your community because -- and we have the skill set in learning how to do satellite stuff. You have to figure out a way to give back. So, that's how I got involved in [a non-profit organization that helps advance girls in computer science] and I'm going to say in a sense those girls have really changed who I am, because you can't tell a young girl, like you're beautiful, you're smart, you can go wherever you want. I can't tell her that and tell myself the opposite when I'm by myself, working on my dissertation.

In addition to her doctoral studies and IGERT participation, Amaia from Suburban works as a Fulbright mentor, which continues to inform her critical view on issues of access to education and STEM fields, which in turn plays into her interdisciplinary lens:

> I'm a Fulbright Ambassador now, so yeah, I'm representing their program on a national scale, trying to get people to apply and not be the thing that's blocking themselves. That's what I'm really passionate about because if it was up to anybody, I wouldn't be there because everybody told me, "No, you're not smart enough for this," like, literally told me things like that, you know? Like, "Why bother applying?" You know? Like, "Fine, I guess, but I have this other student that's so great and they're going to get it." Meanwhile they don't get it, and I do. So, you know? It just, there's not a perfect candidate, there's the amount of soul that you put into a thing, I really believe in that. …it just bothers me to the deepest point of my core that there are so many messages to young people, discouraging them from doing something, socially. And then all of the other political stuff that exists that blocks women from getting

into the careers: of not having role models, of not being able to envision yourself as being a full scientist or a full researcher, and then also not having the support to do any of the things that you want to do at home.

At the time of her interview, Lily at Coastal was about to embark on her third summer of teaching high school students in an interdisciplinary summer program at Yale, which she also described as an experience that has illuminated certain economic, race, and gender inequities integral to her interdisciplinary worldview:

> I teach high school students in the summer…And it's in an interdisciplinary kind of program that has overarching themes, but as instructors we get to teach on any seminar or subject within that theme that we were interested in. I've done it two other years. And what I try to communicate to them, was what my mentor did for me -- was that, you don't have to have everything figured out. You don't have to have the requisite. You may not have any experience in this, and you still have something to contribute to this. That's what I kind of go for is, is that aha moment when I don't have to have a biology undergrad, this master's, this master's, this master's -- to go into something cool and that windy, wavy route is okay, just because…they all want to go to Ivy Leagues. And they're all like the tops of their classes all around the world. So all -- they're trying to impress us because they think if they impress us, then they'll get into Yale. And I'm actually, I push back on that. I say, "You know what? If you go to Yale, cool. But if they don't have what you want, don't go to an Ivy. I didn't apply to any Ivys." And they look at me like, is she crazy?

Chelsea, Maggie, Emily, and Keelin from Coastal, who happened to be part of an all-women IGERT cohort, each described a collective effort to bring discussion of women in science to the IGERT community in more active and transparent ways. One way they did this was by reclaiming their weekly IGERT seminar as an open forum on women's participation and advancement in STEM, including sharing their own experiences as women in STEM, the dynamics of which were characterized this way by Chelsea:

> Across all of the disciplines represented in our cohort, everyone is female, and it's been a really cool support system to have. So one of our major themes that we have kind of settled on -- maybe doing some sort of future project altogether -- is either putting together some sort of science café or workshop or something like that on women in science, and inviting people to come and talk about their experiences, and talk about maybe the way forward to advance women in science. Just make a greater awareness. We're kind of at that stage of figuring out exactly what it is that we want to do, both logistically, but also larger theory wise. So it's kind of a larger conversation that we're very much at the beginning of still. But we're all super excited about it, which is great.

Chelsea also recounted an experience in which her cohort led an IGERT seminar discussion specifically focused on women in the sciences:

> We actually had a really great discussion just yesterday about women in science on International Women's Day, which is great. I think it was a little funny because there were men from the other cohort that are still actively in IGERT and one of our

> advisors. And I think they didn't quite know how to participate. And I think, for some of them, it was really the first time they'd had a conversation like that at all. So, I think for some of them it was a little, "Well, I believe in equality. I just want to help you carry the vacuum up the stairs." It's like, "Okay. We need to re-evaluate -- I understand where you're coming from, but we need to fix something here." And I think for some of them it was starting to get to that realization that there are small things sometimes. It doesn't have to be something so big and blatant all the time. There are small things that sometimes people will do. And it's both men and women that are -- people use the term microaggressions. But I found in my experience sometimes those are the most demoralizing things.

Saying a bit more about the forum on women in science, Chelsea recounted how their male faculty advisor tried to lead the discussion on behalf of the group and how some group members felt safe enough in their IGERT community to directly address this issue with the faculty member:

> Some of us got a little annoyed because our male advisor tried to lead the discussion on women in science, and we all kind of were like, "Okay, you need to just take a step back for a second here and let us guide this a little more. We can all go around and talk about how we feel about this. That's totally fine. But you are not in a position to be leading this. Discussing, sure; leading, no." I think he got the idea because a couple people kind of spoke up in a more polite manner. But again, I think one of the things I brought up was, as a woman and as a woman in science, a lot of

> times I feel the need to justify myself before I give an opinion or say something; almost like pre-defending myself. It’s not all the time, but even in groups like that sometimes. It’s not even that people realize they are making an environment like that, but I think after he heard some of the things that we had to say that were thrown out there I think he realized, “Okay, I need to step back and just shut up for a little while.”

After the seminar, a group of IGERT women doctoral students were comfortable having a follow up discussion with the offending faculty member, which suggested the Coastal IGERT environment supported such difficult conversations around gender discrimination and underscored a process of reclaiming this important aspect of interdisciplinary socialization for Coastal women, as Chelsea noted:

> Then a couple of the female students pulled him aside afterward and actually had a conversation with him for a while about, “We understand what you’re trying to do, but this was not appropriate.” (laughter) “Also talking over us, not appropriate.” For the most part, he really is a great ally for the students, so I really just don’t think he realizes that that’s how he is sometimes. Even then, it was kind of like do you let him get away with it and just tell him, “Okay, consider talking about it better next time”? Or do you get angry and... So even within that, I think it’s a little complicated. Overall, just having that discussion and being able to put that out there was really great. I think the guys were a little stressed. (laughter) But it was a new conversation for them and one that… they’ve heard about, but I don’t think they’ve really been in

> the middle of it before. And I think yesterday hearing some of our stories, they kind of got to the point where they were like, "Oh, I get it a little more now."

In addition to the quotes highlighted above, women consistently recounted their stories of gender discrimination, ranging from subtle microaggressions and marginalizing experiences to outright harassment, and the ways in which interdisciplinarity or IGERT contexts played into how they viewed and traversed these situations. In some cases, being a part of the IGERT community that put women and men from different disciplinary backgrounds together resulted in a supportive environment of peers and faculty who found ways to learn from and trust each other. Particularly at Coastal, but at all three institutions, a number of the participants spoke about ways they processed past and recent discriminatory experiences through the act of sharing these stories of discrimination with their IGERT faculty and peers and having these stories heard, validated, and reflected back to them from a multitude of disciplinary perspectives. In such cases, the IGERT cohort structure was instrumental in facilitating a degree of consciousness-raising around issues of gender discrimination, as well as issues of bias based on race, class, ethnicity, and sexual orientation. Many women were able to bring these discussions and insights into the E-E Dimension as they made assessments about what it meant to be an interdisciplinary science person.

Alysa, a biology PhD student from Suburban, described experiencing a highly supportive and egalitarian academic environment bolstered by her IGERT community which, by contrast, illuminated past educational experiences where she had experienced discrimination:

> I have to say overall I consider myself incredibly lucky. And I think it might be partly the influence of the IGERT, and I'm sure that it's very largely the influence of my own PI just being a wonderful human being. But the people that I've found myself surrounded by are overwhelmingly egalitarian and supportive. And I've never honestly in this program felt like an idea I've put forth was seen as less important or less ground-breaking because I was a woman, which is amazing because I've definitely experienced that at other times in my life. But I became aware of it probably like three months after starting the program, when I started talking to some other women who said that they were nervous about going to graduate school because they've heard bad experiences that women had had in labs. And I knew, I was like I have never in this program felt like I was being treated differently or worse, or even like my gender has been a consideration in things that have happened. So, it's pretty astounding. It is hard for me to know how broad of an indicator it is because I really, I just genuinely feel that I work with amazing people. But one of the moments that got me was when I was describing a prep that I was doing during lab meeting, and my PI, who's like a middle fifties man, leaned over to somebody, said, "Like she's being modest. That's really hard." And I was just so pleased with where I am.

Erica, at Suburban, had traversed significant harassment from one male faculty advisor during her doctoral tenure. However, she was able to leverage the IGERT structure of multiple faculty advisors to help buffer and limit the time she had to spend with the offending faculty member:

> So yeah, I have three advisors. [Advisor 1], who's kind of my primary advisor, [advisor 2], who was my advisor through the IGERT program, my secondary advisor. And then [advisor 3], who kind of came on partway through because he was working on a similar project with an undergrad student loosely connected to IGERT. And so he's the one that's been kind of interesting in terms of I guess…he is definitely a little patronizing, and I think treats his female students a little bit differently. So that's been kind of interesting.

Erica spoke in more concrete terms about specific examples of times she felt harassed and uncomfortable in interactions with the offending advisor, and ways in which another advisor attempted to run interference in an effort to help her:

> But one example was a couple of summers ago, we were arguing over... So, I have this fin ray design for my dissertation. And if you angle these crossbeams one way versus the other, you create a preferred bending direction. I was trying to say that, for what we were doing, you wanted it this way because it required less force to get the same movement. And I had a literature-based analysis that just proved that. And he just refused to believe that it was true. We spent like an hour arguing over this, and it was really frustrating. And I was like, you know, I have data that says that what I'm saying is correct. And at the end, he decided that we could say that we were both correct, which isn't quite true. And so just kind of things like that. Like, he doesn't like being wrong or you arguing with him. Also a lot of times, when he'll compliment you on something, he'll also mention your looks. He'll be like, "Oh, you're smart and

> pretty," or something like that, which is a little not quite OK. [Advisor 1] knows that we didn't get along and that I find him a little creepy so that's helpful, because we normally don't schedule meetings one-on-one or anything like that and [advisor 1] is pretty good at kind of helping that and being like, "Oh, I'm not here this week. Let's not meet." So that's been helpful.

Erica and several women IGERT and doctoral peers supported one another in reporting the offending faculty member to the university, prompting an investigation that seemed to have little effect on curtailing his actions/behaviors. After several more semesters, this group of women went again to file a report, but saw no follow-up or action by the university:

> But, you know, it just seems like there wasn't a huge difference after this first investigation, so I don't... I mean, I still think his interactions with women aren't great. So, I was his TA for his class, and just observing some of his interactions with students. I can see that, you know, he still treats the girls differently. Like, it's been kind of frustrating for a bunch of us, because it's kind of like, what's the university doing about it? We tried to talk to the OEO [Office of Equal Opportunity] about it again a year ago maybe, and they took forever to respond. And it was, you know, we ended up not going in. It took them like a month to respond, which was kind of crazy. They asked if we wanted to come in, but there were three of us who wanted to come in together. And I don't know if they wanted all of us to come in together, and it just kind of fizzled out.

To cope, Erica used an outside therapist for support and confided in her other two advisors, who acted as buffers so that she did not have to meet one-on-one with the offending faculty advisor. At the time of our interview, she had just successfully defended her dissertation and was actively interviewing for potential industry positions, yet still navigating around the offending advisor's unwanted advances:

> Like now when I'm looking for jobs, and I'm like trying to use people's connections and stuff like that, and I'm like, I want to ask him for connections, but…This was another weird thing. When we were talking about it a few weeks ago, or a month ago, he said he would connect me with these guys. So I emailed him to ask about it. But he had texted me asking me if we were meeting, and I said no, and thanked him for getting me in touch with this guy. And he then was like, "Yes, but you owe me a cappuccino," or something. And I was just like, OK. Haha. You're making me feel kind of guilty, but I also don't want to go do this with you. I did not know how to respond to that, so I just said, OK. Haha.

As part of being in the IGERT community and working with a female faculty advisor at Valley, Meera was able to find some peace from past sexual harassment by a fellow intern at a major oil and gas company. She recounted her wrenching harassment story in the context of how her IGERT experience, which made her feel welcomed, valued, and connected to more women, helped her move forward:

> I used to cry about that every time I talked about it, until last year. Last year was when I finally was able to let it be at peace. Which is a long time, like I used to cry

> every time I wanted to talk…because I just I couldn't handle it. And I would just sit there and would just start crying. And I knew, like at the time I knew I should have said something, but I was also like, I was, my boss didn't really think I was doing a good job. He just expected me to know more. And I had never worked in oil and gas before. And then towards the end, he said that he found out that I had been being sexually harassed by somebody and then he was like, "Why didn't you tell me?" Well, I didn't really feel like we had that relationship, (laughs) you know, so it was just kind of like, I just felt like I was competing in the boys' club. So that was really tough. Then when I got here [to Valley], I was at peace. I felt better. People were nice. And people had things that they were doing for fun. And also it was a woman advisor, who also helped me get the IGERT, and I was kind of tired being around a bunch of men all the time. And so, and then also she was the first advisor who said, oh, "Well, you're interested in international development? Yeah, I think we can work that in somewhere."

Similarly, Chelsea from Coastal shared an example of how she was able to process a past discriminatory experience with her new IGERT peers as a way to gain new insights and heal:

> The summer before my senior year of undergrad, I worked on a boat doing GIS work and it was for a federal organization. I was the only woman on the boat, and the men on the boat treated me like crap. They would go and urinate off the side of the boat when I was standing there, and I was like, "A warning would have been nice." Just like a little consideration. They wouldn't let me haul crab pods off the back of the

> boat because they were afraid I was going to fall in. It was like you don't assume that about the male intern though. If it was just an intern thing and you don't want liability, then okay, whatever. But you're letting the male intern do it. Meanwhile, I've got to stay here and take notes. So, a summer of that led to a lot of frustrations. But that was an experience that I was kind of able to share, not yesterday, but in a previous discussion with just my cohort about that experience. Most of the other women had had experiences in some way similar. And just knowing that we have each other to lean on has been really great. But the discussion [on women in STEM] we had yesterday was big, because I think we kind of got the guys thinking a little more about that. And it's just continuing that conversation for us.

On one hand, a more inclusive interdisciplinary environment could not entirely shield my study participants from experiencing discrimination. However, in a number of instances, the IGERT experience provided a safe space or buffer zone for women to engage in perspective-sharing activities that enhanced their recognition of discrimination. This safe space promoted by interdisciplinarity both offset the impact of discriminatory experiences and offered a forum of support to navigate such experiences. Further, the participants also drew on their interdisciplinary experiences to engage in activities that promoted the advancement of women and girls.

Reclaiming by Integrating Self with Science

The group of women who participated in my study included women from a variety of underrepresented populations and backgrounds. As a function of reclaiming interdisciplinary socialization in the E-E Dimension, participants from these groups relayed stories through which they considered and filtered aspects of self in addition to gender (e.g., race, ethnicity, culture, class) through their interdisciplinary socialization experiences and reintegrated these aspects of self into their expanded perspectives on what they valued and how they wished to behave as interdisciplinary science people.

Emily from Coastal described eloquently how the IGERT funding, focus on the environment, and community was instrumental in helping her see how different aspects of herself and her native Hawaiian cultural identity fit with being an interdisciplinary science person:

> There is something that's very deep-rooted with me when it comes to understanding the environment and I think I really need to understand that more. I took my first earth science class when I was at Columbia and basically that changed my life and I -- it's so cheesy but it did, because I think I was so scared of taking a real science class, because I was scared of kind of ruining my cultural understanding of the environment. I didn't want to make it science-y. I didn't want it to be lab coats and have a different -- I guess, I was already so far away and I didn't want to lose any more of who I was as an indigenous woman. And, yeah, so then once I finally immersed myself into the world, I was like, oh, my gosh, it was like a whole other lens…not only the science environment but that it has such a huge impact on my cultural identity. My advisor here [at Coastal] told me that I had this opportunity to physically be home in Hawai‘i and that my dissertation work could revolve around

> the environment I grew up around, I was like, I cannot give that up. Then, when I learned about IGERT, I was like -- this is like the perfect, ideally the perfect program to encompass who I am, as a woman, as an indigenous person with my research interests and it's probably been one of the best decisions I've made.

Emily further noted the critical role her IGERT cohort mates played in supporting her as she considered and activated her interdisciplinary science identity and goals:

> And it's been really nice to be just with women who generally care, not where their strength really matters to them but they kind of care about something more than how far you can go up the academic path. My boyfriend is a PhD at Harvard and he is great but that's kind of like his world and his life and his friendships and it's just like I don't think I could survive like that. It's just if all my friends wanted to do was become tenure-track professors and just pushed the frontiers of their field but could care less about how social dynamics are important in science, I would not be fine with that. But, like all these people, Keelin, Maggie, Chelsea, and all of them -- they have such a passion for the science, but they also see that there's such a larger picture and that's so comforting to be around because I definitely, for four or five years of my life before this, that has never been the case. There are larger frustrations with like IGERT set-up and whatnot, but I would not have been able to meet these really great people that support, you know, me and people just checking in all the time and it's been so nice.

Meera’s IGERT participation was giving her new insights on her status and experiences as an African-American women scientist. She was recognizing that her IGERT participation offered her a more diverse and welcoming community of peers and faculty than her previous educational experiences, while at the same time, also illuminated the chronic absence of other Black women faculty and peers:

> Prior to coming to Valley and the IGERT, I got a Mitchell fellowship to do my masters in Ireland. In Ireland, people were pointing out, I’m a woman engineer, I’m a Black woman engineer, I’m an American, not a European. I’m African American. And I was just like, you guys know that I didn’t even feel like a minority until all of you guys started pointing it out, (laughter) you know, and then it’s like, the problem is like once people point it out you can’t un-see it. Like I just, everybody kept pointing it out and then I couldn’t un-see it. So I was like, I was very happy before. Before all you guys decided to just point out our differences. (laughs) And so, then I came here [to Valley] and there was more diversity here, of course, than there was in Ireland. So I felt better, but then one time looking at my IGERT fellowship and like, browsing, I was the only African American woman. There was another African American in the program, but he didn’t identify as African American because he was a first-generation American and his parents are from Africa.

Through certain IGERT experiences, her former Fulbright fellowship, and her newer role as a Fulbright ambassador, Amaia from Suburban was refining how she saw great inequities in access to science for minority populations through her expanded interdisciplinary lens. This lens also acknowledged and incorporated her experiences as a Latina growing up in a lower-middle class economic background in a rural area of the country. In doing so, Amaia discussed her own growing confidence as a scientist and articulated a strong desire to see a much greater diversity of thought and participants represented in science:

> I've been getting more confidence the longer I've been in the PhD, for which I'm very thankful because before that, I had very low self-perception. So, grateful to have gotten past that with time. I don't think that there was any specific moment that I'm like, "You're a piece of crap," to "You're not a piece of crap." It's just kind of gradual. The longer that you've been in a space with interdisciplinary people and seeing how they navigate, you can also hang out. You can chill and just keep going. It's not like a switch that you can turn off, it's like the more experience you get, the less you feel like you're validated by others' perceptions of what you can and can't do, because if you feel that reactionary every time someone tells you you can't do something, you're never going to get anywhere. Especially not as a woman or a minority in the sciences, because people are super-eager to tell you, like, "Hey, stop what you're doing. Just," you know, "You suck."

The collection of findings presented in this chapter documented the existence of a more experiential and epistemological dimension through which participants processed, filtered, and personalized their interdisciplinary socialization experiences. In the E-E Dimension, women made meaning, critically considered, and reclaimed interdisciplinary socialization in a variety of ways that highlighted new and expanded dimensions of interdisciplinarity. It is through the E-E Dimension that women clarified the goals of interdisciplinarity and brought in aspects of self, identity, and values as features of their own personal representation of interdisciplinarity. In the next and final chapter, the findings presented in chapters four and five will be interpreted and discussed to demonstrate the contributions of this study to the literature, theory, practice, and future research.

CHAPTER 6

CONCLUSION

Interdisciplinary modes of research have been highlighted as facilitating scientific spaces and approaches that engender more collaborative, egalitarian, and society-driven knowledge production with a strengthened focus on real-world complex problems requiring approaches beyond the confines of a single discipline (Holley, 2009b; Klein, 1996; Nowotny, Scott, & Gibbons, 2001). Interdisciplinary modes of scientific knowledge production have also been described as holding the potential of being more closely aligned with the values and thinking of many women scientists (Haraway, 1988; Harding, 1991; Rhoten & Pfirman, 2007), thereby presenting a particularly welcoming environment for women. Women graduate students have often been at the center of these discussions, suggesting a ripe area of investigation at the intersection of interdisciplinarity, gender, and doctoral student socialization. This dissertation sought to gain nuanced and rich insights into women's engagement with interdisciplinarity by investigating the socialization experiences of women

PhD students in the interdisciplinary training contexts of IGERT programs at three research universities in the United States.

The findings of this dissertation present the opportunity for a rich discussion that draws parallels and distinctions to existing literature on interdisciplinarity, doctoral student socialization, and gender and offers new theoretical insights and practical implications for doctoral education. This chapter will first summarize the key findings of this research and discuss them in the context of existing literature. This discussion will be accompanied by a description of theoretical concepts emerging from the findings, holding implications for interdisciplinary doctoral student socialization both in general and in terms of women doctoral students' experiences. Theoretical implications will also be presented in relation to the ways in which women's expressions of interdisciplinarity intersect with other contexts permeating universities and scientific research environments, including a focus on the public good and academic capitalism.

Further, implications will be identified for the education and training of doctoral students that will highlight practical suggestions grounded in the findings of this research study for universities; governmental and other funding bodies and policy-making agencies; doctoral programs and departments; women and other populations of doctoral students; and communities around the world where interdisciplinary approaches to problem-solving are critical to advancing human, environmental, and technological adaptability and sustainability. Finally, several valuable lines of future research that would further understanding of interdisciplinarity in doctoral education, faculty work, and university organization will be identified.

Interdisciplinary Doctoral Socialization from the Standpoints of Women PhD Students: Contexts, Experiences, and Outcomes

As the findings of this study suggest, the lived experiences of the women doctoral students participating in interdisciplinary training contexts illuminated key structural and programmatic facilitators of interdisciplinary socialization formally and informally embedded in the three respective university IGERT programs. Although all three IGERT programs centered interdisciplinarity, the thematic focus, curriculum, range of disciplinary perspectives included, engagement with external stakeholders, and other program activities varied across the three sites. Specific program requirements like shared coursework, seminars, and educational travel experiences played out in each IGERT context in their own way and contributed to women's processes of developing as interdisciplinary scholars and professionals. These variations were reflected in the participants' interdisciplinary socialization experiences and aligned strongly with existing literature pointing to the importance of considering a variety of contexts and experiences in studies of doctoral student socialization (Boden, Borrego, & Newswander, 2011; Gardner, 2007, 2009b; Golde, 2005, 2010; Holley, 2010; Mendoza, 2007, 2010; Szelényi, 2013).

Several key features of interdisciplinary knowledge production documented in the literature were also visible elements of the three IGERT programs, including the exploration of interdisciplinary problems contextualized in environmental, human, and societal concerns.

In addition, access to and collaboration with wider domestic and international academic networks and non-academic stakeholders were apparent in varying degrees at each IGERT. Women's interdisciplinary socialization experiences were varied across the three IGERT contexts in my study, which held implications for the degree to which the participants were exposed to additional disciplinary perspectives and stakeholders within and beyond academe and how they made meaning of their interdisciplinary socialization experiences.

The Coastal IGERT's focus on complex interdisciplinary problems with implications for coasts and communities resulted in Coastal women's engagement with heavily community-centric research problems that required a strong degree of team-collaboration. It was also highly inclusive of a variety of external stakeholders including, but not limited to, community and business leaders, fishing industries, and fishermen. The Coastal IGERT involved a great variety of disciplinary perspectives, extending beyond the natural and biological sciences and engineering to include social science fellows representing global policy and business administration. In this way, the Coastal IGERT was highly contextualized in its community-centric problem-orientation, its high level of inclusiveness and engagement with non-traditional stakeholders outside of academe, and its inclusion of a varied set of disciplines across STEM fields and the social sciences.

The Valley IGERT and its focus on wind energy included disciplinary perspectives outside of the natural and biological sciences and engineering to some degree. Valley IGERT fellows more typically brought non-STEM perspectives from their prior undergraduate and master's degree programs of study, including psychology, policy, and governance.

Opportunities to network with and integrate external stakeholder perspectives, most notably through course-based travel experiences to a variety of domestic and international wind energy sites, was a central feature of interdisciplinary socialization at Valley and a vehicle through which students were able to meet and learn from academic and community-based wind energy stakeholders. Additional networking with industry, government, and other researchers occurred at Valley's annual IGERT poster session.

The Suburban IGERT's focus on soft robotics within which women's interdisciplinary socialization experiences occurred connected trainees with fairly narrowly defined and more pure interdisciplinary research problems in a more individualistic way, with limited to no external stakeholder engagement, save for a few lectures from faculty from other universities or industry scientists. Women depicted their experiences within the Suburban IGERT as a less cohesive or less collaborative approach to soft robotics design and more akin to involvement in loosely coordinated pockets of research activity across STEM departments and labs feeding into one interdisciplinary project. Suburban women who spent more time working in the central soft robotics lab space described having more peer-based informal learning opportunities that facilitated interdisciplinary perspective-sharing than their IGERT counterparts who did not spend measured time in the central lab, but these instances were few.

Modes of Interdisciplinary Practice: Cross-Fertilization, Problem-Orientation, and Team-Collaboration

Women's accounts also provided new insights into how and to what extent the four modes of interdisciplinary practice outlined by Rhoten and Pfirman (2007) entered into their experiences, which resulted in an expanded picture of the processes, contexts, and outcomes of interdisciplinary doctoral student socialization. These findings make substantial research and theoretical contributions towards a model of interdisciplinary doctoral socialization in clarifying the role of Rhoten and Pfirman's (2007) four modes of interdisciplinary practice in interdisciplinary socialization. In addition, the findings offer specific theoretical connections between gender and interdisciplinarity from the exclusive standpoints of women doctoral students in interdisciplinary training contexts. As outlined in other chapters in the dissertation, Rhoten and Pfirman (2007) suggested the ways in which four interdisciplinary modes of practice—cross-fertilization, problem-orientation, team-collaboration, and field-creation—might be gendered. Accordingly, they speculated that such gendered practices may offer a welcoming environment for women and could have the potential to both attract and advance the participation of women in the sciences, where they have been historically under-represented (Rhoten & Pfirman, 2007).

Importantly, of the four modes of interdisciplinary practice, Rhoten and Pfirman (2007) suggested that *cross-fertilization,* in the way it honors tools, concepts, and methods from other disciplines and approaches beyond the scientific method, is in line with women's epistemological views on the norms, values, and practices of science. Further, cross-fertilization was noted by Rhoten and Pfirman (2007) as often occurring through more collaborative, flatter, and less hierarchical interaction underscored by the *team-collaboration* mode of interdisciplinary practice. In addition, Rhoten and Pfirman (2007) suggested that the team-collaboration mode potentially aligned with women's preferred ways of working and was more accessible and equitable than the traditional culture and structure of science.

The third mode of interdisciplinary practice, *problem-orientation*, has been described as embodying gendered properties through its focus on real-world problems and applications that address societal concerns and its engagement with broader missions and stakeholders outside of the university. Rhoten and Pfirman (2007) speculated that interdisciplinary scientific problems that are highly contextualized as addressing environmental, human, and societal health and longevity may be particularly meaningful to women. Finally, the *field-creation* mode of interdisciplinary practice, which supports inquiry at the margins of disciplines and the creation of new fields on the boundaries of disciplines, was underscored as a place in which women are often working, in part, as a result of being marginalized in the male-dominated scientific enterprise.

For the participants in my study, cross-fertilization, team-collaboration, and problem-orientation were integrated into their interdisciplinary training much as Rhoten and Pfirman (2007) depicted these three modes. In the context of doctoral student socialization, however, these modes of practice were facilitated for students through formal and informal IGERT learning experiences. For many women, particularly at Coastal and Valley, "innovation clinics" that encompassed curriculum-based travel, engagement with a wide variety of stakeholders, and collaborative team projects were depicted as perhaps the most powerful facilitators of cross-fertilization, team-collaboration, and problem-orientation. At Suburban, innovation clinics were also cited as a formal learning opportunity that facilitated cross-fertilization, team-collaboration, and problem-orientation, but these were structured as individual and team-based competitions with monetary awards for winners. IGERT-funded research and conference travel was also highly instrumental in creating interplay among cross-fertilization, team-collaboration, and problem-orientation for Suburban women as a feature of their interdisciplinary socialization. The participants of my study, especially at Coastal and Valley, depicted explosions of interdisciplinary learning not only through these more formal experiences, but also through informal perspective sharing with peers. This peer-to-peer interdisciplinary learning was not expressed as strongly by Suburban women. However, faculty at Suburban were more influential socializing agents as mentors and gatekeepers, especially with respect to helping students connect to their networks and encouraging conference participation through research presentations and design competitions that facilitated cross-fertilization, team-collaboration, and problem-orientation.

For Coastal, the interaction between and among cross-fertilization, team-collaboration, and problem-orientation was expanded and further reinforced by the inclusion of external community stakeholders who were viewed as team participants and their perspectives sought and incorporated as part of a problem-based inquiry process. In a similar vein, Valley women described a set of interactions with external experts and stakeholders at various course-based travel sites. These stakeholders acted as critical knowledge exchange partners on a variety of off-shore wind issues and initiatives. In both cases, the cross-disciplinary and stakeholder communication opportunities and the related knowledge-sharing processes were plentiful and varied in their perspectives and participants, with a strong focus on societal impact. Suburban women depicted learning opportunities that facilitated cross-fertilization, team-collaboration, and problem-orientation interactions with a global community of soft robotics scientists and engineers. Participation in individual and team design competitions and IGERT-supported travel to conferences, although not explicitly with a wider non-academic population, also played important roles in encouraging cross-fertilization, team-collaboration, and problem-orientation at Suburban. Also, the soft robotics problem under investigation at the center of the Suburban IGERT was not highly contextualized in environmental, human, and societal concerns, although some women were thinking about their research projects and future work in terms of societal impact.

Despite nuanced differences across IGERT and university contexts, women's narratives were consistently aligned with three of Rhoten and Pfirman's (2007) four modes of interdisciplinary practice—cross-fertilization, team-collaboration, and problem-orientation—as highly prevalent and recursively linked facilitators of their interdisciplinary socialization. Participants consistently expressed ways in which these three modes were activated and in constant interaction through different types of formal and informal IGERT-based learning opportunities. For these women doctoral students, who were expected to gain deep knowledge and specialization in their home disciplines while simultaneously training as interdisciplinary scholars via IGERT, learning opportunities that activated the three modes constituted critical interdisciplinary socializing experiences.

Figure 3. Interdisciplinary Socialization Processes and Contexts for Women Doctoral Students

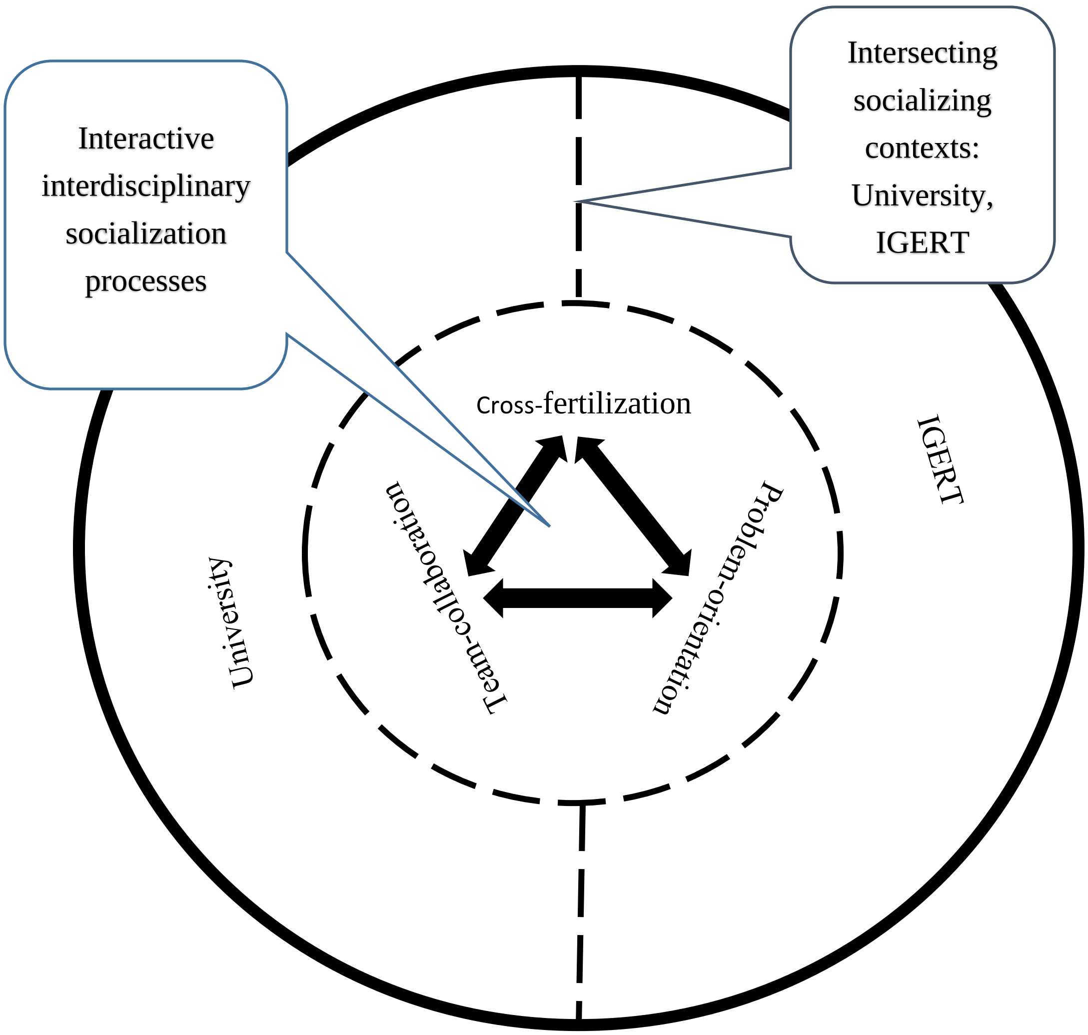
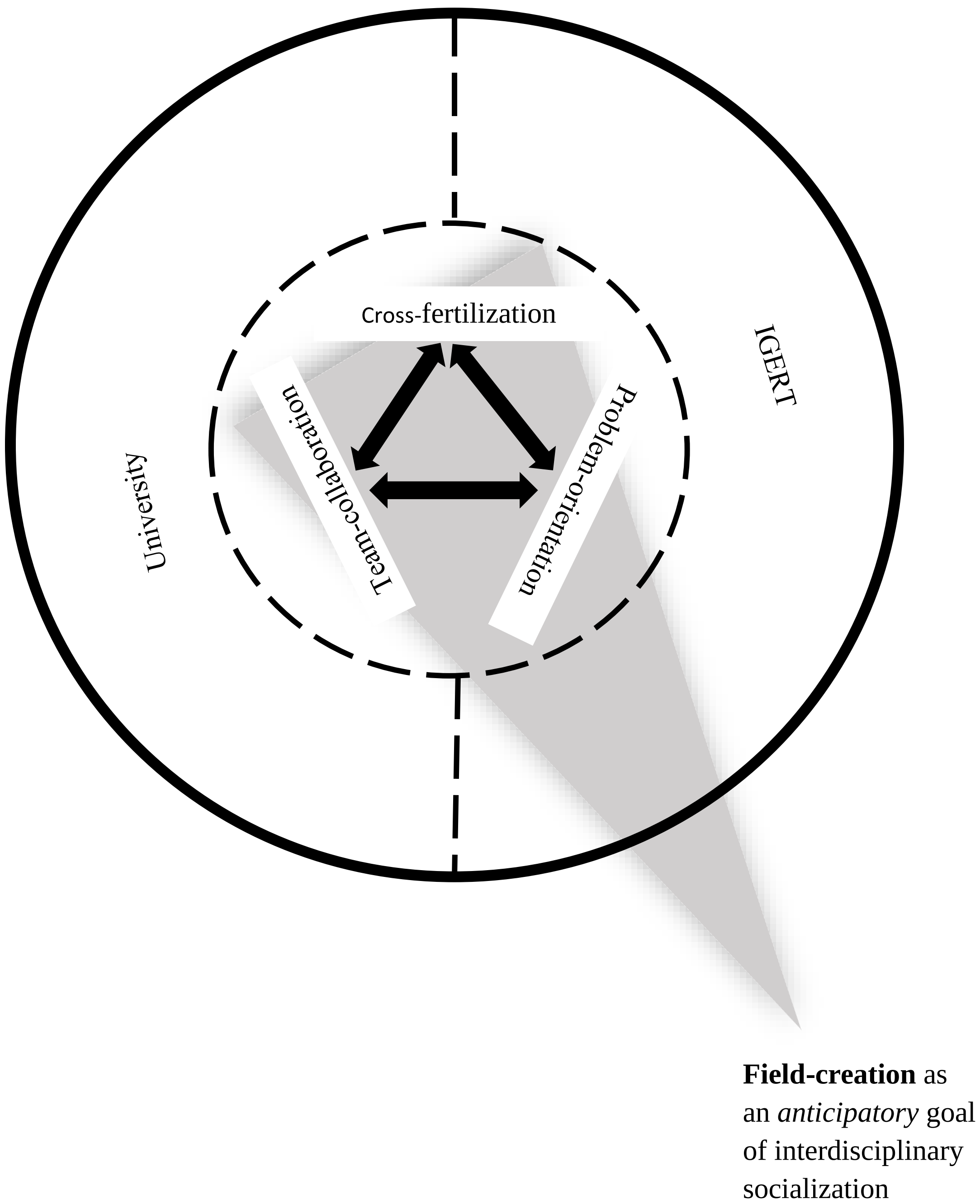


Figure 3 depicts how the women doctoral students in this study characterized their interdisciplinary socialization with an emphasis on formal and informal IGERT-based learning opportunities that facilitated the cross-fertilization, team-collaboration, and problem-orientation modes of interdisciplinary practice. These three modes, positioned at the center of the figure, are depicted as working in constant interaction in the process of interdisciplinary socialization. Cross-fertilization appeared prominently in the women's narratives and was characterized as an individual broadening of content, skills, and methodological knowledge outside of their home disciplines. Cross-fertilization was most typically described as resulting from formal and informal interactions with individuals in the IGERT network, especially cross-disciplinary peers. Team collaboration, similarly, took its own shape for the women doctoral trainees and more typically was depicted as IGERT (and sometimes non-IGERT) peer collaboration in team-based research projects and competitions. The problem-orientation mode of practice was embedded in the IGERT programs' focus on engaging doctoral students in addressing real-world problems with broader environmental, human, and societal missions and often including stakeholders outside the university. Dotted lines encircling the interplay between and among cross-fertilization, team-collaboration, and problem-orientation and delineating IGERT and university contexts are drawn to underscore that these boundaries are blurred, overlapping, and permeating in the interdisciplinary socialization process.

Field-Creation as an Anticipatory Goal of Interdisciplinary Doctoral Socialization

In my study, the fourth mode of practice, field-creation, was reflected differently in the context of interdisciplinary doctoral socialization than originally depicted by Rhoten and Pfirman (2007). Participants expressed field-creation in far less immediate and much more anticipatory terms. Although by the nature of their participation in the IGERT, the participants were positioned at the intersection of disciplines, it was still in the context of learning as doctoral trainees. As such, field-creation was expressed widely by the women as an anticipatory goal of their interdisciplinary socialization and as a way through which to envision how they might embody and enact interdisciplinarity through further learning/training and in discerning a multitude of career pathways. Importantly, anticipatory field-creation was facilitated by the same learning opportunities that supported the cross-fertilization, team-collaboration, and problem-orientation modes of interdisciplinary practice and by the interplay among these three modes.

Figure 4. Field-Creation as an Anticipatory Goal of the Interdisciplinary Socialization of Women Doctoral Students



This alternate form of field-creation that is anticipatory and grounded in the experience of being a doctoral student and interdisciplinary trainee is depicted in Figure 4 at the tip of a three-dimensional cone representing its function as a future goal of interdisciplinary doctoral socialization. Importantly, anticipatory field-creation arises from learning experiences that facilitate ongoing interactions among cross-fertilization, team-collaboration, and problem-orientation in the process of interdisciplinary socialization. As in Figure 3, dotted lines and circles depict permeability and overlap between contexts and processes as an important feature of interdisciplinary socialization. The repositioning of field-creation as an anticipatory goal of interdisciplinary socialization illuminated a dimension of women's socialization experience that was highly personal in nature and demonstrated a rich and nuanced experience of becoming an interdisciplinary science person.

The Emergence of the Experiential-Epistemological Dimension

Participants' depictions of processing and filtering their interdisciplinary socialization experiences pointed to the existence of a new dimension of interdisciplinary socialization from the express standpoints of women. To capture and reflect the dynamic interplay between women's interdisciplinary socialization experiences and their epistemic beliefs, I refer to this dimension of interdisciplinary socialization as the Experiential-Epistemological (E-E) Dimension. In the E-E Dimension, women were actively addressing a tacit guiding question of their interdisciplinary socialization, asking what it meant to become an interdisciplinary science person.

The E-E Dimension encompassed and co-existed with women's interdisciplinary socialization and operated as a space through which women *made meaning*, *critically considered*, and *reclaimed* interdisciplinary socialization. Through these three E-E Dimension processes, the features and goals of interdisciplinarity were illuminated from women's standpoints. As women *made meaning* of what they believed to be central to furthering interdisciplinarity knowledge sharing, creation, and application, they very often prioritized communication as the cornerstone of successful interdisciplinary work and highlighted application as its most significant goal. Intersecting with anticipatory field-creation, women considered a wide variety of traditional and non-traditional approaches to furthering interdisciplinary application, from the creation of new products and technologies to using interdisciplinary knowledge, skills, and perspectives to facilitate application through policy and public outreach initiatives.

As women *critically considered* their interdisciplinary socialization experiences in the E-E Dimension, they identified shortcomings and inequities and considered ways to fill gaps they perceived in their interdisciplinary socialization. One common critique that women underscored pointed to a variety of program design issues that they perceived as either not anticipated or detracting from their interdisciplinary socialization. Across all three IGERTs, for example, women spoke of a regrettable lack of opportunity for more and qualitatively different interactions with IGERT peers from their own and other cohorts as a key shortcoming that could have been attended to more explicitly through program design.

At Coastal and to some degree at Valley, women pointed to inequities and biases with respect to how disciplines were included, valued, and represented within their IGERT contexts, as part of critically considering their interdisciplinary socialization. At Coastal, which intentionally included IGERT fellows from social science and business disciplines, it was clear that women from these disciplines felt less fully included and described their content expertise and disciplinary depth as less valued or inaccurately represented. Participants also implicated shortcomings in IGERT faculty perspectives as the primary facilitator of these cultural and programmatic inequities. At the same time, the inclusion of social science disciplines in the Coastal IGERT made for very rich interdisciplinary learning and perspective sharing among peers, which Coastal women from all disciplines and IGERT cohorts underscored as the most powerful feature of their interdisciplinary socialization. Not surprisingly, such a powerful and rich peer-based interdisciplinary learning and socialization experience was somewhat less evident at Valley and not substantially evident at Suburban.

Issues of clarity about and equitable access to IGERT funding were also highlighted by some women as they critically considered their interdisciplinary socialization in the E-E Dimension. Hannah at Valley described being unclear with regards to activating her IGERT funding to get paid and pointed to a desire for more support and clarity from the program administrator around funding. Lily and others at Coastal expressed frustration about the lack of clear policies and guidelines pertaining to available IGERT funds for research and travel and wondered whether her status as a social science person was a factor in not having access to clear and complete information about available funds.

Access to IGERT funds at Suburban also emerged as an issue. Women described ways in which they could position themselves to win available IGERT funds by competing in and winning IGERT-based innovation and design challenges. Consider the example of Erica, who was fortunate to have individual design projects to enter. She won several different competitions, both as an individual and as part of a small group, and she used these funds to purchase the bulk of the materials she needed for her PhD research project. IGERT funds also supported Erica's international travel to conferences, including her time as a visiting graduate researcher in a soft robotics lab at a university in Italy. Even with IGERT being a government-funded program, some students were distracted from achieving their educational goals in an effort to understand what funding was available and how to access it, while others were put in the position of having to compete for it against other IGERT fellows.

Women also expressed a number of ways in which they actively *reclaimed* interdisciplinary socialization to fill gaps they perceived in their training experience. Many women found avenues to use and expand their interdisciplinary perspectives by adapting IGERT structures. Abby, Martha, Lily, and others at Coastal described instances when they took over the weekly seminar series in their IGERT to workshop dissertations, bring in speakers representing additional interdisciplinary perspectives, and map the interdisciplinary knowledge and skills they and their peers brought to the IGERT so that these could be valued and utilized in interdisciplinary problem-solving. At Valley, students led initiatives to add to curricular offerings and modify course requirements in support of relevance and flexibility.

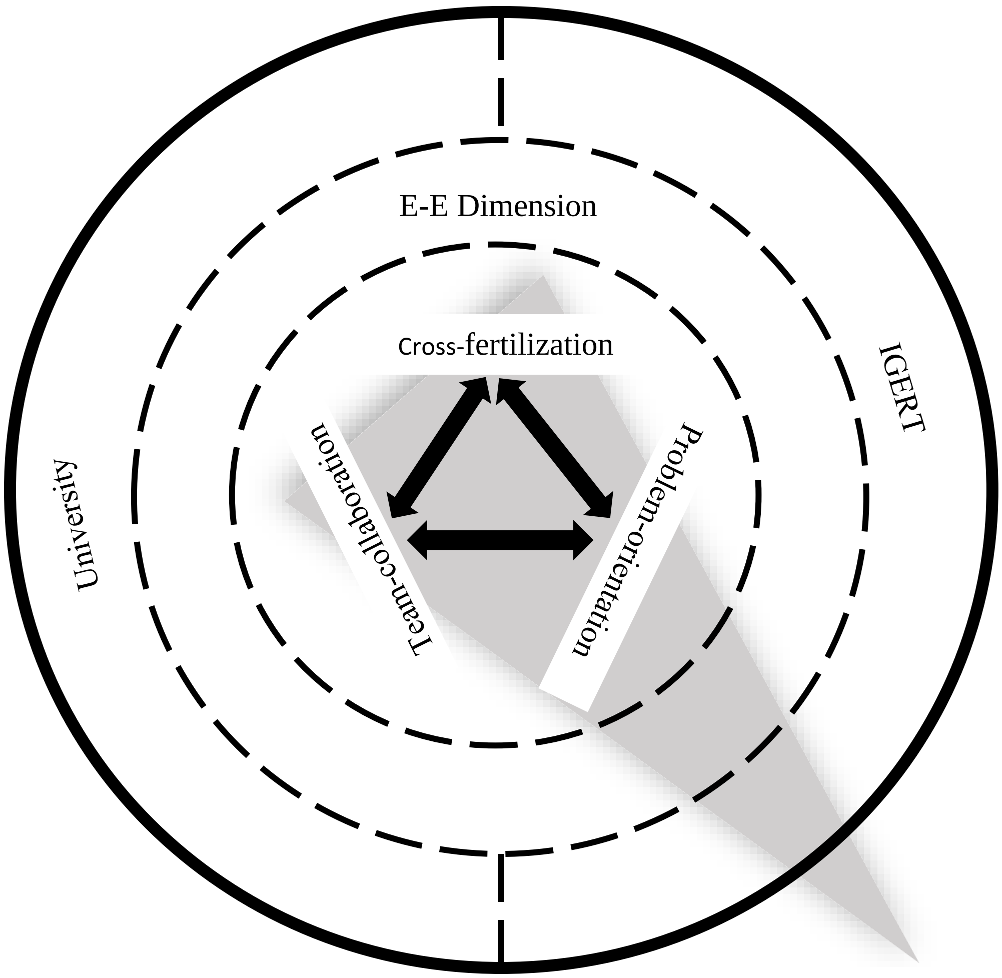
Some women also connected to non-IGERT experiences in an effort to expand their interdisciplinary perspectives in directions that were both under-represented in their IGERT programs and personally meaningful to them. Julia and Caroline each talked about how interdisciplinarity played into their motivation to get involved in graduate student government organizations at their respective universities, Valley and Suburban. In another example, to ensure she was staying connected to real-world interdisciplinary and stakeholder engagement experiences while pursuing her PhD and IGERT programs, Maggie at Coastal remained employed with the EPA in her home state as a leader of a working group on microplastics.

Women also expressed ways in which they reclaimed their interdisciplinary socialization to both a) influence the participation and advancement of women in STEM and society and b) to interpret, reframe, and fight against gender bias and other forms of discrimination. Some women described actively taking on roles in outside programs that expressly promoted the participation and advancement of women in STEM, like Emily's work with the non-profit organization supporting girls' participation in computer science and Lily's work mentoring high school students and fostering their interdisciplinary perspectives through the Yale summer program. At Coastal, women cited a number of examples where they leveraged IGERT forums to lead discussions on and raise awareness of issues faced by women in science and society. For several women at all three universities, specifically Meera (Valley), Erica (Surburban), and Chelsea (Coastal), the IGERT context provided communal support and became a safe space in which to recount, process, and in some cases, act upon past and current harassment experiences. It is unclear to what degree interdisciplinarity played a role in this, but to some degree, cross-fertilization about women's issues was occurring in the IGERT in ways that arguably were becoming incorporated into women's broader views of interdisciplinary. Such a phenomenon was particularly evident at Coastal as a feature of the breadth and depth of cross-fertilization occurring between IGERT peers and heavily influenced by global human rights and global economic frameworks and perspectives brought from the social sciences.

Through reclaiming interdisciplinary socialization in the E-E Dimension, women also described ways in which they purposefully integrated aspects of self and identity into their expressions of interdisciplinarity. Perhaps the most powerful example of this phenomenon could be seen in Emily's description of how the Coastal IGERT and her interdisciplinary socialization experiences were instrumental in illuminating the ways in which she could purposefully merge her practice of science with her indigenous background as part of becoming an interdisciplinary science person. As women made meaning of, critically considered, and reclaimed their interdisciplinary socialization in the E-E Dimension, they were notably able to influence their interdisciplinary socialization environments and fill gaps in their interdisciplinary socialization through meaningful outside activities in support of a personal vision of becoming an interdisciplinary science person.

The emergence of a new and highly personal dimension of interdisciplinary socialization derived expressly from the standpoints of women is perhaps the most important theoretical contribution of my study. In Figure 5, the E-E Dimension is positioned as both encompassing ongoing interactions among cross-fertilization, team-collaboration, and problem-orientation, as well as anticipatory field-creation. This dimension is also permeated by these interdisciplinary socializing processes and by the IGERT and university contexts. As in Figures 3 and 4, dotted circles and lines underscore the existence of blurred boundaries.

Figure 5. The E-E Dimension as a Feature of Interdisciplinary Doctoral Socialization



Field-creation as
an *anticipatory* goal
of interdisciplinary
socialization

In considering what it means to become an interdisciplinary science person, women consistently reflected on the new knowledge and skills that they were learning as a function of their participation in their respective IGERTs and the importance of new information and approaches to the practice of science. Specifically, women often spoke about a desire to engage in and practice science in ways that aligned with a broadened interdisciplinary perspective and that were congruent with their own shifting scientific and personal values. Furthermore, women desired to be supported in creating experiences that furthered this goal. They often pointed to the importance of facilitating application-driven research through which human impact could be envisioned and realized in new products and technologies, but also via non-traditional routes to interdisciplinary application through creating and influencing policy and engaging in public outreach and education initiatives.

The E-E Dimension was distinct for women in underscoring the bi-directional nature of socialization, also indicated by dotted circles and lines in Figure 5. Making meaning, critically considering, and reclaiming in the E-E Dimension resulted in a variety of expressions of interdisciplinarity to direct and shape participants' interdisciplinary socialization within and outside of the IGERT. For example, women actively worked to make scientific and graduate school climates more inclusive, flexible, egalitarian, and welcoming. Several participants also actively rejected messages to maintain a singular focus on PhD work as a means of staying connected to former colleagues and building new networks, developing interdisciplinary skill sets, and valuing and imagining career pathways beyond academe.

Others actively combined a strong social justice lens with their interdisciplinary science aspirations, using interdisciplinary perspectives and IGERT contexts to advocate for the participation and advancement of women and people of color in STEM and to fight against gender bias and other forms of discrimination. Finally, in probably the most striking personal expression of interdisciplinarity, women highlighted the ways in which they actively merged their personal identities, values, and beliefs with their emerging interdisciplinary science identities, intentionally working against cultural messages to shed or separate these from the practice of science. Each of these expressions of interdisciplinarity have implications for theory, intersecting with and extending upon elements of feminist standpoint theory (Harding, 1991, 1996), gendered socialization theory (Sallee, 2011b), and theories of and tensions present between academic capitalism and the public good (Slaughter & Leslie, 1997; Slaughter & Rhodes, 2004, Szelényi & Bresonis, 2014), which the next two sections will discuss.

Implications for Feminist Standpoint and Gendered Socialization Theories

In its application to STEM education and fields, feminist standpoint theory views women as "outsiders within" the historically White and male-dominated enterprise of science (Harding, 1991, p. 124). Arguably, social science perspectives within a scientific research environment can provide an especially rich context highlighting and critiquing women's "outsiders-within" position within science. The majority of participants in this study clearly used their various social locations as outsiders-within to link their interdisciplinary work to issues of gender. This was particularly salient in the ways in which they considered how interdisciplinarity could be a pathway to protecting themselves and others from discrimination, to promoting the participation and advancement of women and girls in science and society, and to rejecting cultural messages to separate self and society from the practice of science and their vision for themselves as interdisciplinary science people.

In the particular context of this study, the act of connecting interdisciplinary socialization to broader issues of discrimination against women derived exclusively from the standpoints of women was most visible through the E-E Dimension and intersected significantly with the core concept of strong objectivity within feminist standpoint theory. Strong objectivity, as discussed in earlier chapters, rejects the traditional scientific method-based concept of objectivity as a feature of practicing good science. Instead, feminist standpoint theory contends that it is not possible for researchers to practice bias-free science or fully divorce scientific discovery from its various social, historical, or political contexts. Harding (1991) views good science as knowledge production that employs a strong objectivity that acknowledges and interrogates the multitude of contexts within which scientific knowledge is produced as part of the research process. Strong objectivity also acknowledges that objective knowledge is not independent from the researcher's social location and advocates for basing inquiry from marginalized perspectives to achieve less partial knowledge creation (Harding, 1991, 1996).

In this dissertation, women expressed strong objectivity in a variety of ways as they actively created a picture of their interdisciplinary socialization, illuminating its processes and, importantly, revealing (and often finding ways to address) tensions and inequities in the socialization environment. Finding ways to elevate marginalized perspectives was a central element of this process. In one such example, Hannah described a perspective sharing and reframing opportunity she took as the one social and behavioral sciences-focused individual in a team of engineers at Valley during an IGERT course-based white paper project. In codrafting their white paper on a wind energy problem, her engineering peers consistently referred to certain groups of individuals as “NIMBYs,” a derogatory acronym for “not in my backyard,” characterizing people who resist wind energy technology in their communities. In this instance, Hannah took on an educational role with her peers, helping them gain deeper understanding of the term and the issue from an alternate and sometimes marginalized psychological disciplinary lens, which resulted in revisions to their paper. Another illustrative example of elevating marginalized perspectives was visible when Chelsea and other women at Coastal actively designed one of the IGERT seminar experiences to function as a discussion of women in STEM, but a male faculty member took it upon himself to lead the discussion. Some of the IGERT students were able to both call attention to that as an issue in the moment and also have a follow-up discussion with him about why he should have stepped back and allowed the forum to unfold in a more gender-inclusive and equitable way.

Women’s expressions of strong objectivity were deeper and more prominent in the IGERTs where more disciplines were included. Those IGERTs with the specific inclusion of social sciences, especially at Coastal and to a lesser degree at Valley, enriched and influenced learning opportunities and the expansion of interdisciplinary perspectives, especially through interactions that supported cross-fertilization between and among IGERT peers of all genders. By bringing her psychological perspective to the study of wind energy and helping her engineering peers gain a more complex and nuanced understanding of human adoption of alternative energies, Hannah actively changed the learning and socialization environment in a way that elevated not only a marginalized psychology perspective, but also community-based perspectives that are important to incorporate into the scope of a complex research problem such as wind energy. The actions of Chelsea and her IGERT cohort peers at Coastal, on the other hand, resulted in a mutual consciousness-raising experience for all IGERT participants and faculty in support of marginalized perspectives.

Women in this dissertation exhibited ways in which they were able to be “active agents in their learning” from varying degrees of outsider-within perspectives, deciding on and directing what they needed from their interdisciplinary socialization (Harding, 1991, p. 126). For example, Lily and Martha, two social science participants in the Coastal IGERT, were able to use their marginalized disciplinary voices – combined with their voices as women – to raise consciousness among faculty and peers in the IGERT about discipline- and gender-based inequities and microaggressions present in their interdisciplinary socialization environment. Lily’s and Martha’s actions contributed not only to a deeper cross-fertilization experience within the IGERT community, but also to a movement to reclaim IGERT learning experiences in a way that included marginalized perspectives.

This dissertation’s findings speak to feminist standpoint theory and strong objectivity in several ways. For instance, doctoral socialization in the interdisciplinary scientific training contexts examined in this dissertation, especially those that included social science disciplines, supported an environment through which women in this study were able to make progress toward identifying androcentric properties of their experience. On some level, this is unsurprising since a primary goal of IGERT is to include and support the participation of underrepresented populations in scientific research, which is aligned with standpoint theory's position that scientific communities need to be adapted to include marginalized perspectives and knowledge communities. Relatedly, the women in this dissertation were beginning to think more specifically about how to influence and perhaps re-envision knowledge creation and application from their own and others' marginalized perspectives, thus valuing and incorporating these views into their future goals for scientific work. In some way, this valuing of self and experience in the women's interdisciplinary socialization process was reflecting standpoint theory both in incorporating a level of self-reflection in a knowledge-producing community and in prioritizing a multitude of perspectives as a way of discouraging or counteracting dominant perspectives in knowledge production.

In addition to implications for feminist standpoint theory, this dissertation both underscores and complicates Sallee's (2011b) theory of gendered socialization when examining interdisciplinary scientific socialization through the standpoints of women doctoral students. On the one hand, the assertion that disciplines are inherently gendered and exist in a hierarchical ladder that places more female-dominated disciplinary perspectives and research approaches closer to the bottom rungs compared to STEM-based perspectives was clearly evident in the marginalization that women from the social sciences in this study experienced, when their disciplinary perspectives and scope of knowledge were minimized, oversimplified, or misrepresented. This was particularly true for the social sciences women at Coastal, who described these experiences and tensions in detail as stemming from IGERT faculty misperceptions of these disciplines, which bled into and negatively affected certain social dynamics and course/seminar content. For example, Lily at Coastal reflected on times when IGERT faculty distilled the social sciences disciplinary scope and contribution to considerations of policy only. She responded to this form of marginalization of self and discipline by interjecting open-ended questions to encourage faculty and peers to think beyond that narrow characterization and engender deeper discussion.

On the other hand, such tensions were valuable in furthering interdisciplinary learning and ways of conceptualizing research problems and methodologies. As a result of such tensions, Coastal women were having the richest and deepest interdisciplinary socialization experiences of all three IGERTs in this study. Women at the other IGERTs were also describing new ways of thinking and conceptualizing future careers through exposure to knowledge and skills embedded in other disciplines. Through a course focused on policy and scientific communication at Valley, Meera's view of future careers in STEM shifted significantly to include ways to leverage interdisciplinary scientific communication skills to educate the public, influence policy, and strengthen the connection of society to science. While such tensions can make interdisciplinary research seem more complex and "messier," these important tensions require both visibility and transparent negotiation for rich interdisciplinary inquiry and complex problem-solving.

Disciplinary tensions were not as strongly revealed or expressed at Suburban, which may have special implications for women in that program in terms of both limiting the scope of anticipatory field-creation and what they were able to filter through and reclaim in the E-E Dimension. Suburban women were working far more independently on their own and on faculty research projects in their home departments, some of which fed into IGERT activities and the central soft robotics lab. However, communal workspaces in the central lab did provide Suburban women some opportunity for interdisciplinary knowledge exchange and perspective-sharing, an example of which was seen though Caroline’s expanded understanding of differences in chemistry and biology disciplinary communication styles.

Active and transparent negotiation of tensions among disciplines was a major factor in how women were envisioning future field-creation. IGERTs that included the widest variety of disciplines not only opened more tensions at disciplinary junctures, but also opened more opportunities for envisioning future field-creation which, especially at Coastal, promoted a strong social justice view of future field-creation. Take Keelin, for example, who, through interdisciplinary perspective-sharing fostered chiefly through peer interactions, was beginning to see herself as more than just a chemist who collected samples and ran experiments. Through the support and encouragement of her IGERT peers and the structure of the coursework, she was becoming versed in stakeholder engagement and thinking deeply about the significant value of including perspectives outside of academe and how to move her research in closer proximity to real-world environmental problems such as climate change.

As the findings of this study show, interdisciplinary training programs in doctoral education can bring together disciplines that feature various expressions of gendered socialization. Perhaps most importantly, interdisciplinary programs that include a wide spectrum of disciplines, seen especially in the Coastal IGERT, hold the potential to re-establish disciplinary hierarchies that highlight the gendered nature of prestige held by female- and male-dominated disciplines (Sallee, 2011b). While strongly cautioning against such hierarchical treatment of disciplines, my study underscores the critical importance of including social science perspectives in STEM interdisciplinary programs. As demonstrated by the findings of this study, such perspectives can not only lead to rich and social justice-oriented problem-solving, research, and application in the experiences of women doctoral students, but also give rise to a widened horizon of anticipatory field-creation expressed in bold and meaningful career aspirations.

Interdisciplinary Doctoral Student Socialization at the Intersection of Academic Capitalism and the Public Good

This dissertation also has implications that may further our understanding of how interdisciplinarity research and doctoral training contexts play into tensions between academic capitalist and public good forces in higher education. In the theory of academic capitalism, Slaughter and Rhodes (2004) posit that universities are increasingly moving from a “public good knowledge regime” characterized by valuing knowledge as a public good to society and its citizens compared to an “academic capitalist knowledge regime,” in which knowledge is viewed as a private good and can be claimed and commercialized for profit by faculty, universities, corporations, or other entities (p. 28). The public good knowledge regime values and supports pure research as leading to important discoveries that will ultimately benefit the public. In the academic capitalist knowledge regime, scientific discovery is valued for its commercial product and technology contributions to a “knowledge economy” (p. 29). In addition, the theory of academic capitalism is “focused on networks—new circuits of knowledge, interstitial organizational emergence, networks that intermediate between public and private sector, extended managerial capacity—that link institutions as well as faculty, administrators, academic professionals and students to the new economy” (Slaughter & Rhodes, 2004, p. 15).

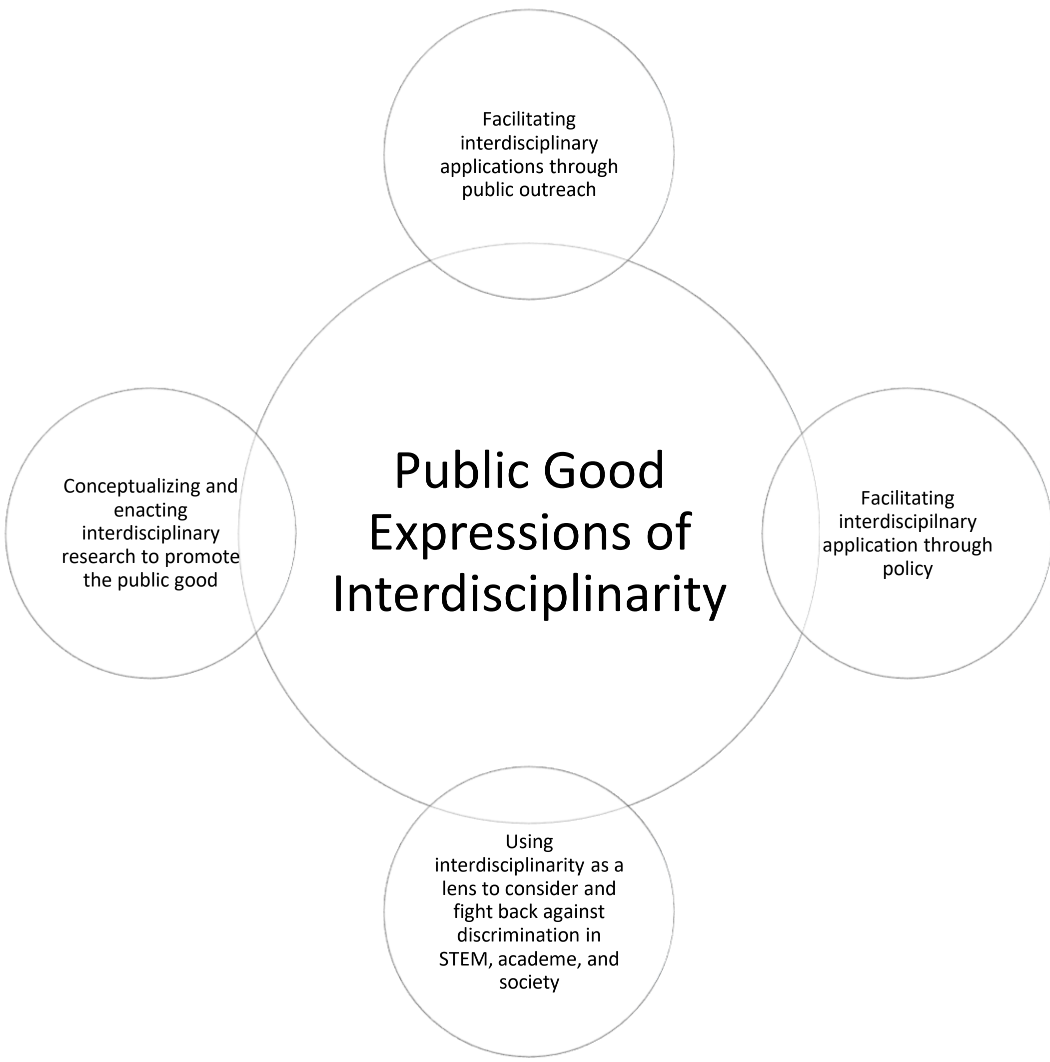
It is important to consider interdisciplinarity through the public good-academic capitalism debate, especially with respect to the underlying assumption that interdisciplinarity aligns with the public good in its problem-orientation and collaborative approaches, thereby presenting an environment in which women may thrive. Findings in this dissertation highlighted both public good and academic capitalist elements of interdisciplinarity that connect to a larger set of issues in terms of the encroachment of neoliberalism in science and higher education through academic capitalism. It is important to understand interdisciplinarity within this larger context, including the ways in which academic capitalism can threaten the public good in interdisciplinary contexts, which is not something that is often considered in the literature.

Overall, interdisciplinary knowledge production approaches and doctoral training contexts, such as those central to this dissertation, could be folded into what Szelényi and Bresonis (2014) found to be an expansive organizational space at the intersection of the academic capitalist and public good knowledge regimes. To some degree, this dissertation clarifies the ways in which interdisciplinary socialization contexts support and engender threads of academic capitalism. For example, in traversing their innovation clinic projects embedded in coastal community concerns, Coastal women were often using market-driven language to characterize their projects. They were serving “clients” and acting as “consultants” as they worked with external stakeholders who represented a variety of outside organizations, including ones in the private sector. An illustrative case in point is the team of IGERT students who were working with a client to help understand the potential for economic growth and expansion of a particular coastal town through the development of an ocean cluster of local businesses and fishing industries.

Market-like influences could also be observed in the availability of and access to additional funding at all three IGERTs to support students’ research projects, facilitate conference participation and travel and, in the case of Suburban, to support entrepreneurial activity. Financial resources were thus highlighted as essential in catalyzing interdisciplinary programs, in clear alignment with the fund-seeking aspects of academic capitalism (Szelényi, 2013). Several women from Coastal and Valley expressed lack of clarity about the nature of these funds and how and under what conditions such funds could be sought or accessed. Suburban women illuminated market-driven properties of their IGERT innovation clinic experiences, which were structured as innovation competitions through which students could win available IGERT funds. Erica, who was fortunate to win several times, used her monetary rewards to fund materials for her dissertation research at Suburban. It was unclear how other Suburban students faired in such events, although some were looking ahead and strategizing about participation in future competitions.

In this dissertation's focus on the socialization experiences of women doctoral students in NSF-funded IGERT contexts, various public good expressions also prominently emerged from women's perspectives. Figure 6 below depicts four distinct public good expressions of interdisciplinarity that women described as they made meaning, critically considered, and reclaimed their interdisciplinary socialization in the E-E Dimension.

Figure 6. Public Good Expressions of Interdisciplinary Conceptualized in the E-E Dimension



The participants described various ways in which their interdisciplinary socialization contexts helped shape and support many discreet forms of public good enactments and helped them envision future research and career directions with clear public good intentions and implications. One expression of public good was visible in the ways in which women were actively thinking and engaging with stakeholders and community members beyond science and underlined the importance of working on research problems grounded in environmental, health, and societal well-being and longevity. Other public good expressions of interdisciplinarity were present in how women were conceiving of and aspiring to facilitate interdisciplinary knowledge through novel applications, including 1) interdisciplinary knowledge applications facilitated through public education and 2) interdisciplinary knowledge applications facilitated through policy. At Coastal, Maggie was cultivating her vision of interdisciplinarity to position herself to not only engage in interdisciplinary knowledge creation as a researcher, but also to marshal the participation of stakeholders and lawmakers, and to communicate interdisciplinary discoveries through public outreach and policy-making in ways that advanced interdisciplinary knowledge application to complex environmental problems.

The public good-oriented activities and aspirations of women in this study were also reflected in how they merged public good notions into their own personal embodiment of interdisciplinarity, especially in the way they stood up for women's rights and fought against gender (and other forms of) discrimination in STEM and society and in the way they were using interdisciplinarity as a lens to conceptualize social justice expressions of the public good. These women had stretched their interdisciplinary perspective to encompass human rights, with a special emphasis on issues of discrimination against women in STEM and society. In this social-justice expression of the public good, some women were actively bringing these topics into IGERT-based experiences. These efforts included Coastal women such as Chelsea, Maggie, Emily, and Abby organizing women in sciences discussions on the International Day of Women and Girls in Science and seeking involvement in outside organizations that addressed related issues, such as Emily's work with the non-profit organization supporting girls in computer science, Julia's (Valley) work in the graduate student organization, and Amaia's work (Suburban) as a Fulbright mentor.

Overall, then, interdisciplinary programs in doctoral education provide important opportunities to support the public good mission of higher education and scientific endeavors. The women doctoral students participating in this study were clearly drawn to not only making a range of public good contributions through their research, policy work, and outreach, but were also actively using their IGERT programs and a range of external organizations to express their perspectives around gender equity and to fight against discrimination in a variety of organizational and societal settings.

Practical Implications: Building and Cultivating Interdisciplinary Capacity

The NSF closed new funding to the IGERT program in 2015, with final funds dispersed to newest existing IGERT programs in 2019. The three IGERTs included in this study were operational during these final years. Thus, this dissertation captured information on doctoral socialization in three specific IGERT and university contexts at a critical period as the IGERT program was in its twilight. In addition to the research and theoretical implications outlined in this chapter, this dissertation also generates practical implications through its exclusive focus on the lived experiences of women doctoral students in IGERT programs. In the ensuing sections, implications flowing from a more nuanced understanding of the processes, contexts, and outcomes of interdisciplinary doctoral socialization will be discussed for universities, doctoral programs and departments, funding agencies, and in consideration of individual doctoral students and faculty who may aspire to engage in interdisciplinary pursuits. Based on the scope and purpose of this dissertation, implications will be focused on the ways in which universities can build and leverage interdisciplinary capacity, how doctoral education might change to foster interdisciplinary learning and perspective-sharing, and how funding agencies can help guide universities in developing and fostering deep and equitable interdisciplinary training experiences.

Implications for Universities

Although the NSF IGERT program has officially come to an end, interdisciplinarity remains a key component of many grant opportunities offered through other NSF programs, the National Institutes of Health (NIH), and other government and private funding agencies. Support for infusing interdisciplinary perspectives into university research thus remains high from a variety of funding agencies. For example, a news item at the Ohio State University College of Engineering website (https://ise.osu.edu/) reported that they recently won a NSF-sponsored National Science Foundation Research Traineeship (NRT) grant "to develop and implement bold, transformative models for science, technology, engineering and mathematics (STEM) graduate education training" (Langen, 2019, About Us/News section). The NRT program expressly focuses on funding effective training of STEM graduate students in high-priority interdisciplinary or convergent research areas. Further, many grant funding opportunities, regardless of the degree to which they focus specifically on interdisciplinarity, do expect proposals to discuss research initiatives in terms of potential impact on or application to other fields or to complex interdisciplinary problems. Fostering interdisciplinary perspectives through university missions, organizational structures, programs, and policies can build institutional capacity to gain grant support for promoting interdisciplinary approaches to research and doctoral education. As such, what institutional activities and incentives could be created that would help position universities to seek monetary support for interdisciplinary endeavors? How can universities draw from and create IGERT-like programming to strengthen interdisciplinary perspectives in all forms of doctoral education and training experiences and through faculty development programs?

One answer to these questions lies in envisioning how universities can capitalize on the benefits of interdisciplinary socialization in existing structures. Ideas for universities to strengthen interdisciplinary capacity could include lower-resource ways to create connections among graduate students and faculty from a broad range of different disciplines. In some universities, opportunities to promote interdisciplinary perspective-sharing could be facilitated through programming in already existing interdisciplinary centers, innovation centers and "maker-spaces," and through curricular interventions that work to expand interdisciplinary perspectives. For example, programming opportunities that bring together students and faculty from different disciplines for think-tank discussions around a central topic could potentially support disciplinary cross-fertilization and perspective-sharing.

To further support interdisciplinary activity in the faculty ranks, universities could consider ways to align tenure and promotion policies to promote, fairly evaluate, and reward interdisciplinary work. According to a report by Friedman and Wardell (2010), some universities have loosened or eliminated an emphasis on publishing in specific disciplinary journals or publishing as a single author. Policies around the make-up of tenure review committees, for example, could also be realigned in ways that support and fairly evaluate interdisciplinary work. Interdisciplinary structures and strategies that have been illuminated by other researchers (Harris & Holley, 2008; Holley, 2009ab; Klein, 2010; Sa, 2007, 2008a), for example, establishing interdisciplinary centers, cluster hiring of faculty, and joint departmental faculty appointments, could also be considered by universities as a way to establish and support more interdisciplinary activity among faculty. Visible and well-supported interdisciplinary activity within the university faculty would not only model interdisciplinary engagement for graduate students, but also provide opportunities to graduate students to become involved in the interdisciplinary research projects of faculty. Such experiences would offer graduate students a way to grow interdisciplinary perspectives, give them practice in framing research and carrying out interdisciplinary research projects, and widen their lens on potential future careers beyond academe.

Universities might also consider ways to strengthen ties with local communities, as well as prioritize and reward research initiatives that focus on various features of the interdisciplinary problems embedded in these communities. One way this can be cultivated is through modifying doctoral education curriculum in ways that place teams of students in closer proximity to research problems in local communities and engage students with a far greater variety of stakeholders. Universities, departments, and programs may be able to look to service-learning programs and participatory action research (PAR) models for expertise in facilitating symbiotic interactions between local communities and university actors.

Ideas for building institutional capacity for interdisciplinarity that would require a higher institutional commitment could also be considered. For example, universities could offer mini-grants, seed money, or other internal funding opportunities to support research and programs that bring together faculty and students from STEM, social/behavioral sciences, education, humanities, and other disciplinary areas to facilitate an expanded interdisciplinary perspective and create potential for collaboration to better understand complex interdisciplinary problems.

Implications for Doctoral Programs

Any doctoral program, not just those with a specific interdisciplinary focus, could consider ways to modify curricular and co-curricular experiences to promote interdisciplinary cross-fertilization, team-collaboration, and problem-orientation as a way of building institutional capacity for interdisciplinarity, to help students envision new and varied future research agendas and career pathways, and to increase the number of graduates better prepared to address 21st-century scientific and technological needs. This dissertation demonstrated ways in which interdisciplinary socialization occurred in three distinct IGERT contexts, two of which were more collaborative and grounded in environmental and societal concerns, and one that was more narrowly defined and grounded in more basic/pure scientific discovery.

In considering ways to foster interdisciplinary perspectives in doctoral education, discipline-focused doctoral programs could build intentional learning experiences that draw upon and facilitate the processes of interdisciplinary socialization, including cross-fertilization, team-collaboration, and problem-orientation, as well as anticipatory field creation. Diversifying the student experience in interdisciplinary ways provides an avenue for graduate students to consider a diverse array of future career pathways, which has become critical to incorporate into doctoral education in an era of decreasing full-time tenure-track faculty opportunities coupled with increased need to better prepare graduate students for non-academic careers (Austin, 2010; Austin & McDaniels, 2006; Hermanowicz, 2016; Maxey & Kezar, 2015; Nerad et al., 2004; Schuster & Finkelstein, 2006).

In bringing interdisciplinarity more intentionally into university organizational structures and graduate education, it is also important to anticipate what drawbacks or unintended consequences could emerge and to actively work to mitigate these. For example, interdisciplinary graduate training has been perceived as a potential disadvantage for students when disciplinary depth/specialization is compromised by time dedicated to increasing interdisciplinary breadth, depth, and fluency (Borrego & Newswander, 2011; Holley, 2009a, 2010, 2018). In considering women in STEM and other under-represented student populations in all disciplines, institutions may wish to ensure that these populations are not being pushed further to the margins by decreasing their focus on disciplinary training. In a very practical way, programs could be instituted to help graduate students who are following interdisciplinary pursuits construct self-narratives that they can utilize in their job search processes. Such assistance in developing career search materials would ideally help students highlight the ways – as demonstrated in this dissertation – in which the interdisciplinary knowledge and skills they exemplify strongly and uniquely position them a variety of careers.

On a larger scale, institutional assessment mechanisms could incorporate ways to assess interdisciplinary graduate student participation, advancement, and outcomes using equity-minded measures, or measures that identify and address patterns of inequity in student experiences and outcomes. This dissertation illuminated specific inequities in women's interdisciplinary doctoral socialization and training experiences visible in various forms of gender bias/discrimination, differential valuing/inclusion of some disciplines over others, and inconsistent access to discretionary IGERT funds, external networks, and career exploration opportunities. Universities could look to the Equity Scorecard tool and process developed at the University of Southern California's (USC) Center for Urban Education for expertise in equity-minded thinking and practice. Although the focus of the Equity Scorecard tool is to illuminate and address racial inequities in student outcomes, it holds the potential to help institutions and programs examine additional identity factors, such as gender, in understanding student experiences and outcomes (Bensimon, Polkinghorne, Bauman, & Vallejo, 2004).

Further, this dissertation's focus exclusively on the perspectives of women doctoral students suggests implications for doctoral education around how interdisciplinary contexts both supported and challenged women's participation and advancement in STEM. More attention should be paid to the role of the E-E Dimension in helping doctoral students actively conceptualize, test, and personalize their interdisciplinary perspective and integrate it into their science identities. In this dissertation, interdisciplinary socialization environments to varying degrees also offered and supported opportunities for discussions of the participation and advancement of women in STEM, and worked, at times, as a safe space for women to process past and current experiences with discrimination and harassment. Doctoral programs could more actively create safe spaces and support for these discussions to occur more frequently and transparently. In addition to bringing such themes into curricular experiences, programs could seek to develop stronger connections to women in STEM graduate organizations like Women in Science and Engineering (WiSE), Graduate Women in Science (GWIS), and other groups offering community and support for graduate students through workshops, seminars, and more informal group processing activities.

Overall, the interdisciplinary training environments in this study illuminated many equitable elements for women in STEM and academe, which underscores Rhoten and Pfirman's (2007) contention that interdisciplinary environments can be supportive places for women to practice science. It is equally important to note that interdisciplinary training environments in this study also highlighted a set of inequities, especially in exposing how disciplinary power and prestige hierarchies (Sallee, 2011b) are also inherently gendered, manifested within interdisciplinary contexts. In certain ways, interdisciplinary contexts can make disciplinary inequities for women more visible than they might be in single-discipline contexts, thus creating more potential for inequities to be addressed through changes in structures, policies, and programs. In other ways, interdisciplinary contexts, like those under examination in this dissertation, may also reproduce and escalate disciplinary tensions precisely because they are so visible and unavoidable.

With such healthy and unhealthy tensions in mind, what can universities and programs do to eliminate the more gendered aspects of disciplines? Can interdisciplinary spaces that are more inclusive of marginalized populations and disciplines serve as an exemplary space within which the work of dismantling disciplinary prestige hierarchies can be done? In considering these questions, a particular challenge grounded in academe as a whole is highlighted. Disciplinary hierarchies are reinforced and perpetuated primarily by the culture and structure of academia, which is where change would likely need to start before disciplines and inter-disciplines could be resourced and co-exist more equitably.

Implications for Government Agencies

The insights from this dissertation illuminate ways in which the depth and breadth of interdisciplinary socialization can vary across IGERT contexts and interdisciplinary doctoral training programs more broadly. The findings also highlight access and equity issues embedded in interdisciplinary doctoral socialization, especially ways in which available funding for students was, at times, unclear or difficult to access, or access was differential depending on discipline, cohort year, or project involvement. Government funding agencies looking to encourage more participation of women and people of color in the scientific enterprise might consider their role in providing administrative and programmatic guidance to awardees as it relates to creating equity-minded training initiatives and outcomes assessment programs. As mentioned above, USC's Center for Urban Education diversity scorecard is one tool that could potentially be adapted to examine, identify, and address a variety of student outcome inequities in interdisciplinary doctoral socialization contexts. Funding agencies could require grant proposals to include equity-minded rationales for programmatic elements, including but not limited to, how diversity and inclusion will be integrated in trainee application and selection, how various disciplines will be included and equitably represented, how trainees will be informed about and access discretionary training funding, and how historically underserved student populations fare in these programs and in their careers compared to students from more privileged populations.

Implications for Future Research

This dissertation's focus on understanding the socialization experiences of women doctoral students in interdisciplinary training contexts represents one way of examining the complexities of interdisciplinarity socialization and structures in higher education. My findings offer valuable insights into how universities could capitalize on the benefits of interdisciplinary doctoral socialization by adapting existing structures and programs to encourage more informal and formal exposure for a variety of audiences to interdisciplinary perspectives. Importantly, these perspectives will better position universities to seek financial support for interdisciplinary initiatives and to engender opportunities for interdisciplinary learning and project development among faculty, programs, and departments. More studies contributing to a broader and more in-depth understanding of this picture are warranted.

Several future lines of investigation flow from this dissertation. First, the narrative inquiry approach in this dissertation sought rich and nuanced understanding of the lived experiences of women doctoral students in IGERT programs. Studies designed to enrich this picture by capturing more longitudinal information represent a clear avenue for further examination. Questions such research might seek to address include: What career directions do women IGERT trainees ultimately follow? In what ways do their interdisciplinary training and perspectives advantage them in career opportunities and decisions? In what ways, if any, is interdisciplinary experience a barrier to envisioned or new career pathways? Studies focused longitudinally might also seek to discover how and to what degree former interdisciplinary trainees, including women, work in interdisciplinary fields or influence/facilitate interdisciplinary applications. Studies in this vein might also examine what public good themes and activities guide the careers of interdisciplinary trainees.

Case studies or other methods of qualitative, mixed methods, or quantitative inquiry that bring in additional methodological perspectives would also create a fuller picture of the processes, contexts, and outcomes of interdisciplinary socialization. These studies should pursue a central focus on issues of access and equity in doctoral student participation and socialization in interdisciplinary contexts. Studies such as these should consider including the perspectives of faculty/PIs; post-docs; administrators; students from all genders, races, and ethnicities; external stakeholders; and funding agencies.

On an organizational level, studies should examine the extent to which institutions that were funded as stewards of interdisciplinary traineeships like IGERT have institutionalized these structures after the conclusion of funding. These studies would help clarify best practices and identify what the challenges are to this type of institutionalization. How and to what extent interdisciplinary traineeship programs, like IGERT or NRT, consider and monitor issues of equity and inclusion would also be an area for further investigation. For these studies, it would be important to focus on differential socialization experiences based on disciplinary background, gender, and certain structural and contextual features of IGERT, including its topical and curricular foci, inclusion of stakeholders and networks outside of academe, and access to discretionary training funding, among others.

Conclusion

The suggestion by Rhoten and Pfirman (2007) that the modes of practice characterizing interdisciplinary work may be gendered in the sense that they are more aligned with the ways in which women envision the practice of scientific research, and thus constitute more welcoming spaces for women to engage, was central to this dissertation's focus. Examining the lived experiences of women PhD students engaged in interdisciplinary scientific traineeships helped to clarify how and to what extent the four modes of interdisciplinary practice entered into women's interdisciplinary socialization experiences. This study also highlighted how learning opportunities in IGERT contexts facilitated a constant interplay among three of the four modes of practice—cross-fertilization, team-collaboration, and problem-orientation—as a core feature of the participants' interdisciplinary socialization. In addition, study findings pointed to the more anticipatory nature of the field-creation mode of practice as a goal of interdisciplinary doctoral socialization, which offered students a powerful way to envision novel interdisciplinary pathways and career opportunities within and beyond academe. Clarifying the distinct functions of the four modes of practice in the interdisciplinary socialization of doctoral students can offer doctoral programs a way to think more explicitly and intentionally about how to create learning opportunities that activate the four modes of interdisciplinary practice and help students incorporate interdisciplinary perspectives and skills into their doctoral education and future activities.

In considering a gendered link between women and interdisciplinarity in the sciences, as suggested by Rhoten and Pfirman (2007), my findings illuminated a far more complex phenomenon at play, visible in how women PhD students made sense of becoming interdisciplinary science people and depicted interdisciplinary values, norms, and beliefs. The specific emergence of the E-E Dimension of processing interdisciplinary socialization from the direct standpoints of women underscored the highly nuanced ways in which each participant made meaning of, critically considered, and reclaimed their interdisciplinary socialization to varying degrees and in a multitude of directions. Overall, the findings derived from the E-E Dimension described many gradations of how interdisciplinary spaces can be both welcoming and challenging for women, especially when factoring in contextual differences of the three IGERTs in this study and other permeating contexts of interdisciplinary socialization environments such as disciplinary hierarchies/cultures (Becher, 1990, 1994; Becher & Trowler, 2001; Sallee, 2011b) and academic capitalist-public good tensions (Slaughter & Leslie, 1997; Slaughter & Rhodes, 2004). The findings of this study thus provide an important and multi-faceted foundation for universities to consider and build on as they create interdisciplinary opportunities for doctoral students, with particular emphasis on women.

APPENDIX A

PARTICIPANT RECRUITMENT INVITATION

Subject Line: You are invited to earn up to $75 participating in a study exploring the experiences of women PhD students engaged in interdisciplinary traineeships

My name is Kate Bresonis and I am a doctoral student in the Higher Education program in the Department of Leadership in Education at the University of Massachusetts Boston. You are receiving this e-mail because you are a woman PhD student engaged in an interdisciplinary traineeship.

The research study I am conducting is interested in exploring how your experiences as a woman PhD students may be shaped by your participation in interdisciplinary traineeship activities. Your participation in this study would be greatly appreciated. By participating, you would be instrumental in helping to inform national science policy with a specific focus on women's interests and how women can be supported in STEM doctoral programs, fields, and careers.

Participation in this study will take approximately 1 to 1.5 hours of your time and will be completely confidential. If you accept the invitation to participate in this study, the researcher will arrange a convenient time for an in-person interview with you at a location of your choosing. For your participation in an interview, you will receive a $75 dollar gift card.

The information you provide in the interview will be completely confidential and will not be connected to any identifying information about you.

Due to the limited number of women involved in these traineeship experiences at the PhD level, your voice is important and your participation is highly valuable. Please contact Kate Bresonis at kateb826@yahoo.com or 617-276-2482 if you are interested in participating in all or part of the study or if I can answer any questions you may have about this study.

APPENDIX B

INTERVIEW GUIDE FOR NARRATIVE INTERVIEWS WITH PARTICIPANTS

This protocol is guided by a narrative inquiry approach. The questions are intended to encourage each participant to engage in story-telling about her own lived experiences. Thus, this protocol is constructed with a modest number of broad open-ended primary questions and a small group of subquestions to be used as potential probes. The primary questions are not intended to overly direct or structure the interview experience. Rather, they are intended to elevate the voice of the participant so she may be free to tell her story in the sequence and form she chooses while allowing space for organic pauses, silences, and other important verbal and non-verbal expressions of the story she tells to unfold.

Actively listening to a participant's story unfold in her own words and strategically asking participants to elaborate by using the phrases such as "Could you please say more about…?" or "Would you mind saying a bit more about what you meant when you said…?" will take precedence over using directive probes.

Select Demographic Information

- Name?
- Age?
- Country of origin?
- Undergraduate degree(s)/major(s)?
- Graduate degree(s)/major(s)?
- PhD program/major
- PhD program department affiliation?
- Year/Stage of PhD program?
- Parents' educational attainment?
- Marital status?
- Children?

Early Experiences with Science, Interdisciplinarity, and Gender

Primary Questions:

- Could you tell me about your experiences with science starting from your earliest memories of the experience through the present?
- Could you tell me about your experiences with interdisciplinarity starting from your earliest memories of the experience through the present?
- Could you tell me about how (if at all) your experiences with science and/or interdisciplinarity have been shaped by your gender, starting with your earliest memories of the experience through the present?

Present Experiences as STEM PhD student

I. Personal Pathway to PhD

Primary Questions:

- Can you tell me the story of your personal pathway to becoming a PhD student?
- When you consider your PhD degree experience as a whole, can you tell me about any successes or proud moments that stand out for you?
- When you consider your PhD degree experience as a whole, can you tell me about any obstacles, challenges, or worries you encountered along the way?

II. Important Influences

Primary Question:

- Can you tell me the story of the people or events in your life from your earliest memories to the present that have been influential in your journey to where you are now as a STEM PhD student?

Potential Probes:

- *Who do you consider to be your most important mentors or supporters in your PhD experience? Can you describe how they support you?*
- *Are there people you expected to be supportive who did not meet those expectations? Please describe.*

III. PhD Dissertation/Thesis

Primary Question:

- Can you tell me about the process of choosing your dissertation/thesis topic and how the process has unfolded for you since then?

Potential Probes:

- *What is the focus of your thesis/dissertation project?*
- *How did you find this topic?*
- *Who is involved?*
- *What are the expectations for successful completion?*
- *What are the publishing expectations?*
- *How (if at all) has the interdisciplinary research experience shaped your thesis project?*

IV. Career Aspirations

Primary Question:

- Can you tell me about what types of careers have interested you most from your earliest memories to the present?

Potential Probes:

- *How or from whom do you get information about possible careers?*
- *Have your career interests changed from when you started your PhD? Please describe.*
- *How (if at all) has your interdisciplinary training shaped your career aspirations?*
- *Can you tell me about how your gender may have shaped your career aspirations?*

Present Experiences with Interdisciplinarity

Primary Questions:

- Can you tell me the story of how you became involved in an interdisciplinary training program?
- Can you walk m through what a typical day is like for you in your interdisciplinary traineeship?

Potential Probes:

- *Could you tell me about what it is like and what it has been like for you to train in and practice science in interdisciplinary contexts?*
- *What is your primary role as a trainee? Are there any other roles you take on? Please describe.*
- *If you have developed any personal or professional thoughts, feelings, and ideas about interdisciplinarity, could you describe these?*
- *What does interdisciplinarity mean to you as a current STEM PhD student? As a (future) scientist?*
- *What are the goals of the interdisciplinary research you are working on? Probes: Basic vs. Applied? Impact? (e.g., Health? Environmental? Economic?)*
- *Can you tell me a little bit about who else works with you on this research? What are their roles? What are your interactions with them like? Relationship with Advisor? Lab mates? PIs? Peers? Post-Docs? External collaborators?*
- *Have you ever felt or experienced any tensions participating in interdisciplinary research? If so, how would you describe these?*
- *How does publishing happen in the interdisciplinary research group? What has been your involvement?*

Present Experiences with Science/Scientific Norms, Values, & Practices

Primary Questions:

- Can you walk me through a time when you felt most excited about being a scientist or participating in scientific research?

Potential Probes:

- *What, in your view, are the most important goals of science?*
- *How would you describe your scientific values? Or, in other words, what is important to consider or value when practicing science or doing scientific research?*
- *How (if at all) have your interdisciplinary research experiences shaped your values about science and scientific research?*
- *If you could make up your own scientific value system, what would it include?*

Present Gendered Experiences

Primary Question:

- Can you walk me through a time when you felt as if your role or status as a women was helpful in in your PhD pathway?
- Can you walk me through a time when you felt as if your role or status as a women was helpful in your interdisciplinary training?
- Can you walk me through a time when you felt as if your role or status as a women was compromising/hurtful in your PhD pathway?
- Can you walk me through a time when you felt as if your role or status as a women was compromising/hurtful in your interdisciplinary training?

Potential Probes:

- *Can you tell me about any positive or negative experiences you have had in your PhD program that stand out to you because gender (yours or someone else's) played a role?*

Advice for Other Women & Girls

Primary Questions:

- What advice would you give to other women who are thinking about pursing or preparing to start a science and engineering PhD program?
- What advice would you give to other women who are considering interdisciplinary training as part of their PhD experience?

APPENDIX C

UMASS BOSTON INSTITUTIONAL REVIEW BOARD

CONSENT TO PARTICPATE IN ONE-ON-ONE INTERVEWS

THE ENTANGLEMENT OF GENDER, SCIENCE, AND INTERDISCIPLINARITY: STANDPOINTS OF WOMEN PHD STUDENTS IN THE SCIENCES

KATE BRESONIS MCKEE, DOCTORAL CANDIDATE

Introduction and Contact Information

You are asked to take part in a research project that studies the socialization of women PhD students in STEM majors who are engaged in interdisciplinary traineeships. The researcher is Kate Bresonis McKee (Doctoral Candidate in Higher Education, Department of Leadership in Education, University of Massachusetts Boston).

Please read this form and feel free to ask questions. If you have further questions later, Kate Bresonis McKee will gladly discuss them with you. Her telephone number is (617) 276-2482 and e-mail address katebresonismckee@gmail.com

Description of the Project

This study seeks to address a significant gap in our understanding of STEM education by examining the socialization of women doctoral students in science, engineering, and technology fields, with specific focus on their experiences as interdisciplinary research trainees. If you decide to participate in this study, you will be asked to participate in a one-on-one interview with the researcher that will take approximately 1 to 1.5 hours. All participants in the one-on-one interview will receive $75 dollars.

Confidentiality

Your part in this research is ***confidential.*** *That is, the information gathered for this project will not be published or presented in a way that would allow anyone to identify you. Information gathered for this project will be stored in a locked file cabinet and a password-protected computer and only the researcher will have* *access to the data. Upon completion of this project, the link between personally identifying information and participant data will be destroyed.*

Risks or Discomforts

The primary risk associated with this study is the emergence of negative or distressful feelings in completing the research materials. You may speak with Kate Bresonis McKee to discuss any distress or other issues related to study participation.

Voluntary Participation

The decision whether or not to take part in this research study is voluntary. If you do decide to take part in this study, you may terminate participation at any time without consequence. If you wish to terminate participation, you should let the researcher know in person or via phone or email. Whatever you decide will in no way penalize you.

Rights

You have the right to ask questions about this research before you sign this form and at any time during the study. You can reach Kate Bresonis McKee via email at katebresonismckee@gmail.com or by phone at (617) 276-2482. If you have any questions or concerns about your rights as a research participant, please contact a representative of the Institutional Review Board (IRB), at the University of Massachusetts Boston, which oversees research involving human participants. The Institutional Review Board may be reached at the following address: IRB, Quinn Administration Building-2-080, University of Massachusetts Boston, 100 Morrissey Boulevard, Boston, MA 02125-3393. You can also contact the Board by telephone or e-mail at (617) 287-5374 or at human.subjects@umb.edu.

Signatures

I have read the consent form. My questions have been answered. My signature on this form means that I consent to participate in this study.

Signature of Participant	**Date**	**Signature of Researcher**
Printed Name of Participant		**Printed Name of Researcher**

APPENDIX D

UMASS BOSTON INSTITUTIONAL REVIEW BOARD

CONSENT TO AUDIO-TAPING & TRANSCRIPTION

THE ENTANGLEMENT OF GENDER, SCIENCE, AND INTERDISCIPLINARITY: STANDPOINTS OF WOMEN PHD STUDENTS IN THE SCIENCES

KATE BRESONIS MCKEE, DOCTORAL CANDIDATE

UNIVERSITY OF MASSACHUSETTS BOSTON

This study involves the audio taping of your interview with the researcher. Neither your name nor any other identifying information will be associated with the audiotape or the transcript. Only the researcher will be able to listen to the tapes.

The tapes will be transcribed by the researcher and erased once the transcriptions are checked for accuracy. Transcripts of your interview may be reproduced in whole or in part for use in presentations or written products that result from this study. Neither your name nor any other identifying information (such as your voice or picture) will be used in presentations or in written products resulting from the study.

Immediately following the interview, you will be given the opportunity to have the tape erased if you wish to withdraw your consent to taping or participation in this study.

By signing this form you are consenting to:

- ❑ having your interview taped;
- ❑ to having the tape transcribed;
- ❑ use of the written transcript in presentations and written products.

By checking the box in front of each item, you are consenting to participate in that procedure.

This consent for taping is effective until the following date: November 15, 2017 (six months after the close of the study, which is scheduled to conclude on May 31, 2017). On or before that date, the tapes will be destroyed.

Participant's Signature ____Date____________

APPENDIX E

RECEIPT OF INCENTIVE FOR RESEARCH PARTICIPATION

I, ____, a participant in an IRB approved research study conducted by Kate Bresonis McKee, Doctoral Candidate, University of Massachusetts Boston, received an incentive in the amount of $75.00 for my participation in an in-depth interview.

________________________________ ___________________________

Signature of Participant Signature of Researcher

____

Date

____

Printed Name of Participant

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