The Intellectual Impact of Interdisciplinarity:

A Series of Studies of Graduate

Students and Faculty Engaged in Interdisciplinary Scholarship

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Abstract

While disciplinarity still dominates college and university life, enthusiasm for interdisciplinary approaches has increased over the past three decades. Proponents often present interdisciplinarity as an *a priori* good, but scholars have noted that we have not yet sufficiently evaluated the efficacy of interdisciplinary initiatives. Most assessments of interdisciplinary initiatives have focused on tangible outcomes such as grants, papers, and patents. This is an unfortunate critical gap in the examination of interdisciplinarity, as it is possible that engagement in interdisciplinary activities changes student and faculty thinking in significant ways. This dissertation proposes to address the gap in the examination of interdisciplinarity regarding interdisciplinary learning outcomes by investigating the intellectual impact of interdisciplinary initiatives on students and faculty.

Utilizing a manuscript approach for the dissertation experience, this series of qualitative studies is organized around three areas of inquiry related to learning in interdisciplinary contexts: (a) how systematic interdisciplinary training affect doctoral students' epistemic beliefs, that is, how they view the construction of knowledge and the nature of scholarship; (b) what faculty learn from engaging in interdisciplinary research initiatives, and what tools mediate this interdisciplinary learning process; and (c) whether an interdisciplinary training effort promotes the creation of an alternative community of practice for participating students and faculty.

The studies were part of a larger mixed methods assessment of the efficacy of the EIGER program. Participants were selected based upon their affiliation with one specific interdisciplinary graduate training initiative, the EIGER program, at Virginia Tech, and came from the hard sciences, engineering, and social sciences. Informed by grounded theory, analysis of the data revealed that both graduate students and faculty achieve interdisciplinary understanding as a result of their interdisciplinary training and research experiences. Furthermore, faculty interdisciplinary learning is mediated by other people and two categories of tools, problem platforms and solution mechanisms, and is achieved by both borrowing and lending of disciplinary expertise. Finally, results suggest that programs like the EIGER may constitute emerging communities of practice that serve as alternatives to traditional disciplinary communities.

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Attribution

Dr. Deborah Olsen, Ph.D., formerly of the Educational Psychology program at Virginia Tech, aided in the writing and research behind Manuscript #1. Specifically, she is named as second author for her role in collecting the data as part of the NSF IGERT Grant # DGE-0504196, and for her assistance in revising the coding scheme employed to organize and analyze the qualitative data, and for her assistance in editing the manuscript.

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Introduction to the Dissertation

Background and Rationale for the Dissertation

Universities are "complex social institutions" that function "as settings for educational activities of teaching and learning, for organizational practices to coordinate and manage academic work, for elaborating careers and professional identities, and for legitimating enduring as well as emerging knowledge categories" (Gumport & Snydman, 2002, p. 400). For over a century, these four facets of the university's mission primarily have been fulfilled by the academic disciplines. Despite their relative historical youth, disciplines dominate academe (Klein, 1990; Lattuca, 2001). In his work detailing the intellectual, cultural, and organizational influences on faculty life, Clark marveled that "there is no more stunning fact about the academic profession anywhere in the world than the simple one that academies are possessed by disciplines… even as they are located in institutions" (Clark, 1987, p. 25). He further characterized the discipline as *the* dominant force defining the professional lives of most faculty. Disciplines each have their own cultures, including unique categories for knowledge classification and validation, initiation rites, social interactions, and approaches to specialization and sub-specialization within the field (Becher, 1987). As a result, faculty's disciplinary loyalties can, on occasion, supersede institutional concerns (Becher, 1987; Clark, 1987; Donald, 2002; Frost & Jean, 2003).

While disciplinarity still dominates post-secondary approaches to research, teaching, and learning, enthusiasm for interdisciplinary approaches has increased over the past three decades. Scholars have articulated multiple reasons for this. Recently, the National Academies identified four drivers behind interdisciplinary research: (a) the inherent complexity of nature and society, (b) the desire to explore problems and questions that are not confined to a single discipline, (c) the need to solve societal problems, and (d) the power of new technologies (National Academies, 2005, p. 40). Other reasons for engaging in interdisciplinary scholarship have been articulated as well. These include: (a) the a desire to ensure a broad interdisciplinary basis for general education, liberal studies, and professional training; (b) response to contemporary social, political, and epistemological critique which works to deconstruct bounded ways of knowing which inherently maintain unproductive biases; (c) transdisciplinary approaches that emphasize networks and thinking in terms of complex systems; and (d) faculty development and

institutional downsizing (Klein & Newell, 1996; Klein, 1996). Regardless of whether interdisciplinary approaches are employed to solve large discipline-crossing societal problems like global warming, or are used to critique existing disciplinary frameworks or to employ paradigms like networks that are applicable in multiple contexts, there is also the basic desire to work with others from different disciplines. This represents the intellectual curiosity that brought many graduate students and faculty to academia in the first place (Bohen & Stiles, 1998; Frost & Jean, 2003). The diversity of reasons for engaging in interdisciplinary scholarship is reflective of the diversity of teaching and research activities interdisciplinarity encompasses.

Proponents have credited interdisciplinarity with adding important new elements to traditional college and university curricula (Bastedo, 2005), and for producing significant scientific breakthroughs (Klein, 1996). Scholars, however, have noted that we have not yet sufficiently evaluated the efficacy of interdisciplinary initiatives (National Academies, 2005). Most assessments of interdisciplinary initiatives have focused on tangible outcomes such as grants, papers, and patents, leaving "intellectual outcomes of interdisciplinary scholarship…virtually unexamined" (Lattuca, 2001, p. 50). Those studies that did include intellectual factors in their design conceptualized them as inputs (i.e., individual intellectual characteristics of participants) shaping the interdisciplinary experience, rather than as measurable learning outcomes, such as the development of new knowledge, skills, or epistemic beliefs (Lattuca, 2001; Lattuca, Voigt, & Fath, 2004).

This is an unfortunate critical gap in the examination of interdisciplinarity, as it is possible that engagement in interdisciplinary activities changes student and faculty thinking in significant ways, perhaps even reshaping their conceptions of their home disciplines and their disciplinary identities (Lattuca, 2001). Research exploring the intellectual outcomes of participation in interdisciplinary work needs to be conducted. The infusion of interdisciplinary approaches to scholarship in academia has important implications for the structures, educational philosophies, and missions of colleges and universities. If institutions of higher education are to continue to serve society as arbiters of knowledge (Gumport & Snydman, 2002), documenting and understanding learning as an outcome of interdisciplinary experiences, as well as how these experiences contribute to the knowledge creation, transmission, and legitimization process, is imperative.

Purpose of the Dissertation

This dissertation proposes to address the gap in the examination of interdisciplinarity regarding interdisciplinary learning outcomes by investigating the intellectual impact of interdisciplinary initiatives on students and faculty. Specifically, the dissertation proposes to investigate doctoral student and faculty learning within one interdisciplinary context, the Exploring Interfaces in Graduate Education and Research, or EIGER, program at Virginia Tech. The EIGER is one of over 100 programs funded by the National Science Foundation's Interdisciplinary Graduate Education and Research Traineeship, or IGERT, program. IGERT programs are designed to augment the traditional disciplinary doctoral training by developing in graduate students the capabilities necessary for engaging in successful interdisciplinary teaching and research (Council of Graduate Schools, 2007). Combining interdisciplinary science with practical experience derived from a combination of academic coursework, internships, and generous funding, the IGERT program's aim is to "establish innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries" ("IGERT FAQ's", n.d.).

Very little is known regarding the learning outcomes experienced by doctoral students participating in explicitly interdisciplinary training, and by faculty engaged in interdisciplinary research and teaching. Furthermore, while there are taxonomies available for evaluating the levels of integration achieved in various interdisciplinary contexts (see Franks, et al., 2007, for a review) and for evaluating specific examples of undergraduate student work (e.g., Boix Mansilla & Duraising, 2007), it does not appear that any one theoretical framework has been applied to evaluate the cognitive changes resulting from an interdisciplinary experience.

Given that it is traditionally in graduate school and then in the practice of the academic profession that individuals more completely integrate disciplinary perspectives into one's sense of self and one's place in the academic universe (Becher, 1989; Mendoza, 2007), an investigation of the intellectual impact of interdisciplinary experiences on doctoral students and faculty members could prove to be particularly fruitful. As such, this dissertation draws upon extant literature not only addressing the phenomenon of interdisciplinarity, but also upon sociocultural theories of cognition and knowledge creation. These theories will help to parse out

the learning outcomes, the process by which learning occurred, and the tools employed to promote learning in interdisciplinary contexts.

Organization of the Dissertation

Utilizing a manuscript approach for the dissertation experience, this series of studies is organized around three areas of inquiry related to learning in interdisciplinary contexts:

1. Manuscript #1: How does systematic interdisciplinary training affect doctoral students' epistemic beliefs, that is, how do they view the construction of knowledge and the nature of scholarship?

2. Manuscript #2: What do faculty learn from engaging in interdisciplinary research initiatives? What tools mediate this interdisciplinary learning process for faculty?

3. Manuscript #3: Does an interdisciplinary training effort promote the creation of an alternative community of practice for participating students and faculty?

The first manuscript, co-authored with Dr. Deborah Olsen, focuses on the impact of the EIGER program on participating doctoral students. Informed by grounded theory (Charmaz, 2006), the study explores how systematic interdisciplinary training affects their epistemic beliefs, or how they view the construction of knowledge and the nature of scholarship (Donald, 2002). The study employs Boix Mansilla & Duraising's (2007) framework for *interdisciplinary understanding*, comprised of the three stages of disciplinary grounding, integration, and critical awareness, as a rubric by which student epistemological development within the EIGER program can be characterized.

Using data collected from interviews with faculty affiliated with the EIGER program, the second manuscript examines one potential intellectual outcome of interdisciplinary faculty work, interdisciplinary understanding, and how it is developed. The purpose of the study is twofold: first to identify and document whether interdisciplinary understanding is a learning outcome for faculty involved in interdisciplinary research, and second to determine what mediates this learning process for faculty. The study employs the framework for interdisciplinary understanding used in the first manuscript, as well as conceptions of faculty work as learning (Lattuca, 2002; Lattuca, 2004) and sociocultural perspectives on learning (Fosnot, 2005; Lattuca, 2002; Rieber & Robinson, 2004; Vygotsky, 1978) to more clearly identify how faculty learning within the interdisciplinary contexts transpired.

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Written specifically for a broader lay audience, the third manuscript examines the lived experience of EIGER fellows and faculty through the first-person account of the author in order to describe and understand the shared patterns of the group (Creswell, 2006). Lave and Wenger's (1991) community of practice metaphor provides the framework for the study. This manuscript uses multiple data sources, including data collected from semi-structured interviews with students and faculty, materials produced as part of the EIGER program (such as course assignments), as well as the author's field notes and reflection journal to determine whether the EIGER program meets Wenger's (1998) criteria for a community of practice.

Limitations and Delimitations of the Dissertation

This study is a qualitative exploration of a single interdisciplinary context at a single institution. This could be construed as a limitation of the study. However, the dearth of current research on the intellectual outcomes of interdisciplinary experiences suggests a lack of available theoretical frameworks to guide hypothesis testing. Instead, a qualitative approach broadly informed by grounded theory allows for the development of new theoretical frameworks regarding interdisciplinary learning outcomes. Furthermore, manuscript three appropriately accommodates the first-person, lived experience of the researcher in the evaluation of the EIGER program as a community of practice. The deep, rich exploration of the EIGER program acknowledges and respects its uniqueness while nesting it within the larger universe of the IGERT program, a significant effort to introduce interdisciplinary training that complements existing disciplinary structures and conventions. Finally, this dissertation represents a first step in this line of research. By achieving an understanding of both the doctoral student and faculty learning, we will ultimately be able to triangulate these perspectives as a next step in this line of scholarship, comparing and contrasting student and faculty experiences and potentially developing subtle, but important distinctions between the two.

Summary

This dissertation examines the intellectual impact of interdisciplinary training and research opportunities on graduate students and faculty, thereby addressing one critical gap in the consideration of interdisciplinarity. Specifically, the studies that constitute the dissertation are designed to: (a) identify and document the development of one potential interdisciplinary

learning outcome, interdisciplinary understanding, in graduate students; (b) determine if interdisciplinary understanding is a learning outcome of faculty's interdisciplinary work, and if so, to identify what mediated faculty's interdisciplinary learning processes; and (c) determine whether the EIGER program constituted an emergent community of practice for its graduate student and faculty participants. Through the use of the manuscript approach, this dissertation aims to help clarify the educational value of interventions like the EIGER program for both scholars of interdisciplinarity as well as institutional leaders and policymakers charged with promoting interdisciplinarity on college and university campuses.

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The Impact of Interdisciplinary Training on Doctoral Students' Epistemic Beliefs:

Interdisciplinary Understanding as an Intellectual Outcome of Graduate Education

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Abstract

The current paper focuses on the impact of one graduate training opportunity, an NSF Interdisciplinary Graduate Education and Research Traineeship (IGERT) program, designed to enhance doctoral students' interdisciplinary experience and skills. Informed by grounded theory, it examines students' interdisciplinary understanding (Boix Mansilla & Duraising, 2007). Specifically, the study explores how systematic interdisciplinary training affects students' epistemic beliefs, that is, how they view the construction of knowledge and the nature of scholarship (Donald, 2002). The paper contends that interdisciplinary understanding is not fully achievable without developing a set of general epistemic beliefs, and that these general epistemic beliefs create knowledge structures that serve as a "tool set" for students navigating the structures, theories, methods, and tools of multiple disciplines. The goal is to help clarify the educational value of interventions specifically intended to promote interdisciplinary scholarship.

Introduction

In the last decade, large-scale studies of doctoral education have been sponsored by the Pew, Carnegie and Ford Foundations, as well as the National Research Council (NRC) and the National Science Foundation (NSF) (Wulff, Austin & Associates, 2004), highlighting concerns regarding the academy's ability to prepare graduate students as future scholars and faculty members. Critics of graduate education have been particularly skeptical about the limited opportunities for interdisciplinary investigation within doctoral programs. In its most recent report, the Council of Graduate Schools (2007) argued that American economic competitiveness will be dependent upon "workers who exhibit not just the mastery of a subject area, but the creative ability and drive to reshape the boundaries of knowledge" (National Academies, 2005, p. 5).

Recommendations for reform to graduate education call for the creation of multi-, cross-, and interdisciplinary experiences for doctoral students ("Re-invisioning the Ph.D.", n.d.). In her consideration of the preparation of the next generation of faculty, Austin (2002) concluded that:

> In addition to the grounding in the history, questions, and methods of one's field, the faculty of the next generation must know how to connect their disciplines to other fields to address questions that demand interdisciplinary expertise and perspectives. They should also develop some knowledge of the range of ways of knowing and the variety of methodological approaches so that they can interact productively with colleagues with different perspectives and engage responsibly in the evaluation of other colleagues, a responsibility that is a critical part of maintaining quality within the academy. (Austin, 2002, p. 125)

Despite such appeals for interdisciplinary components within doctoral curricula, just over one quarter of doctoral students believed their programs of study adequately prepared them for interdisciplinary collaboration (Golde & Dore, 2001).

NSF's Interdisciplinary Graduate Education and Research Traineeship, or IGERT, represents one highly visible attempt to infuse interdisciplinarity into doctoral education. The explicit goal of the IGERT program is to establish "innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries" ("IGERT FAQ's", n.d.). The IGERT program strikes a balance between interdisciplinary and disciplinary concerns, creating a space for graduate students to explore interdisciplinary scholarship and opportunities while simultaneously developing the disciplinary expertise characteristic of traditional doctoral work.

Relatively few studies have focused specifically on student learning resulting from interdisciplinary experiences (e.g., Boix Mansilla & Duraising, 2007; Lattuca, Voigt, & Fath, 2004; Newell, 1994), and most assessments have focused on how closely activities conform to different taxonomies for interdisciplinary work, associating "*quality work* with *greater integration*" (Boix Mansilla & Duraising, 2007, p. 229). It is thus not clear that the educational effects of interdisciplinary training have been calibrated as fully as necessary given current recommendations for reform in this direction. In fact, the National Academies has encouraged social scientists to more "fully elucidate the complex social and intellectual processes" (National Academies, 2005, p. 80) involved in interdisciplinary scholarship.

The current paper focuses on the impact of one IGERT program at Virginia Tech designed to enhance doctoral students' interdisciplinary knowledge and skills. Specifically, it examines the development of participating students' *interdisciplinary understanding* (Boix Mansilla & Duraising, 2007). It explores how systematic interdisciplinary training affects students' epistemic beliefs, that is, how they view the construction of knowledge and the nature of scholarship (Donald, 2002; Hofer, 2002; Hofer & Pintrich, 1997). The review of the literature on disciplinarity, interdisciplinarity, and epistemology demonstrates that rather than competing for emphasis in doctoral training, interdisciplinary and disciplinary efforts can be complementary modes of creating, organizing, understanding, and critiquing knowledge. Informed by grounded theory, this study examines student interviews to determine if interdisciplinary training makes participants more conscious of the knowledge construction process. The goal is to help clarify the educational value of interventions specifically intended to promote interdisciplinary scholarship.

Disciplinarity, Interdisciplinarity, and Epistemology

While currently entrenched in the culture of academia, modern conceptions of disciplinarity came about during the late nineteenth and early twentieth centuries, and can therefore be described as a recent historical phenomenon. Regardless, the effect of disciplinarity is visible throughout the academy (Klein, 1990), from curriculum design to promotion and tenure practices. The list of possible frameworks used to study and define the disciplines is quite long (Braxton & Hargens, 1996). Within the context of the first report on interdisciplinarity issued by the European Organisation for Economic Co-operation and Development (OECD) in the early

1970s, disciplinarity was defined as the "specialized scientific exploration of a given homogenous subject matter producing new knowledge and making obsolete old knowledge" (Heckhausen, 1972, p. 83). Disciplines were also described as being comprised of three types of elements: (a) observable and/or formalized objects manipulated by means of methods and procedures, (b) phenomena that are the materialization of the interaction between these objects, and (c) laws whose terms and/or formulations depend on a set of axioms which account for the phenomena and make it possible to predict how they operate (Boisot, 1972, p. 89-90). More recently, disciplinarity has been described as the "tools, methods, procedures, exempla, concepts, and theories that account coherently for a set of objects or subjects" (Klein, 1990, p. 104). They can be hard, soft, pure, applied, or synoptic (Donald, 2002, Klein, 1990; Klein, 1996); some can even be described as interdisciplinary themselves (e.g., environmental studies or women's studies). Disciplines can be powerful epistemological orientations (Lattuca, 2001), and can provide academic homes, even identities, for students and faculty alike.

Most significant to this discussion, disciplines represent a way of constructing and organizing knowledge. As a body of knowledge, disciplines possess a reasonably logical taxonomy, a specialized vocabulary, an accepted body of theory, a systematic research strategy, and techniques for replication and validation (Donald, 2002, p. 48). There is a focus on standards and on rigor. Each of these factors helps determine how those working within a disciplinary framework can contribute to the knowledge construction process, either by revising or adding to the disciplinary canon. The peer review process is privileged in the development of disciplinary knowledge. In contrast, interdisciplinary work is, by definition, less concerned with adhering to singular disciplinary prescriptions.

The Relationship Between Interdisciplinarity and the Disciplines

Broadly speaking, interdisciplinarity is the interaction among two or more disciplines. This interaction may range from the "simple communication of ideas to the mutual integration of organizing concepts, methodology, procedures, epistemology, terminology, data, and organizations of research and education in a fairly large field" (OECD, 1972, pp. 25-26). Addressing the challenge of defining interdisciplinarity, the National Academies (2005) provided a "point of departure" for future discussions, describing interdisciplinary research as:

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a mode of research by teams or individuals that integrated information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field or research practice. (p. 26)

The idea of integration, the "synthesis of ideas and methods" (National Academies, 2005, p. 27), is pervasive in the literature. It is a necessary component to most conceptions of interdisciplinarity, but integration alone is not sufficient. Interdisciplinarity also involves "knowledge negotiation and new meanings, not simply one more stage in 'normal' science" (Klein, 1990, p. 21).

Interdisciplinarity has also been described using various taxonomies (see Franks, et al., 2007, for a review). In terms of research, Heckhausen (1972) differentiated between indiscriminate interdisciplinarity, pseudointerdisciplinarity, auxiliary interdisciplinarity, composite interdisciplinarity, supplemental interdisciplinarity, and unifying interdisciplinarity, moving up the continuum in order of "ascending maturity" (Heckhausen, 1972, p. 87-89), or greater integration. Jantsch (1972) divided interdisciplinary research into four categories: (a) multidisciplinarity, (b) pluridisciplinarity, (c) crossdisciplinarity, and (d) transdisciplinarity, with transdisciplinary research achieving a desired "coordination of all disciplines and interdisciplines in the education/innovation system" (Jantsch, 1972, p. 106). Interdisciplinary courses and research have also been described as informed disciplinarity, synthetic interdisciplinarity, transdisciplinarity, or conceptual interdisciplinarity (Lattuca, 2001; Lattuca et al., 2002). Categorization within this rubric depends not just on the level of integration achieved, but on the nature of questions being addressed, as "different kinds of questions lead to different kinds of interdisciplinarity" (Lattuca, 2003, p. 5). Research questions might be rooted in a particular discipline but require outreach to another, they could link or cross disciplines, or they could be entirely devoid of any compelling disciplinary foundation or orientation (Lattuca, ibid.).

Lattuca's (2003) point is a significant one. Interdisciplinary research questions may not be so much an outgrowth of disciplinary knowledge as they are the distillation of a broader, complex problem into its key components. The framing of the problem dictates how best to address it and which theoretical and methodological approaches are most appropriate (Karlqvist, 1999). This may be what makes interdisciplinarity difficult to define. It may be an outgrowth of the disciplines, but interdisciplinarity is almost impossible to adequately describe using

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disciplinary vocabulary. While the refinement of the vocabulary around interdisciplinary scholarship has aided in the development of richer and more useful descriptions of its constituent activities, this focus on achieving definitional clarity may have left unanswered more concrete questions about the cognitive impact of interdisciplinary educational experiences, regardless of label or specific definition. Simply put, colleges and universities cannot help students develop intellectually in this direction unless they develop a better sense of what it is they are trying to teach. To that end, the academy must clearly operationalize what it means to become an interdisciplinary scholar.

Interdisciplinary Educational Outcomes

As interdisciplinarity has become more common in academia, its proponents often present it, *a priori*, as a curricular good. Limiting the current discussion to the attainment of higher order thinking skills and abilities, existing research tentatively supports this assertion (Newell, 1994; Lattuca, Voigt, & Fath, 2004). That said, scholars still need to address questions related to: (a) the articulation of learning outcomes for interdisciplinary experiences; (b) the identification of theories of learning and pedagogy employed within interdisciplinary experiences; and finally (c) whether or not interdisciplinarity promotes learning, including whether or not gains in student learning can be attributed to the interdisciplinary nature of an experience itself (Lattuca et al., 2004, p. 42-44).

Boix Mansilla and Duraising (2007) contributed one of the few studies focusing on assessment of the educational impact of interdisciplinarity. The result of a grounded study into expert faculty conceptions of quality interdisciplinary work at the undergraduate level, the framework described key features of interdisciplinary understanding. The authors defined interdisciplinary understanding as "the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement…that would have been impossible or unlikely through single disciplinary means" (p. 219). This cognitive advancement could be "explaining a phenomenon, solving a problem, or creating a product" (p. 219), and was based upon the acquisition and integration of knowledge from different disciplinary sources.

The framework focused on three core dimensions: (a) *disciplinary grounding*, the degree to which student work is grounded in carefully selected and adequately employed disciplinary

insights; (b) *integration*, the degree to which disciplinary insights are clearly integrated so as to advance student understanding; and (c) *critical awareness*, the degree to which the work exhibits a clear sense of purpose, reflectiveness, and self-critique (Boix Mansilla & Duraising, 2007, p. 222). The final stage moves us beyond integration; it represents the attainment of a level of self-consciousness about the knowledge construction process. The interdisciplinary understanding framework provides a useful mechanism by which we can begin to parse out evidence of specific changes in students' thinking about the nature of scientific knowledge and inquiry.

In this view, disciplinary and interdisciplinary approaches can be seen as mutually reinforcing strategies characterized by a productive tension (Klein, 2000; Weingart, 2000). The two are valued for different yet complementary reasons, one promoting innovation, one ensuring rigor and controlling for error (Weingart, 2000, p. 29). While the rhetoric surrounding interdisciplinarity can be heated, researchers studying it as a phenomenon impacting scholarly work have introduced a more measured tone to the conversation, arguing that the "difference between a disciplinary structure and a supposedly interdisciplinary one is not a mystical proximity or a better fit to 'reality'…but lies in the reasons and circumstances" (Weingart, 2000, p. 39) one framework is selected in lieu of the other. As such, sufficient expertise in one's home discipline as well as the knowledge, skills, and ability to differentiate a truly interdisciplinary problem from one that is not is required. Disciplinary expertise can be defined and articulated (e.g., Donald, 2002); interdisciplinary expertise, however, may reflect a more general set of knowledge structures based on broader, more self-conscious and creative conceptions of knowledge and knowing (Lattuca et al., 2004).

The Importance of Epistemology

Philosophically, epistemology "is concerned with the origin, nature, limits, methods, and justification of human knowledge" (Hofer, 2002b, p. 4). Within the realm of higher education, epistemology is generally defined as one's understanding of the nature of knowledge and knowing. It is "a field that examines what individuals believe about how knowing occurs, what counts as knowledge and where it resides, and how knowledge is constructed and evaluated" (Hofer, 2004b, p. 1). The effect of interdisciplinary initiatives on students' epistemic beliefs is one potentially rich area of exploration. Epistemology is of interest to educators and researchers as a variable impacting student learning and as an educational outcome unto itself; research has

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demonstrated that higher levels of epistemological development are associated with desirable learning outcomes like higher critical thinking and scientific reasoning skills and with academic achievement more broadly (e.g. Hofer & Pintrich, 1997; Hofer, 2004a; Klaczynski, 2000; Kuhn, 1999; Schommer, 1993; Schraw, 2001; Trautwein & Ludtke 2005) Interdisciplinarity, which requires navigating disparate or divergent information from multiple disciplines, may also promote the development of a more sophisticated sense of knowledge and knowing in students (Robinson, 1996; Klein, 1996). As such, "researchers will want to study learning outcomes of students in interdisciplinary programs to understand how such learning environments compare with discipline-based programs in terms of their influence on students' epistemological beliefs" (Lattuca et al., 2004, p. 36).

There has been considerable debate in the literature over whether epistemic beliefs exist at a general level that transcends disciplinary boundaries, or instead are located within and therefore shaped by disciplinary frameworks. Qualitatively derived stage models (Baxter Magolda, 1992; Baxter Magolda, 1999; Baxter Magolda, 2004; Belenky, Clinchy, Goldberger, & Tarule, 1986; King & Kitchener, 1994; Perry, 1970) posit that individuals conceptualize a broader, more generalized epistemology, a view challenged by those theorizing that epistemology exists as asynchronously developed, context-driven beliefs or resources (Hofer, 2004b; Hofer & Pintrich, 1997; Louca, Elby, Hammer, & Kagey, 2004; Schommer-Aikens, 2002). In other words, the question that must be considered is whether epistemological development differs from one academic domain to another, where students have one sense of knowledge and knowing in math, another in English, and so on.

Donald's (2002) treatment of learning to think within different disciplinary contexts, though not a study of epistemology in and of itself, did address issues of the nature of knowledge and knowing. She defined epistemology as a "theory of knowledge, its methods and validations" (Donald, 2002, p. 8), and identified differences between disciplines by employing four levels of analysis: (a) the delineation of concepts within a discipline, that is, the unit of thought or element of knowledge that allows for the organization of experience; (b) the logical structure of a discipline; (c) the criteria and processes used to determine validity within a discipline; and (d) methods and modes of inquiry, or the processes of thinking and operations used to describe them within a discipline.

In Donald's (2002) study, faculty participants articulated very specific thoughts about the nature of knowledge and knowing within their disciplines. For example, she contrasted the "orderly thinking" of physicists with their emphasis on coherence (Donald, 2002, p. 31) with the "hard thinking" of engineers, which required the application of structured knowledge to unstructured or ill-structured problems. Her coverage of the disciplines included multiple examples from the sciences, social sciences, and the humanities with *pure* (i.e., disciplines that use specific models or theories) and *applied* (i.e., disciplines that are open to environmental complexity and eclecticism) examples from each. This allowed for both within group and between group comparisons of disciplinary knowledge structures. Not only did "each discipline…(present) a competing way or ways of giving meaning to the world", Donald concluded that students learn different ways of making meaning and articulating that meaning "depending on their decision to concentrate on one discipline rather than another" (Donald, 2002, p. 271).

In an attempt to address the tension between domain-general and domain-specific conceptions of epistemology, Buehl and Alexander (2001) proposed a multilayered conception of epistemological beliefs, with domain-specific beliefs nested within academic epistemological beliefs, which were in turn nested within the broadest category, general epistemological beliefs. This conception lends itself to the consideration of students' interdisciplinary understanding. This paper contends that interdisciplinary understanding is not fully achievable without the development of a set of general epistemic beliefs, and that these general epistemic beliefs create knowledge structures that serve as a "tool set" for students navigating the theories, methods, and tools of multiple disciplines. Furthermore, these tools enable students to deal with whole new strata of research problems; they are able to recognize and transcend disciplinary boundaries while maintaining broader logical, ethical, scientific, and evidentiary standards. Finally, this paper posits that in order to effectively foster interdisciplinary understanding, training opportunities must explicitly address the knowledge construction process by considering the development of these general epistemic beliefs to be a necessary, desirable, and demonstrable student learning outcome.

Methodology

Participants

   The study included students participating in the Exploring Interfaces through Graduate Education and Research, or EIGER, program at Virginia Tech. Designed to augment traditional disciplinary doctoral training, the EIGER aimed to instill in graduate students the knowledge and skills necessary for successful participation in an interdisciplinary world (Council of Graduate Schools, 2007). Participating students and faculty came from the sciences, engineering, and social sciences. Specifically, the EIGER program provided courses to: (a) teach interdisciplinary knowledge and skills; and (b) develop the team-based skills fundamental to successful collaboration, and (c) model interdisciplinary treatment of a thematic research area (e.g., interface science).

   Participating students were in the EIGER program during the 2005-2006 (n=9) and 2006-2007 (n=14) academic years. Participants from 2006-2007 included both new and returning EIGER students; all students from year one persisted to year two. Additionally, with an eye toward theory construction (Chamaz, 2006), the study included a non-traditional "comparison" group of students who were matched to participating EIGER students based upon interest in and experience with interdisciplinarity, disciplinary home, and lab environment. This group of non-EIGER graduate students (n= 7) was included to offer potential points of contrast and comparison. The entire cohort of comparison students persisted to the second year of the study. Table 1.1 provides a breakdown of the participating students by affiliation and discipline.

Conceptual Framework

   The program was developed based on general principles gleaned from current scientific and educational literature on interdisciplinarity (Austin, 2002; National Academies, 2005; Wulff, Austin, & Associates, 2004) as well as the goals of the IGERT program ("IGERT FAQ's", n.d.). That said, there was little to guide expectations for *specific* program outcomes beyond general taxonomic progressions describing greater acquisition of cross-disciplinary content and methods and greater disciplinary integration. Left unanswered were questions about how students' thinking evolves when exposed to different disciplinary canons. As a result, the researchers examined student responses to the EIGER program using grounded theory (Charmaz, 2006; Glasser & Strauss, 1965, 1968; Strauss & Glasser, 1970).

Table 1.1. **Participating Students by Affiliation & Discipline**

	2005-2006		2006-2007	
	EIGER Cohort *4 men, 5 women (2 on one training grant)*	Comparison Cohort *2 men, 5 women*	EIGER Cohort (inclusive) *7 men, 8 women (2 on one training grant)*	Comparison Cohort *2 men, 5 women*
Life Sciences	3	2	4	2
Social Sciences	1	-	3	-
Physical Sciences	3	2	5	2
Engineering	2	3	3	3

Grounded theory provided "systematic, yet flexible guidelines for collecting and analyzing qualitative data" (Charmaz, 2006, p. 2). In line with the principles of grounded theory, the researchers: (a) engaged in simultaneous data collection and analysis; (b) constructed codes and categories from the data, not from preconceived hypotheses; (c) employed the constant comparative method, making comparisons at each stage of the analysis of the EIGER program, (d) made notes and wrote memos to further refine our categories and identify gaps in our data; and (e) developed the literature review after an independent analysis of the data (Charmaz, 2006; Glasser & Strauss, 1967; Glasser, 1978; Strauss, 1987).

This study was part of a larger mixed methods assessment of the efficacy of the EIGER program. Students participated in extensive semi-structured interviews and completed an activity report questionnaire annually. Broadly, they were designed to elicit information regarding students' development within the EIGER program. Students were interviewed in latter half of the fall semester each year. The interviews were approximately one hour in length. The interview protocols were tailored to the participants' status as either an EIGER student or a comparison student; the protocols for the EIGER students included questions specific to their participation in the program. Both protocols included questions regarding students' interdisciplinary background and experiences, current laboratory and/or research group environments, perceptions regarding

the advantages and disadvantages associated with interdisciplinarity, and future plans during and beyond graduate school. EIGER and comparison group students also completed an annual activity report at the conclusion of each academic year, documenting their work and labeling it as either disciplinary or interdisciplinary. They are asked several open-ended questions regarding their perceptions of the advantages and disadvantages of collaboration and interdisciplinary teams. The researchers drew upon the suggestions of Anfara, Brown, and Mangione (2002) when coding, beginning with generating codes that were then aggregated to develop themes from student responses. The third iteration further refined the themes based upon the researchers' return to the literature and subsequent employment of Boix Mansilla and Duraising's framework for interdisciplinary understanding. The fourth iteration represents the conclusion drawn from the study (see Appendix A for the interview protocols and coding map for the study).

Through the analysis of the data, themes related to attitudinal, behavioral, and epistemic changes in participating students emerged; this paper focus entirely on issues related to epistemology. Drawing upon Donald's (2002) work, the researchers operationalized students' epistemic beliefs as how students view the construction of knowledge and the nature of scholarship as it resides in, as well as transcends, their home disciplines. Another way to conceptualize epistemic beliefs is to think of them as evidence of students' habits of mind, which "include not only disciplinary content, but also styles of thinking, styles of presenting, and styles of questioning" (Strober, 2006, p. 320). Subsequent to coding, the researchers encountered literature related to their exploration of students' epistemic changes that was used to further refine the analyses (Boix Mansilla and Duraising, 2007). Finally, it is important to note that due to the small size of the cohorts participating in the study, student quotes are attributed as either EIGER or non-EIGER students only to prevent the identification of any one individual.

Findings and Discussion

Focusing primarily on the interview data, the researchers were able to identify emergent themes related to students' attitudinal, behavioral, and epistemic changes within the EIGER program. Initial coding of the first- and second-year interviews revealed that EIGER and non-EIGER students exhibited a general openness to interdisciplinarity and engaged in a range of behaviors and activities that could be characterized as interdisciplinary in nature. That said, closer reading of the interview transcripts revealed a difference between second-year EIGER

students and both their first-year EIGER as well as comparison student counterparts. By year two, EIGER students' thinking about research and scholarship exhibited a greater level of sophistication. As such, a more targeted consideration of how doctoral students viewed and constructed knowledge within an interdisciplinary context was required. Not surprisingly, themes grounded in the initial coding resonated with Boix Mansilla and Duraising's (2007) framework for assessing interdisciplinary work along three core dimensions: (a) disciplinary grounding, (b) integration, and (c) critical awareness.

The researchers sought to understand and document the changes occurring within EIGER and non-EIGER conceptions of knowledge and knowing by modifying this framework (Boix Mansilla & Duraising, 2007) according to what was heard in the student interviews as consecutive, yet fluid and interdependent stages through which students move as they acquire greater interdisciplinary understanding. In the analysis, students did appear to "progress" through phases of disciplinary grounding – both in their home disciplines as well as the disciplines to which they were exposed either formally or informally as a part of their doctoral experience – to integration and ultimately to critical awareness, an almost "metadisciplinary" stage, where they would be able to "identify disciplinary blind spots, consider opportunities for integration, navigate methodological differences, and choose among competing units of analysis" (Boix Mansilla & Duraising, 2007, p. 228). Careful thought and deliberation went into the application and expansion of the framework in order to evaluate doctoral students' epistemic beliefs as a result of interdisciplinary training.

The researchers expanded the framework – disciplinary grounding, integration, and critical awareness – in three key ways: (a) they interpreted disciplinary grounding to encompass not just the development of a requisite knowledge base in two or more disciplines, but also greater self-consciousness about disciplinary boundaries, examining the strengths and weaknesses of different disciplinary approaches to the knowledge construction process; (b) they operationalized integration as an increasingly sophisticated continuum, moving from the more straightforward accretion of methods, tools, and discrete facts or information (Klein, 1990) to the synthesis of paradigms and theories; and (c) they expanded the final phase of critical awareness to emphasize the adoption of new vantage points acquired through a more sophisticated perspective on interdisciplinarity, one marked by a greater ability to accommodate new ideas. Students in this phase moved beyond the evidentiary standards of their immediate discipline and

looked to more general principles of logic, induction, and even ethics in their problem solving efforts.

Phase I: Disciplinary Grounding - Perceiving Disciplinary Boundaries

Both EIGER participants and non-participants demonstrated a baseline confidence in their disciplinary expertise. As one non-EIGER student said, "I have the tools in place to address my questions." All participants self-identified as having an interest in interdisciplinary work, and they appeared to view interdisciplinarity as an extension of the traditional disciplinary approaches: "I aim to learn about things outside my field. I always wanted to do interdisciplinary work. I was not so much interested in any specific discipline as an undergraduate…I always felt I needed to look at different disciplines to see what they offer" (first-year EIGER student). Students relied on their home lab or research environments to help them develop the requisite expertise in the discipline in which they had selected to pursue the doctorate. A non-EIGER student spoke of the influence of his peers in his lab: "(We) are looking at different aspects of the same problem. A general growing body of knowledge, you know, we can talk the lingo, but from different perspectives."

As exposure to interdisciplinarity increased, the students began to identify levels of disciplinary differentiation. One first-year EIGER student commented on variation in units of analysis and their epistemological significance between his home discipline and others: "Engineering is on a bigger scale. In geosciences you look at things on a smaller scale. With these…courses you get a more complete picture…it's important to do this especially when you are getting a Ph.D. You get so focused you get lost in the details of your work." A second-year EIGER student credited the EIGER with prodding him to "read about new ways to do science, for example, like how civil engineers think and approach science" which resulted in learning about "how different disciplines approach problems." Non-EIGER students also spoke about parsing through disciplinary differences as they related to their research question. One credited his exposure to other disciplines through graduate school with broadening his interests and helping him to re-conceptualize how science works, and advised others to use grad school as a "time to get exposed to different things and learn about different things, a time to get exposure to interdisciplinarity (because) it is easier to learn about different things now rather than later."

Students also appeared to develop an appreciation not only for other disciplinary bodies of information, but also for their "theory of knowledge, (their) methods, and validation" (Donald, 2002, p. 8), a necessary step to developing "interdisciplinary competence" (Ivanitskaya, Clark, Montgomery, & Primeau, 2002, p. 101). A first-year EIGER student described her exposure to other disciplines as "eye-opening," and was fascinated by "other disciplines' mental models and how they think." As students' exposure to other disciplines increased, they also reflected on instances of disciplinary myopia, where scholars refused to acknowledge the usefulness of an alternative frame of reference:

> Even during my master's I was surprised at how different the mindset was coming from different disciplines. In my master's we had an engineering group working with some geologists, (and) they just couldn't get along. Couldn't get it together. We need to understand more about understanding and relating (to one another). These were all people I was inspired by but they were not coming together the way they should have been to make things really work. (first-year EIGER student)

Some students commented on the utility of the exposure to multiple disciplines, which helped them look at their own disciplinary research with fresh eyes:

> [The EIGER] is definitely not in changing my focus, but it may have expanded it to some extent. It helped me become more aware of how the other disciplines relate to what I do in my research. In terms of my thinking and learning, I think I am more open to possibilities, in terms of techniques and methods that I might apply to my research. (second-year EIGER student)

A non-EIGER student spoke of the challenge inherent to become expert in multiple disciplines in order to incorporate them into her dissertation research. That said, she was able to create coherency among disparate content by privileging the process over the product: "Most important (was learning) techniques for experimentation. From this I know how to find questions in my research and how to resolve them. What the project (is) is not as important as how to do the research."

Finally, second-year EIGER students in particular commented on the phenomenon of becoming cognizant of the limitations of their own knowledge base. As one second year EIGER student remarked: "When I was in…courses with scientists…I realized how little science I know. The scientists definitely go more in-depth." For another second-year EIGER, her exposure to other disciplines reshaped her understanding of her own research, reflecting newly divergent thinking on her part: "Well I see [my research problem] as a more specific instance of a larger

issue now. Before I would not have seen it as a surface interaction, so I have a new appreciation for the project and some ideas for things our lab could do." She began to see her research question in a new light. The problem was the same, but its placement within a new and larger context lent itself to considering new perspectives. These findings resonated with the experience of other IGERT students, who described a "'naissance' stage" in their development as scholars when they had to "gain sufficient grounding in various disciplines before identifying links between interdisciplinary and disciplinary identities" (Graybill, et al., 2006, p. 760).

Phase II: Integration – Crossing Disciplinary Boundaries

Across the board, students perceived integration as a necessary component of interdisciplinary work. Most first-year students spoke in terms of methodological integration. One first-year EIGER saw interdisciplinary research as a way to "broaden" his expertise by learning specific methods and techniques, while another described it as a means to an end. A third first-year EIGER student saw the program's chief benefit as providing access to other labs and researchers: "The program forces you to make connections with people that you probably wouldn't otherwise. It forces you to branch out. An example of this would be people who have access to equipment and can train you to do specific lab things."

The majority of the comparison group also appeared to equate borrowing with integration. They spoke of leveraging interdisciplinarity as a way to achieve efficiency in their research. One non-EIGER spoke of preferring collaborations in which each disciplinary representative worried about their own particular area of expertise, because:

> Each researcher has the opportunity to conduct work independently in their areas…This allows for a much more efficient operational structure as it saves time, energy, and money with respect to the learning curves. If the team is truly effective, each discipline will learn key elements from the other members' without becoming bogged down in the day-to-day aspects, allowing them to really focus on their specific areas.

Non-EIGERs, like the first-year EIGER students, saw value in integrating multiple perspectives, but tended to set boundaries or limits to what they would allow integration to achieve. By focusing on more concrete opportunities for integration, they were able to maintain a greater sense of control and security over their projects: "with any project, I prefer to gain full understanding of the project and in the process be in touch with every aspect. I like having full

control over the project because it eliminates competition…and miscommunication with other members of the group" (non-EIGER student).

By the second year, however, a number of EIGER students and, to a lesser degree, a few comparison group students expressed a more sophisticated notion of integration. As one second-year EIGER student commented: "by really learning and understanding someone else's research and bringing your own knowledge to it – new questions, new skills and the ability to solve problems develop", and interdisciplinarity is no longer simply a division of labor. Commenting on her experience interning in a biological lab, a second-year EIGER student stated:

> The internship was a good experience (because) I got to be in a completely different research environment with a biologist and a biochemist. I don't think I read one single paper (in my home discipline) the whole time…After that, as I started to look at my own PhD work, I realized there were no right and no wrong approaches by discipline, just what you can find out and apply in models in a biology context.

A non-EIGER student, while still expressing a preference for the efficiency and level of control afforded by simple borrowing, acknowledged the value of more complex conceptions of integration:

> However, I do think (team) members from different disciplines should meet with each other. They can exchange ideas, get inspired by someone else's ideas, and perhaps come up with something they might not have thought about in the beginning. Although I value the work and ideas contributed by different disciplines, it is easy to lose focus."

For these students, integration was no longer simply a process of adding new techniques and new tools to old ways of thinking. Instead, the integration of new theories or new conceptual perspectives began to qualitatively change students' thinking, which may not necessarily occur through methodological borrowing alone.

Phase III: Critical Awareness and Reflection—Charting New Lands

In contrast to notions of disciplinary grounding and integration, there was substantial difference in the degree to which second-year EIGER students were able to self-consciously reflect on the knowledge construction process within and outside their disciplines versus the first-year EIGER students. There was also a substantial difference between EIGER students in their second year and the majority of the comparison group of students. This is important to note because the entire non-EIGER comparison cohort had persisted to the second year of the study.

This would suggest that differences exhibited by the second-year EIGER students was not simply the result of temporal factors, but instead would suggest that the training and experiences provided by the program, coupled with longer tenure in the program, is responsible for their increased interdisciplinary understanding.

New disciplines offered not only more information and new methods but new ways of thinking about research questions and even a new set of problems, never before considered. Second-year EIGER students implicitly began to understand that problems are in fact constructed by researchers, not found in nature (Brewer, 1999). Many EIGERs commented that in the press of courses and research, intellectual horizons tends to shrink and one becomes mired in the details of his or her work. As one second-year EIGER student put it, "You can go through your entire doctoral career and never once think out of the box." The EIGER program offered a time and space for thinking out of the box, refocusing on the "big picture," and considering new alternatives. One non-EIGER student exhibited a similar level of critical awareness, commenting that as a result of his interdisciplinary work: "I see my research from a different point of view— the grand scheme of things. (I'm) not thinking about it as one question and one answer anymore."

Through their critical awareness of and reflection upon interdisciplinarity, second-year EIGER students also began to explore the connection between it and collaboration, recognizing that while not synonymous, both have a key role to play in research in the sciences and engineering:

> I am very excited about the internship and working in different labs, bringing information and techniques – all the things I'll learn back and forth between disciplines. I like working on teams, as there are opportunities for discussion with other disciplines when they are interdisciplinary. On teams we generate project ideas – not ones we will necessarily do, but it opens doors to projects we might do. Both – collaboration and interdisciplinary work– are essential to research but they are different. (second-year EIGER student)

Another second-year student credited her interdisciplinary exposure from the EIGER program with equipping her for initiating the collaborations that would be necessary for her dissertation research: "Before I thought I should do what I know. Now I am much more willing to go out and get others to help."

Finally, second-year EIGER students began to realize the costs attendant to this more complex form of research and began to calibrate when it was appropriate and when not,

recognizing the need to be purposeful (Hansson, 1999). As one student concluded after engaging in several successful interdisciplinary initiatives:

> People should not do interdisciplinary research without a really worthwhile interdisciplinary research topic. It can take too many precious resources. I read journals outside my field now first, to see if I can solve the problem by myself. [You] should be selective in finding a collaborator from another discipline…you both need to be interested in carrying it out. Before launching, spend some time assessing [the] feasibility of it.

Another second-year EIGER student asserted that in interdisciplinary research, the "question should be paramount, and then interdisciplinarity should grow naturally out of that." He questioned the efficacy of "artificial attempts at interdisciplinarity", or taken an interdisciplinary approach for its own sake, regardless of its appropriateness and applicability to the question at hand. Yet another second-year EIGER student posited that "Even individuals who don't come out of (the EIGER) as enthusiastic about interdisciplinary work get exposed to new areas." They were critically aware of the value of interdisciplinary research experiences like the EIGER as learning experiences, regardless of the outcome from the perspective of scholarly productivity measures.

Conclusion

This paper contributes to current conceptions of the intellectual impact of interdisciplinarity. The review of extant scholarship on interdisciplinarity demonstrated that for all of the time and attention spent describing what constitutes interdisciplinary scholarship, scant attention had been paid to the cognitive changes ensuing from participation in such interdisciplinary experiences. With its explicit focus on the development of graduate students' interdisciplinary research knowledge and skills, the EIGER program at Virginia Tech provided a fruitful environment in which to explore what changes, if any, occurred in students' thinking as a result of their exposure to other disciplines.

Using Boix Mansilla and Duraising's (2007) framework for interdisciplinary understanding, the researchers examined graduate students' epistemological beliefs – how they viewed the construction of knowledge and the nature of scholarship – along the three dimensions of disciplinary grounding, integration, and critical awareness. In order to parse out general epistemological development experienced in graduate school from the effects of the EIGER

program, the researchers interviewed not only EIGER participants but also a comparison group of students selected on the basis of lab and disciplinary affiliation as well as an expressed interest in interdisciplinarity. While both first- and second-year EIGER students as well as their comparison group peers demonstrated sufficient disciplinary grounding and baseline conceptions of integration, only second-year EIGERs and one or two non-EIGERs exhibited more sophisticated notions of integration or the critical awareness that constitutes interdisciplinary understanding. This suggests that there is both a temporal and programmatic component to the development of interdisciplinary understanding; in other words, neither time in a doctoral program nor mere exposure to interdisciplinary training alone results promotes interdisciplinary understanding.

This suggests that programs like the EIGER create and provide a graduate learning environment that systematically promotes interdisciplinary scholarship contributes to doctoral students' interdisciplinary understanding. Whereas most students entering the program identified themselves as being interdisciplinary scholars already, exposure to scholarship outside their disciplinary homes and to the realities of interdisciplinary research increased their interdisciplinary understanding. This led them to redefine their interdisciplinary identities as more than an openness to its possibilities. They spoke of evolving habits of mind that signaled changes in students' views and construction of knowledge. As it is unlikely that disciplinary structures will disappear in the near future, supplementary programs such as the EIGER represent an effective compromise in reforming doctoral education.

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Interdisciplinarity and Faculty Work: Interdisciplinary Understanding and Faculty's Learning Process

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Abstract

This paper examines one potential intellectual outcome of interdisciplinary faculty work, interdisciplinary understanding, and how it is developed. This qualitative study frames faculty work as cognitive acts best understood through the lens of sociocultural conceptions of learning. As such, the learning products and process of faculty affiliated, in various forms, with the Exploring Interfaces in Graduate Education and Research, or EIGER, program, an explicitly interdisciplinary graduate training initiative at Virginia Tech are examined. Informed by the results of previous research regarding doctoral students' development of interdisciplinary understanding (Drezek & Olsen, 2008), this study reveals that faculty leverage three categories of tools in their interdisciplinary work – people, problem platforms, and solution mechanisms – that mediate their learning and facilitate their attainment of the disciplinary grounding, integration, and critical awareness necessary to achieve interdisciplinary understanding. This study holds potential significance not only in determining the educational value of interdisciplinary scholarship, but also in helping us to further elucidate and provide evidence supporting the intellectual value of the cognitive process involved in faculty work.

Introduction

Colleges and universities traditionally have categorized faculty work as belonging to one of three broad categories: teaching, research, and service. The activities in which faculty engage generally are accommodated within this framework. While professors of all ranks described an academic reality of more permeable, almost blurred, boundaries between the three (Clark, 1987), most colleges and universities equate scholarship with research when parsing out faculty members' scholarly work from other activities. In his seminal work, *Scholarship Reconsidered*, Ernest Boyer (1990) called for a new conceptualization of faculty work in American higher education, one that would redefine scholarship "to include teaching, discovering, integrating, and applying new knowledge" (O'Meara, 2002, p. 58). Almost twenty years later, alternative forms of scholarship, such as the scholarship of teaching and learning (Major & Palmer, 2006; Sorcinelli, Austin, Eddy, & Beach, 2006), have entered the academic lexicon, and for some increasingly represent legitimate, rigorous forms of faculty work.

An outgrowth of this emphasis on alternative forms of scholarship is interdisciplinary research. Historically, scholarship has been conducted within the confines of individual disciplines (Becher, 1987; Clark, 1987; Klein, 1990; Lattuca, 2001), the results of which have been reviewed by disciplinary peers and published in discipline-specific journals. As reflected by publishing productivity and peer assessments of expertise, the evaluation of a faculty member's work – and, by extension, his or her eligibility for promotion and tenure – remains highly discipline-dependent. Interdisciplinary activities can challenge traditional disciplinary values and standards for rigor as oftentimes different disciplinary frameworks may stand in opposition to one another theoretically, methodologically, or epistemologically (Rose, 1986; Turner, 2000). As a result, interdisciplinarity may challenge our very conceptions of faculty's scholarly work.

A reconfiguration of our understanding of scholarship to include interdisciplinary research also allows for a more expansive assessment of faculty work. Recent studies (Lattuca, 2002; Lattuca & Creamer, 2005; Neuman, 2005) have looked beyond traditional measures of productivity (e.g., number of papers published, number of grants funded, teaching loads) and considered faculty work as learning:

> Faculty work implies faculty learning... Faculty work may be viewed in good part as acts of cognition, of knowing, for to do the work involves getting to know the work...thus, from a cognitive perspective, professors' work implies the possibility of learning about

research, teaching, outreach, and service as they engage in these activities." (Neuman, 2005, pp. 64-65)

Interdisciplinary scholarship, which requires that participating faculty learn at least the basics of another discipline that they wish to incorporate into their teaching or research, lends itself to consideration within the *work as learning* framework (Lattuca, 2002). Simply put, interdisciplinarians "must know how to learn" (Klein, 1990, p. 183).

Studies of interdisciplinary faculty work-as-learning draw broadly upon a social constructivist or sociocultural understanding of cognition (Lattuca, 2002). Such perspectives define learning as the "personal and shared construction of knowledge" (Lattuca & Creamer, 2005, p. 4). Significantly, this conception of learning as a socially mediated process not only emphasizes the active nature of the individual in the learning process, but also takes into account the context – disciplinary, historical, and cultural – in which the learning occurs, the tools that contribute to the learning process, and finally the interactions among scholars that contribute to the creation of new knowledge (Lattuca, 2002; Lattuca & Creamer, 2005). Social conceptions of the construction of knowledge, in particular sociocultural perspectives on the learning process, provide an appropriate and productive lens through which the identification of new knowledge and the process by which it is cultivated can be viewed. Furthermore, as most assessments of interdisciplinary initiatives have focused on tangible outcomes such as grants, papers, and patents, intellectual outcomes and the processes by which they are derived have received little or no attention from researchers (Boix Mansilla & Duraising, 2007; Lattuca, Voigt, & Fath, 2004). This paper aims to begin to address this critical gap.

The current paper focuses on faculty learning within interdisciplinary contexts. The construction of knowledge by domestic (U.S.-based) and international (U.K.-based) self-identified interdisciplinary scholars associated with the Exploring Interfaces through Graduate Education and Research, or EIGER, program at Virginia Tech, is examined. It explores what faculty learn from their engagement in interdisciplinary research initiatives, as well as how that learning transpires. Specifically, two research questions are considered:

1. Do faculty exhibit *interdisciplinary understanding*, one potential learning outcome, as a result of their interdisciplinary research experiences?
2. What mediates this learning process for faculty? In other words, what "tools" did faculty employ in the process of developing interdisciplinary understanding?

Social Conceptions of the Construction of Knowledge, Interdisciplinarity, and Faculty Learning

Social constructivism, the social construction of knowledge and knowing, provides a robust framework for analyzing faculty learning as a result of interdisciplinary experiences, and appears frequently in the literature (Doolittle & Hicks, 2003; Lattuca, 2002; Rieber & Robinson, 2004). Social constructivism is but one flavor of a collection of constructivist theories based on the premise that learning is self-regulatory; it is a process of negotiating between one's own view of the world, prior knowledge, and sense of meaning on the one hand and discrepant information, novel experiences, and new knowledge on the other (Fosnot, 1996). It asserts the contextual, holistic, and non-reductionist nature of learning (Vygotsky, 1978; Wertsch, 1985).

Within social constructivism, knowledge acquisition is conceived as neither an entirely external nor internal enterprise (Cobb, 2005). Instead, social constructivism itself can be viewed as an umbrella term capturing several sub-theories that hold the social nature of knowledge construction as primary, but vary in the emphasis placed on individual cognition (Berger & Luckman, 1966; Blumer, 1969; Blumer, 1980; Charon, 2007; Gergen, 1999). For purposes of this study of faculty learning, we will focus on a sociocultural conception of social constructivism (Arievitch & Haenen, 2005; Rieber & Robinson, 2004; Vygotsky, 1978).

Sociocultural Theory of Learning

Vygotsky, the "founding father" of sociocultural theory, believed that learning: (a) takes place in cultural contexts; (b) is mediated by language and other symbol systems; and (c) is best understood when investigated developmentally (John-Steiner & Mahn, 1996). He argued that in order to truly understand human cognition, researchers "need to concentrate not on the *product* of development but on the very *process* by which higher forms are established" (Vygotsky, 1978, p. 64). In other words, what is learned is as important and inseparable from how it is learned. From a Vygotskian perspective, knowledge acquisition is the process of building internal models or representations of external structures (Vygotsky, 1978, 1986). The learning process is shaped by an individual's background, including but not limited to his or her culture, language, prior knowledge and expertise. All of these aspects of the individual are brought to bear upon specific interactions with others in the co-creation of knowledge. Cognition, therefore, is a social, context-bound phenomenon (Kirshner & Whitson, 1997).

Vygotsky (1978) characterized learning as a genetic, or developmental process. He rejected the idea that a single, unified set of theoretical principles would explain every phase of human development (Wertsch, 1985). Vygotsky (1978) made distinctions between "elementary" and "higher" mental functions (p. 39). He employed four criteria to distinguish between the two: (a) the shift of control from the environment to the individual, or the emergence of voluntary regulation; (b) the emergence of conscious realization of mental processes; (c) the social origins and social nature of higher mental functions; and (d) the use of signs to mediate higher mental functions (Wertsch, 1985, p. 25). He focused on identifying the qualitative changes that resulted in the transformation from lower to higher levels of thinking.

Key to this transformation was the mediation of appropriate tools and signs. Individuals learn to recognize and appropriately employ tools such as language (Rieber & Robinson, 2004; Vygotsky, 1978). This occurs through participation and acculturation to a specific community, usually in relationship with more expert members of their community (Cobb, 2005; John-Steiner & Mahn, 1996). As their ability to appropriately navigate cultural signs and use tools increases, individuals' knowledge base and attainment of higher mental functions becomes deeper and broader. This ever-expanding prior knowledge and engagement in sociocultural activity are symbiotic components of the learning process. Furthermore, the contexts of learning – the environment in which it takes place, including the other individuals with whom one interacts – are inseparable from the learning that occurs (Lattuca, 2002). Within a social context, individuals must not only learn appropriate behaviors, but must also develop an understanding of the meaning behind those behaviors (Lemke, 1997). For sociocultural conceptions of knowledge creation, individuals learn by doing within specific social contexts, contexts that are not just the setting for a narrative about learning, but are integral to the shaping of the learning storyline of *what* is learned and *how* the learning transpired.

Application of the Sociocultural Approach to Faculty Learning in Interdisciplinary Contexts

Asserting that, at its core, learning is a social and cultural activity has a number of implications for our consideration of faculty learning in interdisciplinary contexts. Vygotsky saw cognitive development as the ability to learn and employ socially relevant tools and culturally based signs (Vygotsky, 1978, 1986) like language. Disciplinary training received as graduate students embeds scholars within the language, symbols, and history of their chosen field; in that

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sense, disciplines can be viewed as both tools that mediate – or promote and shape – faculty learning as well as social and cultural contexts in which learning occurs (Lattuca, 2002). Sociocultural understandings of the learning process also suggest some approaches that can be used to study interdisciplinarity, such as focusing on what and how individuals borrow from other disciplines, such as lab equipment and technology, methodologies, language, empirical data, or theoretical frameworks.

Social constructivism of this kind also offers a framework for exploring faculty learning within an interdisciplinary context involving collaboration among faculty from different disciplines, because it challenges us "to acknowledge and represent the complexity of learning by examining it simultaneously as a cognitive and social activity embedded in a variety of contexts" (Lattuca, 2002, p. 719). It can even be argued that it was individuals in social relationships who created disciplines in the first place, so they should not be viewed as immutable external structures impervious to the will of individuals within its boundaries (Lattuca, 2001). Klein (1996) asserted that interdisciplinary research is inherently dialectical, even when conducted by a sole individual, as he or she is still interacting with the social construction of another discipline. In other words, whether or not the mode of interdisciplinary scholarship involves a single scholar or a group of scholars, the interdisciplinarian interacts with the social and cultural mores, the tools, symbols, and epistemologies of the disciplines in questions that are themselves social constructions (Weingart, 2000).

Interdisciplinary Understanding as an Intellectual Outcome of Faculty Work

Previous studies (Lattuca, 2001; Lattuca, 2002) identified collaboration skills, the ability to overcome disciplinary biases, the successful navigation of language issues, and mastering new methodologies as potential learning outcomes from interdisciplinary work. If interdisciplinarity is conceived as a way to reach meaningful and useful integration of disparate disciplinary approaches to achieve a solution to a particular research problem (Klein, 1990*), interdisciplinary understanding* represents yet another potentially important and powerful intellectual outcome. Interdisciplinary understanding, defined as "the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement…that would have been impossible or unlikely through single disciplinary means" (Boix Mansilla & Duraising, 2007, p. 219), is comprised of three core dimensions: (a)

disciplinary grounding, the degree to which faculty work is grounded in carefully selected and adequately employed disciplinary insights; (b) *integration*, the degree to which disciplinary insights are clearly integrated so as to advance understanding; and (c) *critical awareness*, the degree to which the work exhibits a clear sense of purpose, reflectiveness, and self-critique (Boix Mansilla & Duraising, 2007, p. 222).

That interdisciplinary understanding is a learning outcome of faculty's interdisciplinary research experiences is not a foregone conclusion. Achieving interdisciplinary understanding is not just a matter of acquiring enough information to be grounded in a discipline or demonstrating the ability to integrate multiple perspectives. It also involves consciously identifying and reflecting upon the process by which such knowledge and skills are developed. Furthermore, understanding the process by which interdisciplinary understanding is achieved has the potential to expand our understanding of both interdisciplinarity as well as our conceptions of faculty work.

Methodology

Participants

Participants included faculty from the life and physical sciences, engineering, and social sciences working with the EIGER program at Virginia Tech. Faculty participants included: (a) "core" EIGER faculty, defined as those Virginia Tech faculty who participated in designing the program, the drafting the original grant proposal for NSF funding, the teaching of the program's core courses, and/or the leadership and management of core program functions (i.e., monitoring the program's budget); and (b) affiliated faculty, defined as Virginia Tech faculty advising doctoral students funded through and/or participating in the EIGER program. A total of 13 faculty from Virginia Tech participated.

In addition to the program's three courses in interdisciplinary research methods, team skills, and interface science, EIGER students were highly encouraged to participate in international internships to expose them to scholars engaged in interdisciplinary research outside of the United States. As such, inclusion of these potential international interdisciplinary mentors to EIGER students was an important component of this study. Therefore, the sample of faculty was expanded to include scientists, engineers, and social scientists who work at two British research universities. Participating international faculty were purposefully sampled (Charmaz,

2006) based upon home disciplinary affiliation and interest in and experience with interdisciplinary research. International faculty were identified for inclusion in the study in one of three ways: (a) they were members of a graduate program specifically identified as a potential internship location for EIGER students; (b) they were introduced by another faculty member, domestic or international, already participating in the study; or (c) they were issued a "cold call" invitation from the author based upon a review of the faculty's scholarship and other characteristics (e.g., participation in interdisciplinary grants, centers, etc.) gleaned from information available on the institution's web site. A total of 15 faculty from the two British institutions participated. Table 2.1 provides a breakdown of faculty by disciplinary category and institutional affiliation. Due to the relatively small number of participants, in order to prevent a loss of anonymity for participants, quotations will only be attributed to faculty by the broad categories in which their home discipline resides (e.g., social sciences, life sciences, physical sciences, engineering).

Table 2.1. **Participating Faculty by Affiliation & Discipline**

	Core EIGER Faculty at Virginia Tech	Affiliated EIGER Faculty at Virginia Tech	UK-Institution I	UK-Institution II
Life Sciences	1	3	2	-
Social Sciences	1	-	3	2
Physical Sciences	2	3	3	-
Engineering	2	1	-	5

Conceptual Framework

The predominant modes of inquiry for this qualitative study were semi-structured in-depth interviews designed to elicit information regarding faculty learning resulting from interdisciplinary research experiences. In order to determine if interdisciplinary understanding was indeed a learning outcome achieved through faculty's interdisciplinary research, participants

were asked a variety of questions regarding their interdisciplinary research experiences, including but not limited to questions related to: (a) the level of their identification with their home discipline; (b) their thoughts on the appropriate balance between disciplinary and interdisciplinary approaches; (c) the levels of and methods by which they integrated other perspectives into their work; and (d) their perceptions about the advantages and disadvantages associated with both collaboration and interdisciplinarity. Data analysis was informed significantly by a previous study (Drezek & Olsen, 2008), which examined student response to the EIGER program using grounded theory (Charmaz, 2006; Glasser & Strauss, 1965, 1968; Strauss & Glasser, 1970). The previous study employed Boix Mansilla and Duraising's (2007) framework for interdisciplinary understanding as a rubric by which the researchers could identify students' movement between stages of epistemological development resulting from their participation in the EIGER program. The context of this second study is such that it would be impossible to study similar development in faculty. Instead, the framework was used to help identify whether faculty, when prompted to reflect upon and discuss their interdisciplinary experiences, exhibited evidence of having achieved the requisite disciplinary grounding, sense of integration, and critical awareness that together signify the attainment of interdisciplinary understanding.

The use of Boix Mansilla and Duraising's (2007) framework to assess intellectual outcomes of the interdisciplinary learning process differs from its original application in evaluating undergraduate student work products (Drezek & Olsen, 2008). It is also important to note that this study expanded the framework for interdisciplinary understanding in three key ways: (a) disciplinary grounding was interpreted to encompass not just the development of a requisite knowledge base in two or more disciplines, but also greater self-consciousness about disciplinary boundaries, examining the strengths and weaknesses of different disciplinary approaches to the knowledge construction process; (b) integration was operationalized as an increasingly sophisticated continuum, moving from the more straightforward accretion of methods, tools, and discrete facts or information (Klein, 1990) to the synthesis of paradigms and theories; and (c) critical awareness was expanded to emphasize the adoption of new vantage points acquired through a more sophisticated perspective on interdisciplinarity, one marked by a greater ability to accommodate new ideas (Drezek & Olsen, 2008). It is this expanded sense of interdisciplinary understanding that is employed in the consideration of faculty learning.

Finally, a more open coding process was used in order to identify possible mediators in the faculty learning process. The researcher drew upon concepts derived from sociocultural perspectives of cognition, in particular the role of tools in the learning process, to identify, organize, and analyze faculty responses related to the development of interdisciplinary understanding generally as well as its three core dimensions, disciplinary grounding, integration, and critical awareness. Based on the suggestions of Anfara, Brown, and Mangione, (2002), data analysis occurred in three iterations: (a) the generation of initial codes; (b) the aggregation of those initial codes into themes; and (c) the application of those themes to the data set for purposes of drawing appropriate conclusions based upon participants' responses.

Findings and Discussion

Overall, participating faculty shared several underlying similarities; significantly, few if any differences existed based upon institutional or national affiliation. There were interesting disciplinary differences identified, however. As such, faculty quotations will only be attributed by disciplinary affiliation, except in cases where differences derived from institutional or national affiliations were noted.

Most faculty members saw their participation in interdisciplinary research as an extension of pre-existing proclivities or personality traits: "I've always been interested in new things. I get bored by doing the same thing over and over again" (life sciences faculty member). Many dated their interdisciplinary research experiences back to their undergraduate or early graduate training; that said, while some had selected undergraduate or graduate degree programs that could be considered interdisciplinary unto themselves (e.g., biotechnology), none had participated in a supplemental training program like the EIGER:

> I guess with my dissertation research…I was interested in this particular problem and the problem really required an interdisciplinary approach…it was just natural to do that… So I got a lot of interdisciplinary training as a grad student without knowing that's what I was doing. (physical sciences faculty member)

Instead, they spoke of the role of fortune or happenstance in the development of their interdisciplinary research skills and agendas, which often were shaped in important ways by chance encounters and conversations with researchers in other fields who ultimately became valued collaborators.

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Both U.S. and U.K.-based scholars spoke of the dynamic tension between disciplinary and interdisciplinary research. Several examples illustrative of this tension emerged from the data. The two most common tensions mentioned related to academic structure and research funding. Faculty spoke of the challenges inherent to satisfying their home department's expectations and requirements for promotion and tenure when their research crossed one or more disciplinary silos. One social scientist stated that "essentially (interdisciplinary papers) have no impact" on departmental or programmatic assessments of the quality of his research. Participants lamented accountability standards that privileged traditional disciplinary approaches. Faculty members in the U.K. spoke of accountability measures imposed at the national level that categorize productivity "according to disciplines, so interdisciplinary research isn't normally taken seriously," which has the effect of "mitigat(ing) against change" (life sciences faculty member). While they did not yet face similar accountability structures from the federal government, faculty members at Virginia Tech spoke about institutional structures that inhibited interdisciplinary collaboration. Finally, they stated that while the priorities of major funding entities like the National Science Foundation in the United States or research councils in the United Kingdom were shifting toward more expansive, complex, and interdisciplinary approaches, the "nuts and bolts" of the peer reviewed grant application process had yet to catch up with the rhetoric of proposal calls. Despite these structural challenges, each self-identified U.S. and U.K. interdisciplinary scholar derived pleasure and satisfaction from work that extended beyond the boundaries of their home fields. One physical scientist captured the sentiment of several participants, stating: "I do it because it is fun."

Do faculty exhibit interdisciplinary understanding as a result of their interdisciplinary research experiences?

The study began from the premise that interdisciplinary understanding could not, *a priori,* be considered an outcome of faculty's interdisciplinary work. In other words, interdisciplinary understanding should not be assumed to exist for even self-identified interdisciplinarians, as it involves a level of self-consciousness about the learning process. As such, faculty members' responses were examined to determine whether they exhibited all three constituent parts of interdisciplinary understanding – disciplinary grounding, integration, and critical awareness.

Disciplinary grounding. To a person, faculty members at Virginia Tech and the U.K.-based institutions acknowledged a general need for disciplinary expertise. Even those who indicated that they were, as one physical scientist stated, "always interdisciplinary, from the very beginning," spoke of having expertise in multiple discrete disciplines, rather than a lack of disciplinary grounding. Indeed, several participants expressed a deep and abiding commitment to the home discipline from which they derived much of their scholarly identity. One social scientist spoke of the need to remain rooted in the discipline even when very involved in interdisciplinary research: "Yes, I publish in (social science) journals. I am a (social scientist) by training. I work in the (social science) department. That's important for (social scientists) to name themselves…because then…when people outside (social science) engage with you they kind of know where they are going." Another social scientist reiterated this point: "I think it's very difficult to jump in confidently if you don't feel at home somewhere," arguing that disciplines provide scholars with a "point of reflection throughout their work."

Others possessed slightly more fluid conceptions of their scholarly identities as their research problems existed comfortably within multiple disciplinary paradigms: "The nature of my research area is that it goes across several boundaries. In fact, when I was looking at jobs, I saw descriptions of things that sounded like me in (multiple disciplines). So the kind of work I do is just by nature (interdisciplinary)… So that's just the way it is… There are several people in my department I work with but I work more with people outside the department than inside" (physical scientist).

Disciplinary grounding also encompassed the acknowledgement of the different cultures and world views possessed by other disciplines in contrast to one's own. One faculty member with research that incorporated both "pure" science and engineering commented that "biologists are more in a way more academic… engineers are obviously always looking for applications and they are more, they are quite similar often to people you would meet in industry, while biologists… they think in terms of scientific problems rather than in terms of applications." A life sciences faculty member remarked on the difference between traditional "qualitative" biological methodologies and the more quantitative methods provided by chemistry and physics. A social scientist, characterizing his home discipline as "more porous, perhaps too porous" in contrast to that of other social science fields, appeared all the more impressed with colleagues from "stricter" fields who were involved in interdisciplinary research: "I think economics is a

discipline which draws its boundaries very tightly… (those) that are willing to engage with people in different intellectual frames means they are working against the grain."

Most faculty agreed that their interest in and acknowledgement of the utility of multiple disciplinary perspectives was in large part driven by the specific problem they wished to explore. One particularly enthusiastic interdisciplinarian went as far to say: "I just realized that it was well-recognized that the biggest, well, a lot of big problems… of the pure disciplines have been solved… I think that the biggest things are now across disciplines" (physical scientist). The majority of faculty members were a bit more balanced in their approach to research, allowing for an ebb and flow in their disciplinary versus interdisciplinary activities. A social scientist captured the sentiments of several participants: "I like the (disciplinary) research that I do. I think that one of my feet will always be firmly in a purely disciplinary problem. That doesn't mean I can't bring a perspective from other disciplines into it." Even those who characterized themselves as primarily interdisciplinary argued for the efficacy of producing competent and creative disciplinarians as a pool of potential collaborators: "I think that it is very important, especially important… to have *real* physicists, *real* chemists, and *real* biologists, but who have a flavor for interdisciplinary work. If everyone went interdisciplinary, I don't think that would work at all" (physical scientist).

Overall, faculty members appeared to find value in grounding themselves not only in their primary area of disciplinary expertise, but also in achieving at least a baseline competence for navigating the topical research questions and the paradigms by which they might be answered in other disciplines. As an engineer remarked, "Too often (we) have not been aware enough of what's been going on in related but different disciplines. That's the kind of classic model of the academic in his or her own shroud. That's always a model to avoid."

Integration. At its most basic level, integration implied borrowing. Faculty engaged in interdisciplinary work borrowed both tangible and intangible disciplinary products, including: (a) laboratory equipment; (b) empirical data; (c) methods, with particular emphasis placed on the borrowing of quantitative methodologies by interview participants; (d) theories; and (e) philosophical approaches to research and problem solving. Faculty in the life sciences both in the U.S. and the U.K. spoke primarily of borrowing technologies and methodologies from other disciplines. A scientist from the biological realm described a "typical" borrowing interaction with another discipline:

There's a guy just sitting up the hall running a mass spec(trometer). He's essentially a PhD-level technician and he and I have been working together on some stuff. So, I am getting to learn how to interpret the data, he's running the instrument and helping me get up to speed with what's in the data. I design the experiments and bring it to him-it's clearly just providing the technology. That's typically what goes on.

One engineer posited that his borrowing patterns were driven by the specifics of particular projects: "For (projects) that I have, I know exactly what the issues are in my field, and we need technology from other areas, so I ask my colleagues to contribute (their) technology and therefore it contributes to my field." Another engineer borrowed "content knowledge whenever I can, so its solutions, techniques, and measurement devices." A physical scientist remarked that research collaborations with colleagues in other disciplines had, among other things, altered aspects of his research "personality":

I think, you know, in terms of working with people in engineering and sort of that practical element of it. I tend to have a more practical approach so maybe I am borrowing that from engineering. Sometimes in terms of working with (hard scientists), often times with them they're more theoretical… whereas with me, I also like to bring in the practical end. So I guess I am getting that practical stuff from engineering.

A substantial number of faculty interviewed, particularly those in the social or life sciences, when asked what they borrowed from among theories, methods, technology, empirical data, or philosophies, stated simply: "All of them."

Pressed about the seemingly straightforward nature of their interdisciplinary borrowing, however, faculty elucidated more sophisticated notions of integration. A physical scientist characterized integration as "a very dynamic process," and argued that "the more you find out and the more techniques you learn" from another discipline, "the more you find out about your own work." About work conducted through one of his collaborations, another physical scientist insisted: "It's not like I have no idea what (my collaborators) are doing… they know what I am doing so when we write proposals it's like, we write them together. We don't slap sections together and try to transition it. All the proposals that I have written have been very much people working together because if I don't understand what the other person is doing, then it's not a good project."

In short, integration that began as the simple accretion of methods, technologies, data, or theories from other disciplines often led to important learning on the part of the borrowers. For some, the learning curve prompted them to acknowledge or uncover previously unexplored

elements of their existing research, whereas for others it helped to generate new research questions and problems worthy of pursuit. Interestingly, faculty reflections on the process of integration often transitioned, almost seamlessly, to a critical awareness of and reflection upon interdisciplinarity. They began to consider interdisciplinarity at a "meta" level, whereby faculty from Virginia Tech and the U.K. institutions began to think about and share their thoughts regarding the definition of interdisciplinarity, its advantages and disadvantages, and its effect on our conceptions of scientific inquiry and research.

Critical awareness. Faculty at both the U.S. and U.K. institutions acknowledged that engaging in interdisciplinarity, whether as a primary or significant secondary component of a research agenda, was a departure from the norm of academe. To a person, they described reflecting on their decision to pursue interdisciplinary research by exploring such broad questions as: (a) What, exactly, is interdisciplinarity? (b) Am I truly interdisciplinary? (c) What affect has interdisciplinarity had on science?

For some, work across those boundaries identified as part of their disciplinary grounding could be parsed into two categories: interdisciplinarity within subspecialties of a single discipline or interdisciplinarity across totally distinct and separate disciplines. When asked how long he had been conducting interdisciplinary research, one engineer ruminated:

> When you say interdisciplinary research… there are types of interdisciplinary (research) within the engineering department because I am a _____ engineer working with an electric engineer, is that interdisciplinary? There's the much broader notion of working with people from sociology and that sort of thing, and that is interdisciplinary. So there are different levels of interdisciplinary research.

A social scientist defined his interdisciplinary research as working within subfields rather than across disparate disciplines: "for me my interdisciplinary work tends to be other disciplines (within my field). I am not really crossing." Others, particularly the physical and life scientists, spoke of delving into areas distinct from their disciplinary background. A very small number of participants indicated that they purposefully sought out opportunities to delve into very different academic areas. Another social scientist stated this most explicitly: "I… specifically seek out interdisciplinary (opportunities) that are as different as possible, partly for the personal challenge, partly for the intuition that that's how you find the most surprising results. You could also characterize this as being, intellectually, a high-risk, high-payoff strategy."

Participants' categorizations of interdisciplinary activities implied reflection about the relative space between disciplines, and the effects of traveling greater or lesser distances to achieve integration in one's research. Faculty seemed to use these not only in defining interdisciplinarity, but in conceptualizing their interdisciplinary identities as well. One engineer asserted his interdisciplinary identity:

> For me there is interdisciplinarity getting involved in environmental work, and yet the kind of environmental work that I do falls within engineering. So somebody outside might say that's not interdisciplinary because you are both within the same department or the same college or something. But to me it is.

His colleague, however, did not so much assert his interdisciplinary identity as question it:

> So what I realized is that I still don't really get down in the mud, so to speak, with the other faculty and sort of really exchange ideas. I am still sitting here in my kind of interdisciplinary world (supervising) this student who is hopefully doing that with some other faculty member, but I am not really doing that… I am sort of trying to go broad. Maybe that's the sort of thing where I am doing the most of my interdisciplinary work. I am trying to forge these links with everything else and not go into details of other disciplines but to join them all together.

While participants varied in their definitions of interdisciplinary research and the ways in which they conceptualized their own interdisciplinary identities, in general they seemed comfortable with a certain level of ambiguity. Perhaps their desire to move beyond well-defined disciplinary protocols tempered the impulse to try to put interdisciplinary research into a similarly conceived box. A select few even questioned the need for such boxes, characterizing disciplinary or interdisciplinary distinctions as meaningless. As a physical scientist argued: "I mean for me the different disciplines don't necessarily mean that much. If you have a problem you want to address, you just see what the best possible solution is, and that could be an interdisciplinary one."

Participants were also critically aware that many in academe questioned the level of rigor associated with interdisciplinary inquiry. One challenge facing researchers was providing a succinct explanation of the value added by an interdisciplinary approach: "It takes a long time to know what you are going to get from another discipline. I may take away rich and subtle understandings of the discipline, but that takes a long time" (social scientist). The extended timeframe required, as well as other structural challenges such as finding an audience for interdisciplinary research among discipline-dominated peer reviewed journals, were

acknowledged as significant deterrents to interdisciplinary research. One engineer described navigating the dynamic tension between disciplinary frameworks and interdisciplinary impulses:

> The perception… that needs to be overcome (is) that somehow interdisciplinary means less rigor, and it doesn't have to mean that at all… There is a perception that if you start to do something with somebody from a completely different discipline, the quality of the academic work in some way or another diminishes. That's not necessarily fair, but I think it's very true that a lot of people think that. How do you overcome that?... The way you sell it is, that if you do really well at this, you will make a very bit impact and the stuff you will be writing will soon find a home in a completely different arena. You shouldn't be deterred by that.

Finally, faculty also critically reflected upon the impact of interdisciplinarity on science, structurally and philosophically. A physical scientist described the excitement of significant scientific discovery through interdisciplinary research that was previously unattainable for her particular problem from a pure disciplinary perspective: "I actually see the interdisciplinary work and some of the nano-scale work as really giving us more insight into what's going on and helping to explain a lot of the things that we couldn't explain before. That's actually something I've really enjoyed about it." A life sciences faculty member credited interdisciplinary research with altering his scientific world view and philosophy of life:

> I think that instead of (interdisciplinarity) having a particular effect on my appreciation of what a living system is, it is trying to put that in the context of how molecular systems achieve certain levels of complexity and organization… The more you think about that, the more profoundly it affects the way you think about life,… I think that has profound consequences in terms of also philosophical terms, and I think that everybody who thinks about that in any detail will be struck by that.

For one engineer, interdisciplinarity provided a heightened sense of mission and relevance to his work: "by doing interdisciplinary research, you start to understand how your profession is going to contribute to society, because in many proposals you (actually) have to write 'What is the benefit to society?' And I think that's the biggest plus of interdisciplinary research."

Summary. Interdisciplinary understanding, evidenced by grounding in and beyond one's discipline, the development of a nuanced approach to integration, and critical awareness, was a learning outcome achieved by faculty participating in interdisciplinary research, both at Virginia Tech and UK-Institutions I and II. They demonstrated this understanding by: (a) acknowledging similarities and differences, from language and research paradigms to culture, between their home discipline and others; (b) effectively borrowing from other fields and achieving meaningful

integration that, in many instances, resulted in the subtle revision or reshaping of either existing research questions or future research directions; and (c) reflection and self-critique regarding the impact of interdisciplinarity on scholarly definitions, identities, and scientific world views. Having established interdisciplinary understanding as an important and achievable learning outcome of faculty work, the next step is to understand its attendant learning process.

What tools mediated this interdisciplinary learning process?

Adopting a sociocultural vantage point, the researcher was able to identify two broad categories of mediators in the learning process for participating faculty engaged in interdisciplinary research: people and tools. These tools were further defined as either problem platforms or solution mechanisms, emphasizing the subtle but important distinction of learning through borrowing tools versus learning through *lending* tools to others.

People as Mediators. To a person, faculty utilized other people to achieve interdisciplinary understanding. Engagement with others often began first through engagement with their body of work. Several scholars spoke of interacting with people across disciplinary boundaries by delving into the literature and familiarizing themselves with the vocabulary and style of a field prior to making contact with potential collaborators. As a physical scientist stated, "I am quite happy to read journal articles from different disciplines....I have learned not to be too scared about language differences and jargon and stuff. If something is well-written you usually get the jist of it. Then once I have a reasonable feel for how things work, I am happy to make contact with someone in the discipline." A social scientist described "sinking the time" into the literature of another field to make a particular grant application more competitive:

> In order to do this grant, I had to read books and books on (a different discipline), so I could talk to (them)… and I sunk the time in because it seemed to be the best connection to my expertise on this call for proposals… I looked at the whole call and was like, 'Well, where do I fit with my expertise and strengths? OK, I fit here. Now who do I know in (this discipline) that might be interested in working on this project?' So it went from there.

He described the need not only to find a certain level of expertise, but also to find a collaborator "who could talk to social scientists". The emphasis on developing fluency in the language of a discipline in order to communicate with collaborators is reflective of Vygotsky's emphasis on

language in the learning process. Conversations with collaborators were only effective if the individuals involved were able to establish an appropriate level of inter-subjectivity, one that ensures everyone was on the same rhetorical and conceptual research page.

Collaborators, once identified, were viewed as invaluable, both in learning the specifics of a new field (i.e., disciplinary grounding) and in achieving appropriate levels of integration. Comments regarding collaborating with other people reflected an appreciation of one's own expertise and the contributions made by others. In effect, interdisciplinary researchers expressed a desire to achieve appropriate economies of scale in their projects: "I used to try to do (life sciences) in my lab and I can do a little bit of it, but I just don't have the expertise really to do it the way that it needs to be done. So instead of my doing the interdisciplinary work in my own lab, I am now coordinating with other people… we work together… we are feeding off each other" (physical scientist). This level of efficiency, however, did not discount the learning process. As a life sciences faculty member remarked:

> Where appropriate I would always collaborate with someone… We have another project where we're working with a mathematics professor who is helping us develop models… but I wouldn't just leave it up to that individual. I will endeavor as far as possible to engage with the actual math myself to understand the modeling in order to be able to contribute. But trying to develop advanced new methods or theoretical analysis alone is a bit challenging.

Interestingly, a number of participants specifically identified graduate students as mediators in their learning processes. One social scientist at UK-Institution I looked to graduate students to facilitate disciplinary grounding: "Supervising graduate students across disciplines is a good idea because you know a lot about what's going on by your graduate students. So, if you have students who transcend boundaries then you learn a lot." This was an interesting response that aligned with the faculty member participants from Virginia Tech, all of whom were steeped in the goals and commitment to graduate training of the EIGER program more explicitly than their U.K. counterparts. One Virginia Tech faculty member commented that graduate students helped them maintain disciplinary grounding in their home fields even while they pursued questions that stretched them into interdisciplinary territory: "I mean, I don't know everything and the field changes really fast and I depend on (my students). I expect them to be able to bring me articles that I have not read that they think are relevant… that's what the research team meetings are about!"

Collaborative relationships, when successful, resulted in the co-creation of knowledge. Participants highlighted the importance of mutual benefit in interdisciplinary work, "I tend to write outcomes (into collaborative grants) based on my field, however I want to make sure my colleagues in different areas can publish their work in their fields and make excellent contributions" (engineer). Participants seemed to view the inclusion of multiple perspectives directed at a single research question implied by interdisciplinary collaboration as an inherent good. That said, learning mediated through other people also complicated aspects of the research process, as faculty tried to navigate issues of personality and ego. As one physical scientist argued: "Learning curve? It can also be more tension when you think you understand the science well enough to suggest doing something that the 'expert' doesn't think is a good thing to do. So it takes humility and self-control."

Learning tools: Problem platforms and solution mechanisms. The list of tools – both problem platforms and solution mechanisms – that mediated the learning process for faculty resemble the list of disciplinary items "borrowed" as part of the process of integration. *Problem platforms* are conceived as question-rich environments, such as living systems, in which theories, methodologies, or technologies can be tested. *Solution mechanisms*, in contrast, are available theories, methodologies, or technologies that can be leveraged to answer big questions. Some faculty indicated that they borrowed almost exclusively from one category of tools; biologists, for example, rarely developed new technologies, instead importing lab equipment from physics or chemistry, whereas others looked for opportunities to apply solutions.

Broadening our consideration of learning tools, it became apparent that way faculty leveraged these tools shaped what they learned. For example, use of problem platforms or solution mechanisms as a performance tool (Putnam & Borko, 1999; Salomon, 1993) aimed at simply enhancing how a task is accomplished may help a faculty acquire grounding in another discipline, a point of comparison or contrast to his own, and achieve a basic level of integration. This may be more reflective of simple additive multidisciplinary work, one that does not require nor generate interdisciplinary understanding. These same problem platforms and solution mechanisms, when employed as pedagogical tools that actually change the user's competencies, may in turn trigger a level of critical awareness that pushes faculty into true interdisciplinary understanding (Putnam & Borko, 1999; Salomon, 1993). This also aligns with the work of Vygotsky in that exposure to new tools or learning new uses for existing tools does not erase

prior experience or knowledge of the tool; instead, Vygotsky was deeply concerned with how conceptions of knowing and understanding expanded to accommodate new social and cultural experiences (Wertsch, 1985).

The emphasis on borrowing from other disciplines, however, can overshadow significant learning that transpires through the act of *lending*, or learning mediated through the act of giving one's disciplinary tools. Though arguably subtle, distinctions between learning mediated by borrowing tools and lending tools could be seen in the responses of a small number of faculty. One scientist who worked at the intersection of the life sciences and the physical sciences best engaged in an extended articulation of this concept when asked about what he took away from lending a solution mechanism to other scientists:

> If you are an analytical person, it's the challenge of identifying and quantifying something that becomes part of the game. The ability to quantify, that becomes a challenge. So the ability for me to look at other people's projects and how they tackle a project makes me think about the work I do…We usually sit down, usually they come and they have data that they want analyzed, and I say, 'OK, give me a couple of references or review articles that we can look at.' Then I see what we can and what we can't measure… I need to education them… We could run (the data) all day, and just crank out samples and have no idea what kind of data we're generating and just ship it off, but I think you're sort of doing a service without thinking about what you are doing. All of those little pieces of information mean something if you have a vested interest in the sample itself. You can start to think about it at a different level. I think if everybody does that in their own little bubble, those bubbles eventually merge together and you get something greater out of it. We work on our own sub-discipline, but we have to try to bridge the gap to think about things the way other people think about them, and then you can start to go on in a stronger direction.

Another life sciences faculty member described the give and take implied by successful borrowing of solution mechanisms and the lending of her field, biology, as a problem platform to her interdisciplinary collaborators:

> Biology often provides the questions that can be answered by technologies that have been developed. You develop this new great thing or you know you need to solve this problem because somebody needs to answer this question. Somebody develops the technology then they apply it to the question. It becomes a real nice back and forth. I am the one who really likes the questions and the biological questions and kind of driving from that perspective less than the actual develop(ment) of the technologies but I love getting the data and figuring out what it means and then finding the next question. I think that's a big thing for me… staying on top of what, to me, are the most interesting questions.

In this sense, borrowing and lending is not simply a *quid pro quo* scenario, where the researchers are simply trading wares to ensure the equity of the collaboration. The very act of lending – which implies teaching others about one's own discipline – is an important mediator in faculty's learning process, as individuals work to translate the vocabulary, paradigms, and priorities of their fields for outsiders. Beyond borrowing, it is in this teachable moment of lending that important learning may be taking place.

Conclusion

Through an exploration of one potential alternative form of faculty's scholarship – interdisciplinary research – utilizing a sociocultural conception of learning, this paper expands upon current conceptions of faculty work as well as the intellectual impact of interdisciplinarity. As revealed by interviews with self-identified interdisciplinary scholars affiliated with the EIGER program at Virginia Tech, interdisciplinary understanding appeared to be an intellectual outcome of interdisciplinarity for both U.S. and U.K. based faculty. Faculty members exhibited sufficient grounding in their home discipline as well as in those fields they sought to engage with or incorporate into their research. They demonstrated an understanding of the continuum of activities that constituted integration, from more straightforward borrowing to the reconceptualizing of their problems in light of other disciplinary perspectives. Finally, through their questioning of definitions of interdisciplinarity, their identities as interdisciplinary researchers, and even their sense of what it means to be a scientist, they exhibited critical awareness, the "meta-disciplinary" stage of interdisciplinary understanding.

Faculty members achieved interdisciplinary understanding through a learning process that was mediated by people, including their graduate students and faculty peer collaborators. They also utilized two broad categories of tools, problem platforms and solution mechanisms, to both enhance the execution of research tasks as well as to alter their conceptions of the research itself. While the conversations with faculty focused explicitly on what they learned by borrowing from other disciplines, a small number of faculty described learning that took place as a result of lending – lending of their expertise, their equipment, their environment. This subtle yet potentially significant distinction between learning by borrowing and learning by lending suggests a potentially fruitful next step in the research process, where faculty learning in interdisciplinary contexts is considered from this new perspective.

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The EIGER as an Emerging Alternative Community of Practice

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Abstract

This paper, written for a more general, "lay" audience, examines the lived experience of EIGER fellows and faculty through the first-person account of the author in order to describe and understand the shared patterns of the group (Creswell, 2006). Lave and Wenger's (1991) community of practice metaphor provides the framework for the study. This manuscript uses multiple data sources, including data collected from semi-structured interviews with students and faculty, materials produced as part of the EIGER program (such as course assignments), as well as the author's field notes and reflection journal to determine whether the EIGER program meets Wenger's (1998) criteria for a community of practice.

Introduction

Named for the famous peak in the Swiss Alps, the EIGER program at Virginia Tech is funded by the National Science Foundation's Interdisciplinary Graduate Education and Research Training, or IGERT, program. Over its ten-year history, the IGERT program has worked to catalyze "a cultural change in graduate education for students, faculty, and institutions by establishing new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries" (IGERT FAQ's, n.d.). Each IGERT – and there are approximately 120 around the nation at last count – addresses different interdisciplinary questions facing today's scientists and engineers, and reflects the unique perspectives of participating students, faculty, and academic programs. Virginia Tech has hosted four IGERTs in recent years, ranging in thematic focus from integrating macromolecular interfaces with life sciences investigating oxidative mechanisms, to research targeted at the vision of the future Internet as the common, ubiquitous and global communications infrastructure (for more information, go to the "IGERTs at Virginia Tech" website: http://www.grads.vt.edu/graduate_school/IGERT/index.html).

The EIGER program focuses not only on interfaces in natural systems but also on the *human* interfaces inherent to collaborative interdisciplinary teams. As such, the participating students, referred to as EIGER fellows, come from a range of "hard" scientific disciplines (e.g., biology, biochemistry, geosciences, crop and soil sciences), civil and environmental engineering, and two branches of the social sciences, industrial/organizational psychology and educational psychology. The EIGER is designed to develop fellows' interdisciplinary knowledge and skills as well as the team-based skills fundamental to successful collaboration. All EIGER fellows are required to take three courses: (a) GRAD 5984 *Interdisciplinary Research in Science and Engineering*, (b) PSYCH 5124 *Leadership & Team Processes*, and (c) GEOS 6604, *Fundamentals of Surface Science & Interface Behaviors*, although students, typically those in the social sciences, lacking the requisite scientific background needed for successful completion of the geosciences course are exempted from it. The courses have been offered to two cohorts of EIGER fellows.

The interdisciplinary research course is team taught by no less than six full-time tenured faculty members. Thematically organized around Hurricane Katrina, a particularly salient example of a complex real-world catastrophe that required an interdisciplinary response, faculty

and fellows explored the role that physics, civil and environmental engineering, geosciences, biology, and psychology played, or should have played, in addressing the issues associated with a natural disaster of that magnitude. Discussions ranged from the use of GPS in accurately pinpointing the appropriate height for rebuilding levees at different locations, to the psychology of risk and the role of emotion in heeding or ignoring warnings of impending disaster. The course culminated in an interdisciplinary group project modeled on the grant-writing process for funding agencies such as NSF. Teams were required to define an interdisciplinary question, leverage the expertise of the various disciplines represented, and develop a truly integrative solution to the posed problem. While arguably a forced versus organic jaunt into interdisciplinary research, the process was privileged over the product. Within the structured realm of this course, fellows began to experience, not just hypothesize about, the challenges inherent to navigating disparate vocabulary, methodology, theories, and standards for truth and rigor.

The course on leadership and team processes challenged fellows as well, particularly those in the hard sciences and engineering. The class focused on developing in fellows an understanding of the language and vocabulary in organizational psychology, selected methods for conducting teams research, and concepts and research relevant to working in interdisciplinary teams. On a more practical applied level, fellows worked to develop self-awareness in several skills areas related to working in research teams, and how best to communicate research ideas to an interdisciplinary audience. Beyond coursework, supplementary co-curricular activities on campus (e.g., a speakers' series, brown bag luncheons) and the intensive training received during internships at the international locations served to round out each fellow's individual experience.

<center>My Role in the EIGER Program</center>

In 2005, I began my doctoral work on a full-time basis at Virginia Tech. I became an EIGER fellow in January, 2007. I wore two hats, that of a regular EIGER fellow expected to complete all of the requirements of the program, as well as the hat of graduate research assistant for assessing the EIGER program. In other words, I was to help my advisor and EIGER faculty member, Dr. Deborah Olsen, evaluate the outcomes of the EIGER, at the same time that I was navigating the program itself.

Our evaluation of the EIGER would ultimately serve as my dissertation research. While also pragmatically concerned with assessing "countable" outcomes (e.g., how many

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interdisciplinary publications did fellows and faculty produce?), we were keenly interested in exploring the cognitive changes that resulted from participation in an interdisciplinary training program. We drew heavily from and expanded upon Veronica Boix Mansilla's conception of *interdisciplinary understanding*, which she defined as the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement that would have been impossible or unlikely through single disciplinary means. She and her colleagues at Harvard's Interdisciplinary Studies Project developed this concept as a means for assessing interdisciplinary work produced by undergraduate students. According to Boix Mansilla's framework, interdisciplinary understanding encompasses three broad stages: (a) *disciplinary grounding,* both within your "home" discipline as well as sufficient grounding in at least one other discipline; (b) the ability to achieve *integration* of the two; and finally (c) a *critical awareness* of what the integration added to the way you think about or make meaning of the problem you were trying to address. We employed the framework as a rubric by which epistemological changes in graduate students – how they view the construction of knowledge and the nature of scholarship both within and beyond their chosen field of study – could be gauged.

Our qualitative study of students' epistemological development in the EIGER was based primarily on annual student interviews. We interviewed not only EIGER fellows, but also a group of non-EIGER "comparison" students matched on the basis of discipline and lab environment. It elicited several interesting results. Whereas most students entering the program identified themselves as being interdisciplinary scholars already, exposure to scholarship outside their disciplinary homes and to the realities of interdisciplinary research increased their interdisciplinary understanding, and led them to redefine their interdisciplinary identities as more than just an openness to its possibilities. Fellows spoke of evolving habits of mind that signaled changes in their views and construction of knowledge (Drezek & Olsen, 2008). We concluded that interdisciplinary understanding is not fully achievable without developing a set of broad epistemic beliefs that in turn serve as a "tool set" for students navigating the vocabulary, structures, theories, methods, and criteria for truth and rigor of multiple disciplines. Though based on the experiences of a relatively small (n=22) group of participants, we believe that the results of this study support the work of the EIGER program and suggest that a graduate learning

environment that systematically promotes interdisciplinary scholarship contributes to doctoral students' interdisciplinary understanding.

Our consideration of the epistemological changes transpiring as a result of participation in the EIGER was exciting in and of itself. That said, viewing the impact of the EIGER solely through a cognitive lens failed to fully capture my experiences in the program. As I figuratively bounced between my roles as research assistant to that of EIGER fellow, I found myself searching for a framework that went beyond the learning outcomes that had been my primary focus, one that could encapsulate the complementary interpersonal aspects that made this interdisciplinary experience so meaningful to me. It was then that I came across the notion of a *community of practice*, and began to consider my EIGER experience as illuminated by this metaphorical light.

The Community of Practice Model

For over a decade, the undergraduate curriculum has included programmatic structures explicitly designed to foster a sense of community that would, in turn, shape and enhance the learning process. These learning communities come in various flavors, shapes, and forms, and are generally credited with providing several positive benefits to the institution and its undergraduates, from improving first-year retention rates to contributing to the development of higher order thinking skills. In contrast to the experience within undergraduate education, formal curricular communities at the graduate level, such as cohort-based programs of study, are relatively rare. The paucity of these programs, however, does not negate the existence of real and vibrant communities that shape and are shaped by individuals engaged in the learning process. Recent literature investigating this phenomenon has utilized Lave and Wenger's (1991) "community of practice" model, defined as "a set of relations among persons, activity, and the world, over time and in relation with other tangential and overlapping communities of practice" (Lave & Wenger, 1991, p. 98).

Participation in such communities usually begins with a period of legitimate peripheral participation, in which new members to the community acculturate themselves by essentially serving as apprentices to more senior members and performing tasks appropriately scaffolded to their level of expertise. As their skills and knowledge base expand and they become more comfortable navigating community mores and their use of methods improves, these novices

migrate from the periphery toward the center of the community. It is the shared experiences of its members, novice and expert, that define and legitimate the practices of the community (Yamagata-Lynch, 2001).

According to this conception of communities of practice, traditional doctoral study within the disciplines may qualify as initiation into a community of practice. The discipline and the doctoral student ideally engage in a relationship of reciprocal influence. Doctoral students' identities as scholars form through their adoption of the research priorities, methodologies, and theoretical paradigms of their chosen disciplines. One powerful example of this is the adoption of a discipline's language and its protocols for writing as one's own. This is an important aspect of initiation into the community, as it is through writing and speaking as a disciplinary expert that a doctoral student begins to create a recognizable body of scholarship. Students, by extension, impact the discipline by both employing traditional disciplinary frameworks to generate new knowledge, as well as by questioning the disciplinary truths from within the community of practice. This process of reciprocal influence ideally persists through a lifetime of scholarship.

For some doctoral students and faculty, however, the disciplinary community of practice, while important, does not completely satisfy their conceptions of themselves as academicians, and they seek out opportunities to interact with members of other disciplines. Colleges, universities, and external funding agencies in part have sought to satisfy this need through the cultivation of formal interdisciplinary communities on campuses. These interactions may constitute the creation of new communities of practice, like the community of EIGER faculty and fellows.

Lave (1998) delineated fourteen indicators that marked the existence of a community of practice by which the EIGER can be judged: (a) sustained mutual relationships, harmonious or conflictual; (b) shared ways of engaging in doing things together; (c) the rapid flow of information and the propagation of innovation; (d) absence of introductory preambles, as if conversations and interactions were merely the continuation of an ongoing process; (e) very quick setup of a problem to be discussed; (f) substantial overlap in participants' discussion of who belongs; (g) knowing what others know, what they can do, and how they can contribute to an enterprise; (h) mutually defining identities; (i) the ability to assess the appropriateness of actions and products; (j) specific tools, representations, and other artifacts; (k) local lore, shared

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stories, inside jokes, and knowing laughter; (l) jargon and shortcuts to communication as well as the ease of producing new ones; (m) certain styles recognized as displaying membership; and (n) a shared discourse reflecting a certain perspective of the world. I believe a strong case can be made that the EIGER program at Virginia Tech represents an emerging community of practice that satisfies several indicators.

<div align="center">The EIGER as an Emerging Alternative Community of Practice</div>

First, the program's generous funding comes with certain curricular "strings" attached – required courses, student presentations to internal and external audiences, co-curricular engagements – that ensure sustained mutual engagement between and among EIGER fellows and faculty, as well as shared ways of doing those things together. Student interviews consistently reflect a desire for more, not fewer, formal opportunities for doing things together as EIGER fellows. Faculty too have expressed similar sentiments. In my experience, despite busy lives that may preclude regular contact with all fellows and faculty, conversations between EIGERs hang in a state of suspended animation between encounters, and need no introductory preambles. For the hard scientists and engineers conducting research at the interfaces inherent to surface science, the EIGER provides unprecedented ease of access to specific tools and new methodologies with which students may conduct cutting edge research. There is also substantial overlap in participants' sense of who belongs, as well as a trajectory that resembles steady progression from legitimate peripheral participation to centrality in the EIGER program, a step greatly facilitated by the core course experiences. My own path from the outside-in has had interesting developments; the insights I developed along my path from peripheral to central participation have been solicited not only by my EIGER faculty mentors, but in interesting and exciting ways from others on campus, most recently by the dean of our graduate school, within the context of a summit on interdisciplinary graduate education at Virginia Tech.

That said, two particular indicators – mutually defining identities and a shared discourse reflecting a certain perspective of the world – best capture the essence of the EIGER as an emerging community of practice. They exemplify learning as social participation, which involves not only participating in the practices of the EIGER, but constructing identities *as EIGER* fellows as well. Drawing on my own personal narrative as an EIGER fellow, I believe

that these are most salient to what makes the EIGER a place where scientific creativity and meaningful collaboration are privileged.

Mutually Defining Identities and Shared Discourse

"Hello, my name is Kate Drezek, and I am a graduate student in educational psychology." And so began my introduction to my EIGER peers in our interdisciplinary research course. As all of the other students introduced themselves, it became very clear that (a) I was the only social science grad student in the room, and (b) I had no idea what they were talking about when they discussed their research. My insecurities flared – I reached into the depths of my ed psych soul, and grasped at rhetorical spears to throw at them: *Epistemology! Sociocultural understandings of the learning process! Vygotsky!* I told myself that I could sound just as esoteric and confusing as the rest of them. I felt doomed to fail at interdisciplinarity, cognizant that my retreat to the fortress of my discipline, with its own jargon and theories, was a move based on one of the greatest unspoken fears of would-be academics: looking stupid.

Wielding my copy of Janet Donald's *Learning to Think: Disciplinary Perspectives* like I would an English-French dictionary in Paris, I compared the disciplines represented in the EIGER to my own, trying to translate their languages into something that I could understand. I was looking for bridge-building opportunities. Interestingly, I discovered that the one discipline that scared me the most—engineering—shared important similarities with education. According to Donald, both were more "fields" than disciplines that utilized diverse methodologies to explore a virtually unlimited range of phenomena. Both were more applied areas of study as well, which she characterized as being open to environmental complexity and eclecticism. Translation: I discovered that engineering could be as "messy" as educational research.

When I say messy, I do not mean sloppy or shoddy. The engineering faculty and students with whom I had the opportunity to work were highly organized, precise in their use of language, logical, driven, and oriented toward successful completion of the task at hand. That said, compared to some of our biological or physical science compatriots, engineers and educators were charged with building things – levees, bridges, educational interventions – that *worked in the real world*, not just the lab. In the real world, however, things also break. Bridges fall, tunnels collapse, school programs fail. That heady responsibility was a shared sentiment that provided a point of departure for talking with my new engineering friends.

I was fascinated by the analysis of Hurricane Katrina from the civil engineering perspective. However, one assignment in particular – the "memo" assignment – terrified me. We were charged with identifying and explaining either: (a) how a research topic in our own disciplinary area could be better investigated using the tools, methods, theories, or philosophies from engineering; or (b) how theoretical or empirical work from engineering changed the way we conceptualize a specific research topic in our own discipline. I spent days agonizing over this assignment, until I read an article critiquing the way adequate yearly progress (AYP) was measured for high schools under *No Child Left Behind*. The authors of the article argued for a measurement that accommodated important contextual factors, including the inter-state differences in defining success versus failure thresholds in graduation rates and proficiency standards. They found that schools held accountable to more rigorous standards and for a greater number of subgroups (e.g., disaggregating scores for subgroups like non-native English speakers from school averages) are more likely to fail to meet AYP. I then remembered a key concept from civil engineering: *factor of safety.*

Broadly, the factor of safety is the ratio of those forces or elements resisting failure over those forces or elements driving the failure of a structure:

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

Engineers work to mitigate the potential for failure by ensuring that the resisting forces are stronger than the driving forces by an industry standard of 1.5. Why couldn't we come up with a factor of safety for schools? It could include not only standardized test scores and graduation rates, but also the variables identified as influencing AYP for low-performing schools. For example, we could create a variable to represent the rigor of established school proficiency levels; schools in states with more rigorous standards would be given "credit" for this in the model, whereas those states with lower baselines would be penalized. We could give credit to those institutions that, by virtue of their population, faced a greater level of subgroup accountability than those that did not. My model attempted to quantify identified "driving forces" of school failure. Though not an area of research that I pursued, the exercise stretched the synapses, so to speak, and made me look at my own field in a new way.

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Civil engineering proved to be important in other ways to me as well. My group project centered around the conclusion of a 1990s NSF report that 95% of engineering failures were essentially not engineering problems at all; they were human problems, primarily a result of failures to communicate. Using recent examples of engineering disasters like the Big Dig in Boston and the bridge failure in Minneapolis, we designed a hypothetical communications network, leveraging technologies like fiber optic sensing coupled with training to improve communication and create discourse communities among those responsible for the design, construction, and maintenance of major infrastructure. A bit pie-in-the-sky, yes, but big thinking among engineering, geochemical, and educational psychology graduate students was fun. I appreciated the very difficult task my peers faced in simply working to integrate my area into what could have been a very technical approach to the question.

The EIGERS also engaged in a give-and-take about how we presented ourselves to the world. In the course on teams processes, we were asked to write a one-page description of our research that could be easily understood by others. My partner in this exercise, a civil engineer, was doing fascinating work on the environmental impact of nanotechnology by measuring the effect through the use of organic biosensors. I had heard him present his research before, but was finding the description that he had written to be somewhat difficult to understand. It all sounded too technical for a "lay" audience. Finally, it hit me. When speaking to an audience of non-experts in one's field, it is important to make the complex concrete and descriptive whenever possible. I suggested that he eliminate his disciplinary labels and jargon and reveal his organic biosensors for what they were – clams. In turn, he critiqued my own research description, helping me to unpack the notion of epistemology and social constructivism.

These interactions, as well as the time spent getting to know the other faculty and fellows, their research areas, their likes and dislikes, contributed to the development of our collective identity as EIGERs. We were a group defined by our mutual interest in interdisciplinarity, and an increasing ability to humble ourselves and ask "dumb" questions of other disciplinary perspectives in order to expand our understanding of research and what it meant to "do" science. Wenger (1998) talks of the mutually reinforcing acts of participation and reification in the development of meaning and identity within a community of practice. Participation, according to Wenger, is both action and connection. It is doing the work of the group, as well as connecting to one another as you navigate the process of completing the work.

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There is the possibility of *mutual recognition*, the idea that when engaged in a conversation with another EIGER fellow, I recognize a bit of myself in him, and vice versa. In my engineering friends, I see bits of my pragmatic, "make it work" mentality. In my bioscience colleagues, I see my attention to detail and love of the "aha" moment, like when things in a laboratory gel, well – *gel.* In my geoscientist friends, I see a blend of the quantitative and qualitative approaches to research, as they struggle – as I have – to employ the right methodology for the question at hand.

In our mutual ability to make meaning in our conversations, participation becomes a source of identity; as Wenger put it, "by recognizing the mutuality of our participation, we become part of each other" (1998, p. 56). Reification is our external projection to the world, how we make concrete representations of ourselves. Through our interactions, our negotiated definitions of ourselves as interdisciplinary learners, we are, as a group, projecting ourselves as EIGER fellows, onto our worlds: our programs, our departments, our campus. The EIGER label means something to participants and non-participants who encounter it.

Our shared EIGER perspective of the world is, at this point, fluid. It reflects the particulars of the home disciplines encompassed by the program. There is an ebb and flow to priorities within that perspective. One week there is an emphasis on exploring the human interfaces by analyzing the components necessary for team innovation, another week it shifts to philosophical discussions between the merits of reductionist versus holistic approaches to science. Regardless, the worldview is one encompassing multiple methodologies, multiple units of analysis, and multiple paradigms. It is also a conversation of multiple metaphors, metaphors all the more powerful and challenging because they must cross the confines of one discipline and engage the ear of another. As eloquently stated by another EIGER fellow (and musician):

> "I have always been an interdisciplinary person because… I feel that to create new music you have to have a fusion of different styles as well to find your own, because if (not) you do something that is already done… for me, the perfect interdisciplinary example is Miles Davis. So if you listen to Miles Davis, that's probably like EIGER, it's all interfaces and craziness. Because that's what he was, you know, and he did that his whole life. So he played something in the Forties, in the Fifties, he moved. In the Sixties, he moved. Seventies he moved. Eighties, he moved, and died in 1991. So I think that's a perfect analogy."

Our discourse is less linear and rules-based, perhaps, but no less significant than the conversations taking place within the disciplines. More jazz riff than orchestral movement.

Lessons Learned from the EIGER Program

There are, of course, areas in which the EIGER fails to exhibit certain indicators of a community of practice, such as the rapid flow of information and the propagation of innovation, or the quick set up of problems. Interdisciplinary discourse, even among the true believers, takes time. We aim for innovation in solving complex problems that rest somewhere at the interfaces, but as graduate students we are still working on our sense of what those problems might be. There also are limitations inherent to the use of the community of practice metaphor to be taken into consideration. These limitations reflect a significant gap between an idealized conception of the community of practice and what can be a harsh reality. Differential power dynamics between an advisor and student, for example, could potentially prevent new members from moving beyond their apprenticeship to achieving full membership within the community, especially if EIGER's time commitments are seen as detrimental to progress in a home research group or lab. Furthermore, a lack of trust could inhibit discourse among community members, thereby stymieing the co-creation of knowledge. Predispositions, or *habitus*, may predate the practice of the community. If I had clung to my educational psychology ways and refused to trust that interactions with engineering had anything to add to my conceptions of the scholarly enterprise in and beyond my field, I would have severely hampered the development of my identity as an EIGER, potentially inhibiting new knowledge from emerging through practice.

Of the myriad lessons learned from exploring the interfaces of my disciplinary world view and those of my EIGER colleagues, three emerge as potentially significant to our conceptions of interdisciplinary graduate education:

1) Interdisciplinary graduate students are not professional amateurs.
2) Interdisciplinary graduate students need time.
3) Interdisciplinary graduate students need space.

We are not professional amateurs. For some, our interest in interdisciplinarity stems from a deep and abiding commitment to a research question that, try as we might, cannot be answered to our satisfaction through our home discipline. Or perhaps we are attracted by the inherent challenge of combining disciplinary perspectives in a meaningful way. We recognize and commit ourselves to the one truth of interdisciplinary research: we must work to achieve an equivalent level of rigor that we would expect of ourselves as disciplinarians, even as those

criteria shift to encompass other paradigms. To do this, interdisciplinary graduate students need *time* and *space.* We need time to fully foment our research questions, to pursue interdisciplinary trajectories, to regroup when one goes awry, and to reflect upon and intellectualize the process of interdisciplinary scholarship. We need space in both the literal and figurative senses of the word. We need lab benches and work groups unencumbered by the demands of other responsibilities (e.g., other grants' requirements) that compete with – and often trump – interdisciplinary interests. This space too must provide for a forum for deliberation and discussion with others, students and faculty, like-minded in their appreciation of an interdisciplinary approach. In order to maintain a balance between our desire for disciplinary expertise as well as interdisciplinary exposure, both viable and laudable outcomes for graduate education, supplemental programs like the EIGER are a good place to start. In short, they provide a means for building interdisciplinary communities of practice, which is essential for twenty-first century scholarship.

Suggested Resources

Boix Mansilla, V., & Duraising, E.D. (2007). Targeted assessment of students' interdisciplinary work: An empirically grounded framework proposed [Electronic version]. *The Journal of Higher Education, 78*(2), 216-237.

Donald, J. (2002). *Learning to think: Disciplinary perspectives.* San Francisco, CA: Jossey-Bass.

Handley, K., Sturdy, A., Fincham, R., & Clark, T. (2006). Within and beyond communities of practice: Making sense of learning through participation, identity, and practice. [Electronic version]. *Journal of Management Studies, 43*(3), 641-653.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge, UK: Cambridge University Press.

Levinson, B.A., & Holland, D.C. (2007). The cultural production of the educated person: An introduction. In B.A. Levinson, D.E. Foley, & D.C.Holland (Eds.), *The cultural production of the educated person: Critical ethnographies of schooling and local practice* (pp. 1-53). New York: State University of New York Press.

Mutch, A. (2003). Communities of practice and habitus: A critique. [Electronic version]. *Organization Studies*, *24*(3), 383-401.

Roberts, J. (2006). Limits to communities of practice. [Electronic version]. *Journal of Management Studies, 43*(3), 623-639).

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* Cambridge, UK: Cambridge University Press.

Yamagata-Lynch, L.C. (2000). Community of practice: What is it, and how can we use this metaphor for teacher professional development? [Electronic version]. Atlanta, GA: Annual Proceedings of Selected Research and Development and Practice Papers Presented at the National Convention of the Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED470198)

Conclusion to the Dissertation

This dissertation aimed at answering the call issued by the National Academies (2005) to explore the complex social and intellectual processes inherent to interdisciplinary scholarship. This series of qualitative studies proceeded from the premise that the lack of attention paid to intellectual outcomes was an unfortunate critical gap in the examination of interdisciplinarity, as it is possible that engagement in interdisciplinary activities changes student and faculty thinking in significant ways. The studies focused on one interdisciplinary initiative in particular, the EIGER program at Virginia Tech. Specifically, this series of studies explored the intellectual impact of interdisciplinarity by: (a) identifying and documenting the development of one potential interdisciplinary learning outcome, interdisciplinary understanding, in graduate students; (b) determining if interdisciplinary understanding is a learning outcome of faculty's interdisciplinary work, and if so, to identify what mediated faculty's interdisciplinary learning processes; and (c) determining whether the EIGER program constituted an emergent community of practice for its graduate student and faculty participants.

The first study focused on the impact of interdisciplinary training on how doctoral students viewed the construction of knowledge and the nature of scholarship. Using Boix Mansilla and Duraising's (2007) framework for interdisciplinary understanding, the researchers examined graduate students' epistemological beliefs along the three constituent dimensions – disciplinary grounding, integration, and critical awareness. The researchers determined that while both first- and second-year EIGER students as well as their comparison group peers demonstrated sufficient disciplinary grounding and baseline conceptions of integration, only second-year EIGERs and one or two non-EIGERs exhibited sophisticated notions of integration or the critical awareness that constitutes interdisciplinary understanding. This suggests that prolonged participation in training programs like the EIGER provides a learning environment that systematically promotes interdisciplinary scholarship, contributing to doctoral students' interdisciplinary understanding.

The second study explored the development of interdisciplinary understanding as a learning outcome of faculty's interdisciplinary work. Drawing upon conceptions of "faculty work as learning" as well as sociocultural approaches to cognition, the study also explored the process by which faculty members achieved interdisciplinary understanding. The study revealed that faculty members used other people and two categories of tools, problem platforms and

solution mechanisms, to mediate the interdisciplinary learning process. This study contributes to the scholarship on "faculty work as learning" as well as the research on the intellectual impact of interdisciplinary experiences.

The third and final manuscript focused on the EIGER program at Virginia Tech as an emerging alternative community of practice. In her first person account as an EIGER fellow, the researcher identified points of alignment between the EIGER program and the established indicators of a community of practice, as well as points of departure between the program and the community of practice metaphor. The researcher argued that members of the EIGER program engaged in mutually defining each other's identity and maintained a shared discourse that reflected an interdisciplinary world view of doctoral work and the scholarly enterprise.

Together, these studies expand current conceptions of the intellectual impact of interdisciplinary training and research. Manuscripts one and two, in particular, provide a concrete example of one potential learning outcome, interdisciplinary understanding, as well as a means by which it can be measured. That said, one potentially significant limitation is the applicability of the interdisciplinary understanding framework if it is employed to assess the intellectual impact of interdisciplinary activities for which integration is not a chief aim or constituent component of the work. As identified by Lattuca (2003), it is possible that for those engaging in research that "marks and privileges difference and particularity" (p. 16), often critiquing existing disciplinary structures and paradigms, integration or unity of knowledge in the interdisciplinary process is immaterial. Research on conceptions of interdisciplinary understanding and the epistemic beliefs of those adopting a more post-modern approach will likely need to account for this aspect of the framework if it is to be applied. Furthermore, most conceptions of interdisciplinary integration rely upon the borrowing of tools from one discipline for application within another. By focusing on learning about and from other disciplines by borrowing, subtle yet important conceptions of learning by lending of one's disciplinary tools may be overlooked.

Future research could address both questions about interdisciplinarity that does not emphasize integration as well as learning by lending within interdisciplinary contexts. Subsequent studies could be designed to allow for comparisons of interdisciplinary activities engaged in by those whose home disciplines are more or less oriented toward positivist conceptions of research and the primacy of the scientific method versus those whose home

disciplines proceed from more post-modernist or post-structural perspectives for which integration may, or may not, be a priority. Additionally, research questions should be designed to address explicitly the issue of learning through lending. Studies that include non-integrative interdisciplinary scholarship and learning by lending would expand upon this dissertation's elucidation of the intellectual impact of interdisciplinarity. Finally, the results of this qualitative study, rooted in grounded theory, inform the development of more quantitative measures of interdisciplinary understanding to facilitate the expansion of the research beyond the confines of a single interdisciplinary experience, thereby testing some or all of the conclusions drawn herein.

New EIGER Fellows

1. It helps to know a little bit about your academic background and how you ended up here at Tech.

    Undergraduate institution (graduated from) _____

    Major$_1$ _____
    Major$_2$ _____
    Major$_3$ _____

    Degree_____   Date _____
    Degree_____   Date _____

2. Did you do any graduate work before your current doctoral work at Tech? [recognize disciplinary diffs]

    No   ____
    Yes   ____→Institution _____Degree?
                                            Masters____
                                            Other _____
                                            None_____

            Institution _____Degree?
                                            Masters____
                                            Other _____
                                            None_____

    Other work experience?

3. How did you hear about the EIGER training grant and the fellowship?

    Code as able while recording open-ended answer

            _____ Tech faculty participating in EIGER→ EIGER role_____
            _____ Tech faculty other
            _____ Faculty from other institution→ Institution_____
            _____ National media/source→ Specify_____
            _____ Other _____

4. Can you talk a bit about why you decided to become a fellow?
    Code as able while recording open-ended answer

_____ Stipend
_____ Research resources
_____ Research opportunities at other institutions
_____ Interdisciplinary approach
_____ Collaborative research opportunities
_____ Faculty involved in EIGER
_____ Opportunity to work on specific research topic
_____ Take EIGER core courses
_____ Career credential

5. Next I would like to ask about the lab or research group you work in.

   Check here if student does not work in lab or group and skip next questions _____

   How many people are in the group? _____
   Do you work closely with them?
   _____ No, *student's explanation…*
   _____ Yes, *student's explanation…*

   Prompt for funding and publication arrangements.

6. How involved is your advisor in the work carried out by the group?
   _____ Very, *student's explanation…*
   _____ Somewhat *student's explanation…*
   _____ Not very much, *student's explanation…*

7. Are the research interests of the different members of the group closely aligned or fairly disparate?   _____ closely aligned
   _____ fairly disparate

8. I'd like to focus now more specifically on what you see ahead in the next couple of years as you participate in the training grant. What are your expectations of the program and of your experience in it?

9. What in particular are you looking forward to as the fellowship continues? What are you less sure about?

10. What impact, if any do you think the EIGER grant will have on you and your academic training and career? Will it add to your program or change it in any way? e.g., taking different courses, change of research focus, change how you learn?

11. The grant focuses on interfaces within natural systems—is that focus relevant to you or your work or were there other aspects of the grant that attracted you more?

12. What kind of interdisciplinary experiences have you had in the past, if any?

13. As you know, NSF and some other key organizations in the engineering and science community have been strong proponents of interdisciplinary research. Of course, not all opinions about interdisciplinary research are favorable. Many influential researchers still feel work within the discipline is best. Based on whatever experiences you may have had, as well as your own general impressions, please complete the series of questions on this paper. (*Hand paper to respondent*).

The following items provide different reasons why you, or someone like you, would become involved in an interdisciplinary project. **On a 1 to 5 scale, with 1 = not at all important to 5 = very important,** rate each of the following as a rationale for interdisciplinary research:

	5 = very important

Serve colleagues, employer or funding agency	1	2	3	4	5
To acquire a new set of technical or methodological skills	1	2	3	4	5
To acquire a new perspective on a topic of research interest	1	2	3	4	5
To work in a less isolated context	1	2	3	4	5
Represent one's self or one's department or organization	1	2	3	4	5
Meet degree requirements	1	2	3	4	5
Meet career expectations e.g., as a resume builder for a position	1	2	3	4	5
To grow professionally	1	2	3	4	5
To accomplish work that could not be done otherwise	1	2	3	4	5
To explore a complex problem of professional interest	1	2	3	4	5
Other_____	1	2	3	4	5

14. There are a number of ways to structure and implement an interdisciplinary project. Often the structure of the project will depend upon the nature of the research question posed. Personal preference also plays a role in shaping research collaborations, however. If you had a research problem that lent itself to interdisciplinary study and could choose any of the following formats to pursue the topic, which would you choose?

- Model #1: Pursue the project as a single investigator gleaning information from other disciplines through journals, personal contacts etc and incorporating the interdisciplinary information in your ongoing research.

- Model #2: Pursue the project with researchers from other fields, dividing up research tasks in a way that optimizes disciplinary expertise and allows the PI to efficiently coordinate research efforts.

- Model #3: Pursue the project working jointly as part of a team with researchers from other disciplines, taking the necessary time to gain some facility with other disciplinary areas as part of the execution of the research.

- Model #4: Please briefly explain why you prefer one model over another? Consider issues such as the following: the amount of structure you believe is necessary in conducting a successful project; the benefit of broader vs. more-focused discussion; the value of time spent meeting, exchanging e-mail etc; the value of time spent working through different research methods and language.

15. On a scale of 1=not at all likely to 5=very likely, are you likely to pursue interdisciplinary research in the future?

16. Do you know what you would like to do professionally when you finish your PhD? If so, what do you plan to do?

17. How does your EIGER fellowship fit in with your career plans?

18. Are there any other thoughts or comments you would like to share at this time?

Returning EIGER Fellows

1. I'd like to start by talking about your expectations of the EIGER program and how well your expectations matched your actual experience in the program in the last year.

   As respondent provides open-ended answer record and code gaps below as well, noting direction of gap:

   Overall administration of program _____
   Scheduling issues associated with program _____
   Culture of program _____
   Courses
       Interface course _____
       Team Course _____
       Interdisciplinary course _____
   Internship _____
   Outside Speaker _____
   Collaborative opportunities _____
   Opportunities to gain interdisciplinary skills _____

Interaction with faculty _____
Other e.g., meeting with the Board, social events, etc _____

2. What aspects of the EIGER program, formal and informal, intentional and unintentional, have had the greatest impact on your professional development? *Keep question below in mind as respondent answers*

3. Overall, has the EIGER grant encouraged you to change or expand your research focus, changed how you think or learn?

4. What has been the most difficult part of the EIGER for you?

5. Each year, your graduate school experience brings something new. What distinguished last year academically or professionally for you-- new perspectives, knowledge, experience, techniques, professional networks? Any of these? Something else?

6. Next I would like to ask about the lab or research group you work in.

   Check here if student does not work in lab or group and skip next questions _____

   How many people are in the group? _____
   Do you work closely with them?
   _____ No, *student's explanation…*
   _____ Yes, *student's explanation…*

7. How involved is your advisor in the work carried out by the group?
   _____ Very, *student's explanation…*
   _____ Somewhat *student's explanation…*
   _____ Not very much, *student's explanation…*

8. Are the research interests of the different members of the group closely aligned or fairly disparate?   _____ No, *student's explanation…*
   _____ Yes, *student's explanation…*

9. As you know, NSF and some other key organizations in the engineering and science community have been strong proponents of interdisciplinary research. Of course, not all opinions about interdisciplinary research are favorable. Many influential researchers still feel work within the discipline is best. Based on whatever experiences you may have had, as well as your own general impressions, please complete the series of questions on this paper. (*Hand paper to respondent*).

   The following items provide different reasons why you, or someone like you, would become involved in an interdisciplinary project. **On a 1 to 5 scale, with 1 = not at all important to 5 = very important,** rate each of the following as a rationale for interdisciplinary research:

Serve colleagues, employer or funding agency	1	2	3	4	5
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To acquire a new perspective on a topic of research interest	1	2	3	4	5
To work in a less isolated context	1	2	3	4	5
Represent one's self or one's department or organization	1	2	3	4	5
Meet degree requirements	1	2	3	4	5
Meet career expectations e.g., as a resume builder for a position	1	2	3	4	5
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To accomplish work that could not be done otherwise	1	2	3	4	5
To explore a complex problem of professional interest	1	2	3	4	5
Other_____	1	2	3	4	5

10. There are a number of ways to structure and implement an interdisciplinary project. Often the structure of the project will depend upon the nature of the research question posed. Personal preference also plays a role in shaping research collaborations, however. If you had a research problem that lent itself to interdisciplinary study and could choose any of the following formats to pursue the topic, which would you choose?

- Model #1: Pursue the project as a single investigator gleaning information from other disciplines through journals, personal contacts etc and incorporating the interdisciplinary information in your ongoing research.

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- Model #3: Pursue the project working jointly as part of a team with researchers from other disciplines, taking the necessary time to gain some facility with other disciplinary areas as part of the execution of the research.

- Model #4: Please briefly explain why you prefer one model over another? Consider issues such as the following: the amount of structure you believe is necessary in conducting a successful project; the benefit of broader vs. more-focused discussion;

the value of time spent meeting, exchanging e-mail etc; the value of time spent working through different research methods and language.

11. In summary, what are the strongest arguments for and against interdisciplinary research?

12. On a scale of 1=not at all 5=very likely, are you likely to pursue interdisciplinary research in the future?

13. On a scale of 1 to 5 with 5 = accomplished a great deal, how well has the EIGER program accomplished the following goals? Please provide some justification for your answer.
    Generation of new ideas and knowledge? _____
    Generation of tools and infrastructure for research?_____
    Training of scientists and engineers?_____

14. Do you know what you would like to do professionally when you finish your PhD? If so, what do you plan to do?

15. How does your EIGER fellowship fit in with your career plans?

16. What advice would you give a graduate student starting an EIGER fellowship?

17. On a scale of 1 to 5 with 5 = very satisfied, overall have you been satisfied with you experience as an EIGER fellow? _____

18. If you had to do it all over again, would you still become an EIGER fellow?
    Yes_____
    No_____

19. Would you recommend an EIGER fellowship to a friend?
    Yes_____
    No_____

20. Any other comments or observations you would like to make?

Comparison Group Students

1. It helps to know a little bit about your academic background and how you ended up here at Tech.

    Undergraduate institution (graduated from) _____

    Major$_1$ _____
    Major$_2$ _____
    Major$_3$ _____

Degree_____ Date _____
Degree_____ Date _____

2. Did you do any graduate work before your current doctoral work at Tech? [recognize disciplinary diffs]

No   ____
Yes   ____→Institution _____ Degree?
                                              Masters____
                                              Other _____
                                              None_____

             Institution _____ Degree?
                                              Masters____
                                              Other _____
                                              None_____

Other work experience?

3. Next I would like to ask about the lab or research group you work in.

   Check here if student does not work in lab or group and skip next questions _____

   How many people are in the group? _____
   Do you work closely with them?
         ____ No, *student's explanation…*
         ____ Yes, *student's explanation…*

4. How involved is your advisor in the work carried out by the group?
         ____ Very, *student's explanation…*
         ____ Somewhat *student's explanation…*
         ____ Not very much, *student's explanation…*

5. Are the research interests of the different members of the group closely aligned or fairly disparate?   ____ No, *student's explanation…*
                                              ____ Yes, *student's explanation…*

6. (New Comparison Group Students only): I'd like to focus now more specifically on what you see ahead in the next couple of years as you move through your graduate training. What are your expectations of your graduate program and of your experience in it? What in particular are you looking forward to as your program continues? What are you less sure about?

7. (New Comparison Group Students only): What impact, if any, do you think your graduate program will have on you and your career? Is it likely to expand or change the nature or focus of your research interests, or how you think or learn?

8. (Returning Comparison Group students only): What aspects of your graduate program, formal or informal, intentional or unintentional, have had the greatest impact on your professional development?

9. (Returning Comparison Group students only): Overall, has your graduate program encouraged you to change or expand your research focus, or how you think or learn?

10. (Returning Comparison Group students only): What has been the most difficult part of your graduate training?

11. (Returning Comparison Group students only): Each year, your graduate school experience brings something new. What distinguished last year academically or professionally for you-- new perspectives, knowledge, experience, techniques, professional networks? Any of these? Something else?

BACK TO ALL STUDENTS.

12. What kind of interdisciplinary experiences have you had in the past, if any?

13. As you know, NSF and some other key organizations in the engineering and science community have been strong proponents of interdisciplinary research. Of course, not all opinions about interdisciplinary research are favorable. Many influential researchers still feel work within the discipline is best. Based on whatever experiences you may have had, as well as your own general impressions, please complete the series of questions on this paper. (*Hand paper to respondent).*

The following items provide different reasons why you, or someone like you, would become involved in an interdisciplinary project. **On a 1 to 5 scale, with 1 = not at all important to 5 = very important,** rate each of the following as a rationale for interdisciplinary research:

5 = very important

Serve colleagues, employer or funding agency	1	2	3	4	5
To acquire a new set of technical or methodological skills	1	2	3	4	5

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Meet career expectations e.g., as a resume builder for a position	1	2	3	4	5
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Other_____	1	2	3	4	5

14. There are a number of ways to structure and implement an interdisciplinary project. Often the structure of the project will depend upon the nature of the research question posed. Personal preference also plays a role in shaping research collaborations, however. If you had a research problem that lent itself to interdisciplinary study and could choose any of the following formats to pursue the topic, which would you choose?

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15. In summary, what are the strongest arguments for and against interdisciplinary research?

16. On a scale of 1=not at all 5=very likely, are you likely to pursue interdisciplinary research in the future?

17. On a scale of 1 to 5 with 5 = accomplished a great deal, how well has the EIGER program accomplished the following goals? Please provide some justification for your answer.

    Generation of new ideas and knowledge? _____

    Generation of tools and infrastructure for research?_____

    Training of scientists and engineers?_____

18. Do you know what you would like to do professionally when you finish your PhD? If so, what do you plan to do?

19. What advice would you give a graduate student starting your Ph.D. program?

20. On a scale of 1 to 5 with 5 = very satisfied, overall have you been satisfied with you experience as a doctoral student? _____

21. If you had to do it all over again, would you still become a doctoral student?

    Yes_____

    No_____

22. Would you recommend your graduate program to a friend?

    Yes_____

    No_____

23. Any other comments or observations you would like to make?

Code Mapping for Students' Epistemic Beliefs: Four Iterations of Analysis (to be read from the bottom up)

| Research Question: |
| How does systematic interdisciplinary training affect students' epistemic beliefs, that is, how they view the construction of knowledge and the nature of scholarship? |

| Fourth Iteration: Application to the Data Set |
| Training programs like the EIGER that systematically promote interdisciplinary scholarship create and provide a graduate learning environment that contributes to students' interdisciplinary understanding. |

Third Iteration:
Return to the Literature – Pattern Variables for *Interdisciplinary Understanding*

| 1. Phase I: Disciplinary Grounding | 2. Phase II: Integration | 3. Phase III: Reflection/Critical Awareness |

Second Iteration: Pattern Variables

| 1A. Disciplinary Expertise, Own | 2A. Integration, Borrowing | 3A. New habits of thinking |
| 1B. Disciplinary Expertise, Other | 2B. Integration, Beyond Borrowing | 3B. Recognition of constructed nature of knowledge, science |

First Iteration: Initial Codes/Surface Content Analysis

1A. Expertise in content	2A. Borrow tools	3A. New questions
1A. Mastery of tools, methods	2A. Borrow methods	3A. Calculated risk-taking
1A. Recognize limits of own knowledge base	2A. Learn specific techniques	3A. Connection to Collaboration
1A. Recognize limits/ boundaries of field	2A. Self-imposed boundaries on extent of integration	3A. Big picture perspective
	2A. Maintain control	

1B. Familiar other field(s)	2B. Evolve from division-of-labor to qualitative change	3B. New problems
1B. Distance between own/ others		3B. Reframe old problems
1B. Difference unit of analysis	2B. No right, no wrong way to integrate	3B. "Meta" level of reflection on research activities
1B. Other ways to "do" Science	2B. Reframe some problems	3B. Question paramount
1B. New mental models	2B. Relinquish some control	3B. Process over product

1. What percentage of your day-to-day responsibilities include:
   a. Teaching
   b. Advising graduate students
   c. Supervising research
   d. Writing grants/proposals
   e. Other (please specify)

2. Are any of your current research projects being formally conducted with other investigators, students or faculty?

3. How often would you say that you collaborate with others (Never, Sometimes, Often, Almost Always)?

4. Is it typical to work in research teams in your field (Yes, No)?

5. How long/how many years have you been conducting what you would consider to be interdisciplinary research? Can you talk a little bit about how you became interested in working across disciplines? What served as the catalyst for your interdisciplinary work?

   Probes include: Can you pinpoint a specific "trigger" for your interest in interdisciplinary research, such as: A course? A presentation? (conference, seminar, etc.) A colleague?

   Was it problem-driven?

6. When did you first begin to consider the boundaries of your own discipline? How did you initially conceive of these boundaries? How did you begin to cross them?

7. How would you describe your research: Interdisciplinary across subspecialties in your own discipline? Interdisciplinary across other social and/or natural sciences?

8. Outside of your own, what disciplines do you primarily draw upon/work with?

9. Can you describe your approach to integrating a different discipline into your research?

10. Do you generally work with someone from another field?

11. What kinds of things do you "borrow"? Do you borrow: Techniques? Methods? Empirical data? Theoretical frameworks?

12. Has this integration led you to reconsider (reformulate, revise, reshape) any aspects of your own discipline?

Probe for: the techniques? The methods? The theoretical frameworks within your own discipline?

13. There are a number of ways to structure and implement a research project. Often the structure of the project will depend upon the nature of the research question posed. Which of the following formats most closely describes your research as it is currently conducted?

- Model #1: Pursue the project as a single investigator (PI) building on prior research and proven methods primarily within your disciplinary area.

- Model #2: Pursue the project as a single investigator (PI) gleaning information from other disciplines through journals, personal contacts etc and incorporating the information from other disciplines into your ongoing research.

- Model #3: Pursue the project with researchers from other fields, dividing up research tasks in a way that optimizes disciplinary expertise and allows the PI to efficiently coordinate research efforts.

- Model #4: Pursue the project working jointly as part of a team with researchers from other disciplines, taking the necessary time to gain some facility with other disciplinary areas as part of the execution of the research.

Which of the three most closely approximates the research interdisciplinary research experiences you have had to date?   1   2   3   4

14. What advantages and disadvantages do you see with the research model you have followed?

Probes (if necessary): What about issues related to: The amount of structure you believe is necessary in conducting a successful project? The benefit of broader vs. more-focused discussion? The value of time spent meeting, exchanging e-mail etc? The value of time spent working through different research methods and language?

I wonder if you could illustrate what you are saying with any specific examples from your research?

15. What did you gain, if anything, from interdisciplinary nature of the project?

16. Putting aside the tangible outcomes regarding the interdisciplinary project, did you learn anything unique or new as a result of working in an interdisciplinary manner? Use non-interdisciplinary experiences as baseline for comparison:

New knowledge? New skills? New frameworks? Think about problems differently? Any other "takeaways"?

17. Who was or is the audience for your results and publication? [discipline? external groups/larger issues?]

18. Of these models, is any one better than another for a graduate student or new faculty member to pursue at this stage in their career? Why?

19. Considering the priorities of your research area today, as well as where it is going in the near future, will any these three models become more dominant over time? Why or why not?

20. Now we are going to move from the specific models to discussing interdisciplinary research more broadly again. Based on your experiences so far, what would you say is the greatest difficulty associated with carrying out interdisciplinary research?

21. What is the greatest advantage?

22. What are the advantages and disadvantages of working on a research team?

23. In speaking with American graduate students, they cite a number of reasons for doing interdisciplinary research. Students' views appeared to converge, however, on the notion that interdisciplinary research is particularly well suited to "complex" problems. The term "complexity" is used fairly often in the literature on interdisciplinarity but meanings vary, at least in emphasis. We have sketched out three different definitions of complexity on this sheet, please take a quick look (hand out sheet to participant):

    Although, definitions of complexity obviously share some overlap, they differ in their emphasis. Thus the complexity of a problem has been described as denoting:

    - Those problems where the phenomenon of interest is so multifaceted that a solution can only be "constructed" from a number of different vantage points. Here the focus is on the sheer variety of perspectives required to solve a problem.

    - Those problems posed for us by the world outside the academy—e.g., social and environmental issues which span disciplinary boundaries.

    - Those problems that require a new way of thinking that attempts to study, and even predict, emergent and random properties of phenomena, and moves away from more linear, rule-based thinking that we often can apply to solve single-discipline problems.

    Given your goals as a scientist/engineer are any of these types of complexity relevant to you in the work you do? Do you think interdisciplinary research helps address complexity in any of the ways discussed?

24. How do you conceive of the future of interdisciplinary research initiatives (in your country)? Prompt: discuss issues like structural/cultural inhibitors of interdisciplinary research, funding, etc.

25. On a scale of 1 to 5, with 1 = not at all likely to 5 = very likely, how likely are you to continue to pursue interdisciplinary research in the future? 1 2 3 4 5

26. The following items provide different reasons why you, or someone like you, would become involved in an interdisciplinary project. **On a 1 to 5 scale, with 1 = not at all important to 5 = very important,** rate each of the following as a rationale for interdisciplinary research:

Serve colleagues, employer or funding agency	1	2	3	4	5
To acquire a new set of technical or methodological skills	1	2	3	4	5
To acquire a new perspective on a topic of research interest	1	2	3	4	5
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To explore a complex problem of professional interest	1	2	3	4	5
Other_____	1	2	3	4	5

Code Mapping for Faculty Interdisciplinary Learning: Three Iterations of Analysis (to be read from the bottom up)

Research Questions: RQ#1: Do faculty exhibit interdisciplinary understanding as a result of their interdisciplinary research experiences?   RQ#2: What mediates this learning process for faculty?
Third Iteration: Application to the Data Set Faculty members achieved interdisciplinary understanding through a learning process that was mediated by people, problem platforms, and solution mechanisms, to both enhance the execution of research tasks as well as to alter their conceptions of the research itself.

Second Iteration: Pattern Variables

1A. Disciplinary Grounding	2A. People
1B. Integration	2B. Tools
1C. Critical Awareness	

First Iteration: Initial Codes/Surface Content Analysis

1A. Need for own disciplinary expertise	2A. Engagement with scholar's body of work
1A. Fluency in other disciplines	2A. Collaborators from other fields
1A. Commitment to home discipline	2A. Supervising graduate students
1A. Acknowledgement different disciplinary cultures	
1A. Primacy of problems/research questions in research	
1A. Straddle both disciplinary and interdisciplinary work	

1B. Borrow tangibles (i.e., tools, equipment)	2B. Items "borrowed" during integration
1B. Borrow methods, data	2B. Question rich environments
1B. Borrow theories, philosophical approaches	2B. Items leveraged to answer big questions
1B. Alteration of research "personality"	2B. Performance tools vs. pedagogical tools
1B. Reframe research approach	2B. Learning through lending
1B. Reframe problems	
1B. Generate new research areas	

1C. Reflection upon definitions of Interdisciplinarity
1C. Negotiation of multiple scholarly identities
1C. Questioning utility of disciplinary labels
1C. Challenges of interdisciplinary research
1C. Societal & scientific impact