Interdisciplinary Research Connections and Attitudes in Research Universities

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ABSTRACT

This study explores the factors that support the development of interdisciplinary research connections in a large public research university. Graduate students and faculty from 15 departments (n = 227) responded to an online survey focusing on an individual's openness toward interdisciplinary research, applied epistemological orientation, and potential interdisciplinary collaborations. The findings suggest that the formation of interdisciplinary connections is tied to two main determinants: interdisciplinary openness, which is supported by reporting a more applied epistemological orientation and being a graduate student. The diversity of interdisciplinary connections is influenced by the academic status, with tenured faculty exhibiting the most diversity in connections. Finally, research network analysis suggests that the patterns of interdisciplinary collaborations tend to orient toward collaborations between similar and familiar methodological partners, and not toward collaborations with partners that are wholly unfamiliar in terms of methodology or research focus.

DEDICATION

This dissertation, along with the time and energy directed toward it, is dedicated to Sarah, Kaitlyn, and Ainsley. Sarah, thank you for your patience, encouragement, and serving as my greater purpose; this is truly our shared accomplishment. Kaitlyn and Ainsley, of all of the things that I have accomplished there is nothing that will compare to the joy of being your Father. My hopes and dreams for the two of you are endless.

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Introduction

A crucial component of America's role as a global leader is the ability to actively develop technologies and scientific innovations (Segal, 2004). An engine of the innovative capacity of the United States is the public science sector of our modern research universities (McMillan, Narin & Deeds, 2000; Narin, Hamilton & Olivastro, 1997). Scientific knowledge generated in research universities serves to support the emergence, and sustainment, of commercial scientific and technological ventures (Ndonzuau, Pirnay & Surlemont, 2002; Murray, 2004).

This fact is clearly understood and indicated by the government's passage of The America Creating Opportunities to Meaningfully Provide Excellence in Technology, Education and Science Act (COMPETEs) in 2007. America COMPETEs sets forth a plan focused on understanding the barriers that impede creativity and innovation in Science and Technology. One important mandate of the act is an exploration of the federal funding opportunities provided to pursue interdisciplinary research, which should enhance our understanding of how interdisciplinary scientific and technological advances are being supported.

The National Science Board, charged with reviewing the funding of interdisciplinary research by the National Science Foundation (NSF), provided a succinct review that reflects the increasing prominence of interdisciplinary research (National Science Board, 2008). Funding opportunities for interdisciplinary research have risen from 18 percent of NSF funded projects in 1987, to represent 46 percent in 2007 (National Science Board, 2008). The National Science Board found that while there was an increase in interdisciplinary funding, and thus more research being conducted, many lines of interdisciplinary research were left unfunded based on the greater demand than supply (National Science Board, 2008).

While securing funding is crucial to all types of research, interdisciplinary research in higher education faces additional hurdles due to the organizational context and culture that is unique to the modern research university. At the university level, there are several potential barriers to consider, such as span of control, organizational objectives, and issues of administration and funding. Today's universities are often described as organizations that are comprised of smaller disciplinary/departmental units operating independently of one another (Birnbaum, 1981), and that lack experience dealing with boundary spanning research (Stokols et al, 2003). When considering the potential to successfully conduct interdisciplinary research, one must consider the ability of the university administration to successfully oversee such efforts (Stokols, Harvey, Gress, Fuqua, & Phillips, 2005).

Large research universities are funded, in part, by the monies that are brought in through research grants. The distribution of grant money must contend with issues of accounting, operation, and budgets that constrain how much money a researcher can access from a grant. Not only is the individual researcher concerned with the disbursement of grant money, but the university administration must consider how to best apply research monies to the operation and mission of the university. While the difficulty in funding interdisciplinary research was offered as an argument against the pursuit of interdisciplinary projects, the funding tide is changing and the grant offerings of the National Science Foundation and the National Institutes of Health are embracing interdisciplinary research (Metzger & Zare, 1999). The shift in funding opportunities suggests that those who fund research do not have a specific stake in disciplinary research; instead, the stake is in advancing knowledge, and the betterment of the human condition (Schoenberger, 2001).

Finding funding for research can be challenging enough, and that challenge can be compounded by looking to conduct interdisciplinary work, yet it appears that this hurdle is diminishing. By exploring the context and culture of higher education, the intention of this research is to understand how the barriers facing interdisciplinary research manifest themselves in higher education. Within the higher education context, I will examine how the various barriers, described across diverse literatures, shape individual attitudes and support the collaborative opportunities necessary to conduct interdisciplinary research.

As outlined in the APS Observer (Cacioppo, 2007), the field of Psychology is uniquely qualified to examine the barriers facing interdisciplinary research and to offer constructive suggestions regarding the mechanisms that can shape and support successful interdisciplinary research. Psychological research offers us insight into the social and cognitive processes related to collaboration, along with insight on how different epistemological perspectives and cultural traditions may impact the process of interdisciplinary collaboration. The important role of psychological research in understanding the mechanisms underlying successful interdisciplinary research is advocated by the Committee on Science, Engineering, and Public Policy (COSEPUP, 2004) call for research examining the social and cognitive components related to successful interdisciplinary research.

Thus, the specific purpose of this research is to test, the anecdotal findings around interdisciplinary research within a useful organizing model that can guide questions and hypotheses related to the development of interdisciplinary research in higher education. In order to fully appreciate the challenges that face interdisciplinary research, and to orient previous research findings toward a suitable model, I will begin by exploring the differences between disciplinary and interdisciplinary research. Next, I will review interdisciplinary research barriers that are thought to shape the development, and success of interdisciplinary research in higher education. These points will be followed by an overview of how research networks influence interdisciplinary research and a brief overview of social network analysis. Finally, an organizing framework will be presented to guide the development of hypotheses and research questions.

Differentiating Disciplinary and Interdisciplinary Research

To begin with, it is appropriate to acknowledge that explorations of interdisciplinary research are often bogged down by differing definitions of what constitutes interdisciplinary research (COSEPUP, 2004). While it may be tempting to follow in the footsteps of Supreme Court Justice Potter Stewart who famously stated that "I know it when I see it" when attempting to define obscenity (Jacobellis v. Ohio, 1964), I will instead attempt to offer a measure of insight into what interdisciplinary research means for the purposes of this discussion. One approach is to define interdisciplinary research as any research that is beyond disciplinary, which provides a basic framework for definition, but neglects the nuance that truly makes interdisciplinary research a valuable avenue for scientific advancement. So, in order to understand what interdisciplinary research is, I will first explore what disciplinary research is and then build to an understanding of interdisciplinary research (Klein, 1990).

Disciplinary Research

Klein (1990) describes the idea of disciplinary science as "a stable epistemic community and agreement on what constitutes excellence in a field" (p. 107). Evaluating what constitutes a stable epistemic community, and where the interfaces and gaps exist between epistemic communities, will allow us to better understand what differentiates our disciplines from on another (Becher, 1995). Scientific research as a disciplinary focus is a function of the post-World War II emphasis in America on developing more specialized knowledge in science and engineering (Frost & Jean, 2003; Metzger & Zare, 1999). As a function of the technological needs of the time, our pursuit of knowledge moved away from that of the Renaissance man, and toward a perspective that was focused on the mastery of a specific domain of scientific knowledge (Nissani, 1997).

The gains in scientific knowledge that emerged from an emphasis on specialized disciplines of science led to the emergence of discipline specific languages, methodologies, theories, and worldviews. However, research suggests that language differences, in terms of meaning and usage, can impede interdisciplinary collaboration. Bracken & Oughton (2006) found that within the broader discipline of Geography, commonly used words did not always exhibit the same shared understanding of the word (e.g., dynamic). Using words in the absence of shared meaning may lead to a misunderstanding of the framework shared by collaborators and lead to confusion and disagreement for all involved parties (Bracken & Oughten, 2006). Even with this issue in mind, the idiosyncratic differences between scientific disciplines allow the various disciplines to lay claim to unique territories in the universe of scientific research.

These discipline specific differences do not necessarily suggest a lack of commonality between disciplines, however, these differences do serve to delineate where one disciplinary field ends and another begins. These epistemic differences also serve as a filter through which scientists evaluate knowledge within their own disciplinary domain. An important point to acknowledge is that while the scientific disciplines of today share a common goal of adding to scientific knowledge in general, each disciplinary field was formed in a way that makes it unique and therefore, potentially challenging for non-disciplinarians to fully access. While these disciplinary differences may be a source of frustration for those attempting interdisciplinary collaborations, it is essential to understand that a strong disciplinary base is fundamental to the successful pursuit of interdisciplinary research (Metzger & Zare, 1999).

As an approach to conducting science, disciplinary research requires the use and acceptance of a common language, common methods, common values, and adherence to specific boundaries that designate what is valued by the scientific discipline. The disciplinary approach makes navigation clearer and easier for those involved in pursuing questions of the same nature, serving to make scientific gains within a field more purposeful and successful. Even if one accepts the notion that disciplinary research exists within the boundaries outlined above, and that the collaborative act of two or more researchers from different disciplines is a base requirement for interdisciplinary research, we must not stop there. Instead, our understanding of the nature of interdisciplinary research should seek to understand the process as free from the constraints of any single discipline. Our understanding of this process may be best served by envisioning a collection of disciplinary trees coming together to form an interdisciplinary canopy. Within the larger interdisciplinary canopy, the individual domains of each discipline is lost, and blended into something new, where the disciplinary boundaries of each tree fades into those of the others. The net effect is a new approach to science, engineering, or technology, that is greater than the sum of its component disciplines.

Interdisciplinary Research

While the definition of what constitutes interdisciplinary research will vary depending on the source (Klein, 1990; Payne, 1999; COSEPUP, 2004), I believe that at the basic level interdisciplinary research is a process that extends beyond multidisciplinary collaborations (Payne, 1999). Multidisciplinary research may be what is most common when people consider spanning disciplinary boundaries by bringing together scientists from different disciplines.

Multidisciplinary research can be achieved when scientists work on a single problem together, by contributing their discipline specific expertise, and then go their separate ways once the common concern has been addressed (Stokols et al., 2005; Golde & Gallagher, 1999; COSEPUP, 2004). Interdisciplinary research is more than the act of working with scientists from other disciplines; it is a process that transcends subject matter expertise (Klein, 1990).

At the heart of the interdisciplinary research process is collaboration beyond a disciplinary focus; it is a process that requires high levels of communication and knowledge sharing (Stokols et al., 2005). This interactive process leads to the blurring of disciplinary lines and expertise, because participants begin to understand the varied approaches, languages, and culture of the other disciplines. A pure interdisciplinary research process results in the emergence of new knowledge and methodologies being shared across varied disciplinary scientists (Nissani, 1997; COSEPUP, 2004), but not to the complete abandonment of one's disciplinary framework in favor of a completely unique epistemological understanding and field. Though this may seem like a subtle difference, when a novel and unitary scientific framework emerges and serves as the guide for all of the researchers, then the outcome is more properly referred to as transdisciplinary research (Stokols et al., 2005; Klein, 1990). Transdisciplinary research transcends the existing disciplinary perspectives and reveals a new conceptual framework beyond what exists, a domain that is not defined by an intact methodological history or culture (Klein, 1990).

The idea of new knowledge or methodologies emerging as a part of the interdisciplinary process is based on the creative synergy that occurs when disciplinary "immigrants" bring a new perspective to a problem (Nissani, 1997). Based on the various descriptions offered for interdisciplinary research (Klein, 1990; Nissani, 1997; COSEPUP, 2004; Morse, Nielsen-Pincus, Force & Wulfhorst, 2007) my understanding of interdisciplinary research as a process does not allow a single disciplinary paradigm to dominate; instead paradigms are melded together via the interactive collaborations of the researchers. Interdisciplinary research is a process that requires the assimilation of complementary theories, languages, and perspectives that on the surface may appear to be in conflict with one another. Interdisciplinary research should not merely be the meeting of individuals from different, yet related, departments. The core of the process requires a stretching of the mind and an abandonment of obvious and common solutions to the questions being examined.

Within interdisciplinary science, the processes underlying the creation of boundary pushing solutions may be best understood as an experience in socio-cognitive conflict. Socio-cognitive conflict emerges when individuals hold different perspectives on how to solve a mutually shared problem (Mugny & Doise, 1978). The emergence of this cognitive conflict pushes the ideas that are in conflict into a social arena, where a new approach will be constructed by the individuals. Research suggests that the emergence of socio-cognitive conflict can lead to more diverse and creative solutions to problems (Levine, Resnick & Higgins 1993), which is at the heart of the interdisciplinary research process.

The outcomes associated with socio-cognitive conflict may support the perception among interdisciplinary research advocates that the answers to the difficult and large-scale questions lay within the interdisciplinary research process (Stokols, et. al., 2005; Rhoten & Parker, 2004). In the spaces that lie between our scientific disciplines, researchers can come together and work through their cognitive based differences in epistemologies, methodologies, and priorities to find new and creative answers to relevant research problems (Sung, Gordon, Rose, Getzoff, Kron, Mumford et al., 2003). With all of that being said, the potential for discovery that is inherent in the interdisciplinary research process must still overcome issues related to the culture of the modern research university, our individual attitudes and beliefs, and the challenges inherent in managing a diverse group of individuals (Mannix & Neale, 2005)

Barriers Facing Interdisciplinary Scientific Research across the University

The problems facing the process of interdisciplinary collaboration in the modern research university are complex, and do not rest solely with one specific group or individual. Instead the barriers cut across all levels of the university setting, where there are differences in disciplinary epistemologies and cultures, tenure and promotion processes, approaches to graduate training, and even the organizational and physical design of the university. These multisource and multilevel issues combine to inhibit the development of the crucial interpersonal connections that scientists from different disciplines need to support their engagement in interdisciplinary research.

Disciplines, Departments and Interdisciplinary Research

The most often cited level of influence on an individual's willingness to pursue interdisciplinary research is the nature of his or her discipline. Some argue that specific spheres of scientific inquiry are more receptive to the pursuit of interdisciplinary research, such as the social sciences, while others are less receptive, such the natural sciences (Gaff & Wilson, 1971). Varied disciplines are suggested to have distinct epistemologies and cultures that define the way researchers conduct, disseminate, and evaluate scientific research; which may impede interdisciplinary collaboration.

While discussing the nature of disciplines and departments, it is important to note that Klein (1990) cautions against treating the two as interchangeable entities. While Klein is correct in asserting that a department does not equal a discipline, as one can easily enter a department and find individuals that practice very different forms of the same discipline, or even a complementary discipline, it is reasonable to argue that departments capture a great deal of the disciplinary essence within higher education. With Klein's cautionary statement considered, for reasons of functionality, this research will treat departments as organizational representatives of a discipline. The rationale is that departments serve to train undergraduates and graduates in the principles of their respective disciplines, as well as serving to drive research that contributes generally to the knowledge base of the departmental discipline. To further echo this point, when discussing the graduate degrees conferred by a program, or the status of a professor at a university, the general practice is to refer to the department, not necessarily the individual's discipline (i.e., Dr. Smith, Professor of Economics, or Ph.D. in Entomology). In that vein, departments are where a good deal of the career level concerns of the university researcher will emerge, making the organizational unit of a department an appropriate area in which to explore the challenges facing interdisciplinary research.

Disciplinary Epistemologies

Essential to the scientific process of inquiry are the epistemological maps that guide the work we do as researchers. Over time, disciplines have developed their own concepts and languages, standards of proof, modes of inquiry, means of defining a problem (Petrie, 1976). As disciplinary practitioners immersed in our respective epistemologies, we begin to evaluate the world based on our specific languages and customs (Nissani, 1997; Schoenberger, 2001). We spend so much time immersed in our own epistemology; we may begin to develop a form of disciplinary or departmental chauvinism, leading us to have less respect for other fields of scientific inquiry (Stokols et al., 2003). Some disciplines or departments can become so epistemologically established and respected, that simply the status of a discipline can shield them from interdisciplinary "intrusion," or in the case of low status discipline, hasten the intrusion (Becher, 1995). So, now coupled with the difficulties interdisciplinary researchers must face in terms of communication, and stepping outside of one's own understanding, researchers may have to deal with the perceptions of others who believe that their field is less than equal.

The presence of departmental chauvinism is not expected, because as researchers competing for limited resources, we may feel a need to protect our departmental/disciplinary group, by diminishing the importance of other groups. Social identity theory suggests that as an individual begins to identify more closely with a specific group, there is pressure to distinguish the individual's group from groups of others. This theoretical approach finds that a group will establish norms for behavior, and the boundaries and appropriate activities that group members are permitted to pursue. The groups will provide information, in the form of "social beliefs," that will identify the other groups that are appropriate to collaborate with, while indicating the groups that are not acceptable (Hornsey & Hogg, 2000). Social identity theory suggests that the research focus of specific disciplines, such as applied vs. pure orientations, could serve to encourage or impede attempts at interdisciplinary research. For example, researchers in pure science fields may be less willing to work with researchers focused on applied research (McNeill, 1999), while applied researchers are thought to be more open to interdisciplinary collaboration. So, while an individual's disciplinary group may not forbid collaboration outside of the group, the group will express beliefs that will encourage collaboration with some outsiders and not others.

Disciplinary Cultures

Adherents of disciplinary cultures align with the beliefs and values of their focal group. While often abstract and intangible, these beliefs and values manifest themselves in the cultural norms and tacit practices of a disciplinary field (DeLong & Fahey, 2000). The tacit practices and norms of disciplines, such as being competitive, individualistic, or open, serve as distinctive markers of the disciplines (Becher, 1994). As a researcher becomes more socialized within a discipline, he/she will begin to take on and identify with the similar attitudes and values of disciplinary peers (Gaff & Wilson, 1971). Again, the expectations of a disciplinary culture begin to define the individuals with whom one should and should not collaborate. Disciplinary norms direct an individual's behavior toward the group's expectations and will direct the knowledge sharing behavior of the group members (DeLong & Fahey, 2000).

As disciplinary identity is strengthened with time and experience, so too are perceptions and awareness of in-group and out-group membership. The process of group identification serves to strengthen an individual's adherence to the in-group norms, which will continue to reinforce an individual's identification with the in-group (Van Knippenberg & Wilke, 1992). The pressure to conform to the expectations of the in-group may influence the degree of ease an individual experiences if they attempt to cross disciplinary boundaries, particularly if they are attempting to pair with collaborators misaligned with the in-group. Within academia, the boundaries facing collaborations may be most salient at the departmental level, where the disciplinary and departmental expectations shape tenure considerations, determine what research is considered valuable, and the nature of graduate training.

Tenure Considerations

Within an academic department there are clear delineations of status that are reflected in the titles that faculty earn. These differences in status make the process of promotion and tenure an important component of most academic careers, reflecting a departmental level evaluation of a faculty member's achievements within the department's discipline (DeFleur, 2007). As one secures tenure, and moves up the academic ranks toward the position of Professor, there should be a corresponding increase in academic freedom. Additionally, promotions awarded to faculty often correspond with increases in salary and status; these incentives should serve to motivate individuals toward the desired behaviors of the department (Tien & Blackburn, 1996).

In research universities, research productivity is often the most important the criterion when considering tenure and promotion (Tang & Chamberlain, 1997; Kasten, 1984), hence the old adage of "Publish or Perish."   Researchers are required to disseminate new scientific understanding in a timely manner and in a fashion that establishes a contribution within a specific domain, by communicating with a relevant audience. Because of the different writing styles across the varied fields of science (McNeill, 1999), preparation of an interdisciplinary research manuscript may take more time and may be evaluated using criteria that is unfamiliar to some, or all of the contributing researchers. Shifts in styles across disciplinary practitioners, as well as manuscript reviewers, may cause the review process for interdisciplinary research to be longer than the review process normally associated with one's disciplinary science journals. These issues related to research productivity may serve to discourage interdisciplinary research (Tress, Tress, & Fry, 2006; Wear, 1999; Stokols et al. 2003) among faculty, particularly those concerned with demonstrating their research productivity as a means to secure tenure.

While the adage of "Publish or Perish" may support a drive to publish research, what is considered valuable research is not always measured similarly across disciplines. During the tenure and promotion review process, departmental peers may consider factors such as the count of manuscripts published, or a manuscript's impact factor (Ramsden, 1994), which may lead to the devaluation of interdisciplinary research, given the time constraints and review concerns mentioned above. Departmental peers may also evaluate the quality of the research using the standards of the discipline (Ramsden, 1994), which may be cause challenges if the research embraces unfamiliar scientific methods, languages, and perspectives. Understanding that one's disciplinary peers will be evaluating not only the quality, but also the quantity, of a researcher's work may give pause to those considering research that steps outside of his/her disciplinary norms and epistemology.

The above points suggest that the tenure and promotion process lacks incentives to pursue, and may even serve to discourage, interdisciplinary research (Stokols et al, 2003). So while some might consider junior faculty open to pursuing interdisciplinary research as they establish their research programs (Rhoten & Parker, 2004), these same faculty must focus on securing tenure and establishing a strong reputation among their peers (Frost & Jean, 2003). Junior faculty may possess unique research goals and interests (Metzger & Zare, 1999), but choosing to break from the disciplinary research path early in one's career may be viewed with skepticism by the departmental peers who are crucial in the process of evaluation (McNeill, 1999).

If junior faculty exhibit higher levels of openness toward interdisciplinary research, yet are faced with conforming to the norms of the department, then where can one reasonably expect to see interdisciplinary research occurring? Research on conformity provides insight on how the status of group members can support or diminish the tendency to conform. Individuals who possess a mid-level status within a group are found to exhibit the highest levels of conformity to group behaviors, while individuals with high-level status are seen as exhibiting higher levels of deviance from the group norms (Phillips & Zuckerman, 2001). Individuals low in status may demonstrate low levels of conformity or high levels of conformity, depending on the importance of referent group acceptance (Dittes & Kelley, 1956; Blau, 1960). A common assertion is that status and conformity to group norms exhibits an inverted U relationship, such that tendency to conform rises along with group status until a high level status is achieved, which allows for less conformity and more norm-based deviance (Phillips & Zuckerman, 2001).

Based on the findings of research related to adherence to group norms, assertions can be made regarding the type of faculty that would be most open to interdisciplinary research. Assuming that pursuing interdisciplinary research is considered a divergence from the norms of a department, junior faculty, such as Assistant Professors, should exhibit mixed tendencies in terms of their openness to interdisciplinary research, with most preferring to avoid interdisciplinary research. Mid-level faculty, such as Associate Professors, should also exhibit a mixed tendency toward interdisciplinary research, based on the fact that they have reached a tenured position, and may differ on whether there is an interest in pursuing a Full Professor status. Those who are content to conduct the research that they prefer, without concern for further promotion, may be completely open to exploring new options. Meanwhile, those who are still trying to move up the ranks will be pressured to conform to the expectations of the group, or at least one's perceptions of the expectations. Full Professors, who possess a high-status level within a department, should exhibit a greater degree of openness to pursuing interdisciplinary research than their academic peers. This does not mean that Full Professors will fully abandon the notion of a disciplinary focus, but they would clearly be in the position based on status and experience to be open to the possibilities of interdisciplinary research. With the U-shape model suggesting that Professors are the most open to interdisciplinary research, this raises the real concern that those who are most able to pursue research outside of a discipline will no longer be interested in charting a new path once they have spent the time establishing their careers (Petrie, 1976).

Graduate Training

Outside of the potential for interdisciplinary research within the faculty population, a frequently discussed resource in the development of interdisciplinary research are the graduate students being trained to conduct the research of the future (Sung et al., 2003; Rhoten & Parker, 2004; Fry, Tress & Tress, 2005; Mitrany & Stokols, 2005). While some envision graduate education as the frontier of interdisciplinary research, the training of graduate students is a multi-faceted process that is complex and differs greatly across departments and their disciplines (Turner, Miller & Mitchell-Kernan, 2002). Because of the vast differences and challenges associated with graduate training, graduate students face three significant hurdles that could inhibit the pace of interdisciplinary research among graduate students. Specifically, graduate students must contend with securing funding, demonstrating appropriate competence, and ensuring proper career development. These hurdles reflect the fact that graduate students are novice researchers, training to become expert researchers under the tutelage of faculty members embedded in a disciplinary and departmental culture (Turner et. al., 2002).

Primarily, the ability of a graduate student to pursue research outside of his or her discipline is shaped by the standards and criteria established by one's departments and advisors (Golde & Gallagher, 1999). In addition to having to meet the criteria established by departments and advisors, graduate students have to secure funding, which is often tied to research projects defined by their advisors. Additionally, there must be an acknowledgment that even if a graduate student has the latitude to initiate and engage in collaboration with researchers outside of his/her department, he/she is probably still limited in opportunities to collaborate due to diminished power to bridge disciplines and open doors. Beyond this point, if a graduate student is in a position where interdisciplinary research is supported by his or her advisor, and is provided funding, then is he or she competent enough to fully engage in interdisciplinary research?

Graduate student training focuses on developing disciplinary researchers, and in the beginning does not necessarily provide graduate students with the skills to be productive interdisciplinary researchers (Golde & Gallagher, 1999). The issue of competence is not necessarily a reflection of the quality of the graduate student, but based on the fact that graduate students must first develop competency within their own scientific discipline (Payne, 1999; Petrie, 1976). In the absence of an appropriate level of disciplinary competence, the novice researcher may miss important discoveries and/or approaches related to their interdisciplinary research (Nissani, 1997). The concerns around balancing the depth and breadth of training will carry beyond the years of graduate training.

There is a concern that graduate students who focus on research that is truly interdisciplinary will have diminished career options when compared to their disciplinary peers. As Frost & Jean (2003) point out, the same expectations that are in place for junior faculty are often of concern for graduate students considering academic careers. In order to secure an academic job upon graduation, graduate students must have demonstrated their disciplinary competencies and potential for making meaningful contributions in the future. Graduate students, considering what a future employer might consider important, may have little desire to restrict their career options by developing a skill set that may not align with the goals of academia (Golde & Gallagher, 1999).

The barriers graduate students face may suggest that interdisciplinary research is too costly for graduate students to pursue (Rhoten & Parker, 2004). This suggestion is supported by evidence that publication and graduation rates are found to decrease when graduate students pursue interdisciplinary research (Birnbaum, 1981). So, while graduate students may be seen as a viable frontier in the evolution of interdisciplinary research, the reality is that by the time graduate students have completed the necessary training, secured a position within academia, they may have lost the motivation and flexibility to be interested in and/or perform interdisciplinary research (Sung et al., 2003).

University Organizational Barriers to Interdisciplinary Research

All of the issues mentioned above are embedded within the larger organizational context of the modern research university. An important organizational consideration for successful interdisciplinary collaboration is having a shared venue for the process of collaboration, so that the interdisciplinary collaborators have and the ability to directly engage one another in the research process (Stokols et al., 2003; Stokols et al., 2005). The difficulties in finding an appropriate research venue may be further exacerbated if individuals are working across different universities (COSEPUP, 2004). Toker & Gray (2008) examined the impact of workplace configuration on outcomes related to interdisciplinary collaboration, such as innovation and connectivity. When researchers had greater accessibility, as indicated by shorter walking distances and unity of shared space, they were more likely to exhibit higher levels of innovation and consultation, which supports research objectives around interdisciplinary collaboration (Toker & Gray, 2008).

If universities are structured to support disciplinary silos as the norm, and supports varied practices related to tenure and promotion, graduate training, and the designation of research space, then are there areas within higher education where interdisciplinary research connections can successfully form? A leading scenario is that interdisciplinary connections are simply formed at the level of the individual, who is personally compelled to pursue a specific research path, and through his or her own ambition reaches out to others they may know outside of his/her department. Another viable and equally important scenario is that individual disciplines and departments may have natural networks of collaborators with common goals and methodologies, shared questions and perspectives, or even shared physical space.

Interdisciplinary Research Patterns in Scientific and Engineering Research

If we consider the department of a research university to be the niche in which an individual professor or graduate student secures a good deal of his/her professional reputation, then it is reasonable to consider that individuals within a department would work to form connections that support the sharing of similar attitudes and values. From that point, it is then reasonable to consider that those same individuals would at the very least avoid the sharing of incongruent attitudes and values (McPherson, Smith-Lovin & Cook, 2001). Given this tendency, McPherson et al. (2001) suggests that individuals tend to have fewer and more fragile connections outside of our developed niches, which would further suggest that interdisciplinary research collaborations are less likely to occur if we are required to step outside of what we know and who our group identifies with. Understanding interdisciplinary research requires us to evaluate where and how the research connections that support it will emerge. An understanding of how our connections manifest is important, because beyond any individual's disposition toward interdisciplinary research, the presence of connections outside of one's research discipline is required for the boundary spanning process of interdisciplinary research (COSEPUP, 2004).

Within interdisciplinary research, our formal and informal networks serve to support the transfer of group specific knowledge, such as the specialized knowledge of disciplines, between individual researchers from otherwise disconnected disciplines (Liebeskind, Oliver, Zucker &

Brewer, 1996). The existence of a research network with diverse disciplinary knowledge will provide the individual actors the necessary flexibility to span the boundaries that may exist within an organization (Liebeskind et. al, 1996). If the research network is a vital component of successful interdisciplinary research, then the trends of interdisciplinary connections that have been discovered by other researchers should provide further insight into where interdisciplinary research is present and absent.

Some recent research efforts have examined the areas of interdisciplinary research activity by examining the output of interdisciplinary collaborations as a function of publication information. Boyack, Klavans & Borner (2005), used social network analysis to explore where the boundaries of disciplinary research were being crossed. In a review of over 1 million research documents, Boyack et al. (2005) found that there is a there is a tendency for certain scientific disciplines to align themselves with others, which suggests the presence of semi-permeable boundaries between certain disciplines (see Figure 1). Based on the findings of the social network analysis, Boyack et al. (2005) suggest that Biochemistry is an "interdisciplinary hub," because 52 other disciplines have a notable percentage of shared citations with Biochemistry. This fact is demonstrated by the large node size of Biochemistry, the large number of edges (lines) connected to Biochemistry, and the fact that most disciplines nodes are presented in around Biochemistry as the center of the network. Boyack et al. (2005) also comment on the relative independence within social sciences when compared to the more "traditional" sciences such as Chemistry and Physics, which both exhibit a larger number of edges (lines) moving to and from one another. Other fields are described as having "tenuous links" with one another, such as Mathematics and Social Sciences, with the connections between these disciplines being few to none. The findings suggest that with regard to research with non-departmental collaborators, disciplines tend to have relationships that are more likely than others.

Morillo, Bordons & Gomez (2003) presents similar findings from a cluster-analysis of journal citations that explored the strength of connection existing between scientific disciplines by evaluating the pattern of shared research journals. The evaluation of shared journals indicated that there are specific patterns of interdisciplinary collaboration. In evaluating the interdisciplinary trends observed in the shared journals, the authors suggest that some disciplines engage in “big” interdisciplinary research, while others engage in “small” interdisciplinary research (Morillo et. al, 2003). “Big” interdisciplinary research is the type that reaches out to distant disciplines, while “small” indicates research that crosses disciplinary boundaries by partnering with a closely related discipline.

In addition to their comments on “Big” vs. “Small” interdisciplinary research, Morillo et al. (2003) also demonstrated a pattern of collaboration that aligns with those presented in Boyack et al. (2005). The Social Sciences demonstrated a lower pattern of interdisciplinary relationships when compared to the Biology, Agriculture, and Medicine, which exhibited a higher pattern of interconnectedness between one another. Morillo et al. (2003) also found that Engineering, Chemistry, and Physics clustered together, which aligns with the findings of Boyack et al. (2005).

While Boyack et al. (2005) and Morillo et al. (2003) are both mapping out disciplines, the nature of their respective explorations is to determine where collaboration is occurring through an examination of publication outputs. Biglan (1973) provides additional information on the relative position of scientific disciplines by evaluating the disciplines across various epistemological dimensions (see Figure 2). If disciplinary epistemologies influence our collaboration patterns, then it would be reasonable to discover similarities between epistemological relatedness and collaborative relationships. Comparing Biglan's (1973) layout of disciplines, around the applied and pure dimension, with the layout of the disciplinary fields in Boyack et al. (2005) it is revealed that there are commonalities between the two layouts. As evidenced in Figure 3, the departments that fall in Biglan's (1973) range of pure sciences are represented in a band of disciplines within the layout presented by Boyack et al. (2005). The disciplinary fields outside of the band in Figure 3 are described as applied within the Biglan (1973) plot. Within the band, there appears to be a second set of disciplinary clusters, representing the "hard sciences" and the "social sciences" as described in Biglan's (1973) mapping of the disciplines. These observations support the idea that similarities in epistemological orientation support research collaborations.

Overall, the above findings suggest that there are interdisciplinary research opportunities that would be expected or tolerated areas of collaboration (e.g., Biochemistry and Chemistry), and then there may be those research projects that would deviate from the standard patterns of collaboration (e.g., Mathematics and Psychology), the so-called "big" interdisciplinary projects. Additionally, there are disciplines that are more interdisciplinary by nature, such as the "hub" science of Biochemistry (Boyack et al., 2005; Morillo et al., 2003). These observed patterns suggest that it would take significant direction and authority, on the part of a researcher, in order to span the larger distances that might exist between the less connected disciplines. Thus, the findings suggest that "big" interdisciplinary projects would occur less frequently than "small" interdisciplinary collaborations. Looking at the necessary effort and resources that would be required of a researcher pursuing "big" interdisciplinary collaboration, it is not surprising that there are more factors (e.g., disciplinary norms, status, access) that discourage "big" interdisciplinary research, than those would that encourage "big" interdisciplinary research (e.g., shared research space, adjusted tenure expectations).

As suggested above, understanding how the patterns of interdisciplinary research connections are formed in light of the boundaries will benefit future efforts to support interdisciplinary research. The above research relied on social network analysis techniques to illuminate where collaborations occur (Morillo et al, 2003; Boyack, et al, 2005), and this research will also utilize social network analysis to provide an understanding of research collaborations and answer some specific research questions. A brief overview of the technique is offered below.

Social Networks, Attitudes and Boundary Spanning

At the core of social network analysis is an attempt to understand the connections that support the communication of information and the sharing of resources among a set of actors, which is vital to the interdisciplinary research process. The actors within any social network can be individuals, or larger collectives, such as neighborhoods, companies, or states. What social network analysis does is collect information about where connections exist between individual actors. From this information, a network is developed that can be explored numerically as a relationship matrix, which is complemented by a graphic representation of where connections lie between the actors of interest (Freeman, 2000).

Whatever the approach is, either numerical or graphical, the general information is the same. Researchers can understand how actors within a network perceive one another (attitudinal), or how they are connected to one another (relational). Evaluating the connections allows for the identification of key players within the network, and an understanding of the ease with which any particular actor can make contact with another actor, either directly or indirectly.

Researchers can also examine who is not connected within the larger network, and seek to understand where and why subgroups exist.

Within the social network approach each actor within the network is a node, with connections (referred to as edges in graph theory) between the actors being present or absent. Beyond the nodes, network analysis can rely on a directed network, or non-directed network. Directed networks evaluate the connections between the actors by considering whether the connections are one-way, or mutually reported by the connected actors. Non-directed networks are simply evaluating connections as a function of whether or not a connection is reported by any actor in the network, regardless of whether the connection is mutually reported.

Information from social networks can be evaluated at multiple levels, such as the individual, department, branch, etc. Analyses related to the connections within a network can focus on the characteristics of the overall network itself, such as network density, or on the characteristics of the actors within the network, such as actor centrality. Often, analyses will provide information across multiple levels (e.g., individuals and departments), which will provide a more robust understanding of the network under investigation.

An important network characteristic is density, which indicates the degree of connectedness observed across the entire network of actors. As a numerical value, social network density is derived by calculating the proportion of connections that are reported in a network to the number of possible connections in a network. This calculation provides a value ranging from 0 to 1 and indicates the extent to which all of the actors in the network are directly connected to one another. A network that has a greater proportion of direct connections among all of the actors has a higher density value. Another helpful network value is graph centrality, which is the extent to which a single network node serves as the hub of communication within a network. For example, if within a network of 50 actors, the only connections reported by 49 of the 50 actors are with the same single actor, then that network would exhibit high graph centrality. Such a scenario is represented graphically by a wheel with all of the spokes (or edges) emanating from the single connecting actor's point in the middle. These network level attributes give us a means of understanding the relative interconnectedness and patterns that are present within a network as a whole unit of observation. While network level values, such as density and centrality, provide information about the composition of a network, we may also be interested in the roles of specific actors within the network.

When considering the role of specific actors, we often seek to understand the effect an actor has on information flow, or how easily actors can reach one another. A common actor based index is point centrality. Point centrality reflects the degree to which a connecting with a point, or actor, allows for the flow of information or goods between points that are not directly connected (Freeman, 1977). Point centrality can be conceptualized using two approaches, for the purpose of this discussion is conceptualized as betweenness centrality (Freeman, 1978; 1979).

Freeman's (1978; 1979) betweenness centrality indicates the extent to which an actor is receiving and sending connections to others, or how often an actor is between two other non-connected actors. The more frequently an actor serves serve as a go-between for other actors, the more central that actor. Betweenness centrality can be calculated by tallying the number of times an actor serves as a go-between and then calculating a proportion relative to the maximum number of possible go-between relationships. Betweenness centrality is reported as a percentage that indicates the relative betweenness centrality of any actor (Hanneman & Riddle, 2005).

Beyond the roles of specific actors, and the general composition of the network as a whole, one of the more informative components of social network analysis is the examination of cliques. Cliques are cohesive groups of actors that are directly connected to one another, such that each actor can directly contact every other member of the clique. By examining cliques, social network analysis identifies subgroups of actors who have formed a cohesive group, allowing researchers to look for commonalities, such as culture, status, etc., which may reveal the commonalities among a particular set of highly interconnected actors (Hanneman & Riddle, 2005).

For the purposes of the research presented here, it is most relevant to discuss cliques that are not as strictly defined. While it may be desirable to look for a group of researchers within one department, who are maximally connected to another group of researchers from another department, this expectation may not be practical. Instead, modified cliques referred to as n-cliques and n-clans will be examined. N-cliques and n-clans consider clique membership by looking for individuals that are connected to a clique via an actor in the clique; this is what Hanneman & Riddle (2005) refer to as being a "friend of a friend." By exploring these cliques, it is possible to assess the extent to which members of a specific department are reaching out to members of other departments, and if there are commonalities within a department in terms of preferred collaborators. Applying social network analysis to the area of interdisciplinary research will provide more contextual information to where collaborations are found, identify important collaboration patterns, and insight on the prevalence and shape of interdisciplinary collaboration.

A Framework for Understanding the Emergence of Interdisciplinary Research

In summation, the literature suggests that individual researchers in universities are generally embedded within disciplinary departments that provide delineation from other disciplines through unique languages, methodologies and epistemologies. Within the departments, the discipline specific norms and values support the adherence to a common set of career-based behaviors, incentives and research paths. Evidence from group research suggests that as one begins to identify with a group of people, the tendency to adhere to group norms will drive individual attitudes to become more representative of the overall group's attitude. As the attitudes within a group become more similar, one could expect that shared intentions around behavior, and actual behavior, would begin to emerge, serving to reinforce the norms and expectations of the group (Smith, Hogg, Martin & Terry, 2007).

The experience of the researcher in a modern research university is one that is influenced by external and internal forces. The forces are a function of organizational structure, power differentials, biases, philosophical bents and individual differences in thought, attitudes and personality. The forces that shape the path and propensity of a researcher to engage in interdisciplinary research cut across so many levels and factors that developing a cogent explanatory model may be a challenge. In order to make sense of how the various forces may come together, the ideas imbedded in the Theory of Planned Behavior (Ajzen, 1985; Ajzen, 1987) were used as a template for formulating a general framework of relationships to explain the emergence of interdisciplinary research behaviors.

The Theory of Planned Behavior (Ajzen, 1985; Ajzen, 1987) is a theoretical framework that explains how external factors and experiences are internalized to shape perceptions and attitudes around behavior, which then influence the actual expression of the behavior. As interdisciplinary collaboration is a specific behavioral process, the Theory of Planned Behavior seems to be an appropriate organizing framework for the development of hypotheses related to the emergence of interdisciplinary collaboration.

The Theory of Planned Behavior begins by looking at the role of the external inputs (real and imagined) of norms and expectations as they constrain or support our behavior. Normative beliefs are higher order shared understandings of how important parties in our lives evaluate and value the various behaviors that we may engage in (Ajzen, 1985; Ajzen, 1987). In higher education the normative beliefs are reflected in the higher level departmental epistemological orientations, such expectations of disciplines and departments to be applied vs. pure, or hard vs. soft (Biglan, 1973). What is valued and expected will be a function of the epistemological bent of a department, which will delineate between work that is valued and work that is wasteful, which will in turn influence the processes related to promotion and tenure. Departmental epistemologies, as a normative force, will influence how an individual perceives interdisciplinary collaboration by indicating if interdisciplinary research is valued within an individual's department.

Perceptions of the various external inputs are internalized by a person to become perceived norms, perceived behavioral control, and behavioral attitudes. These internalized factors serve as throughputs by directly influencing behavioral intentions. Perceived norms are individually held internalized representations of the external group norms, which act as a barometer for the "social pressure" that someone might experience. Perceived norms, as reflections of some larger group norm, are subjective, but bound by the external normative beliefs of the department (e.g., epistemologies). For example, in the realm of departmental research, an individual may internalize departmental epistemology as a component of defining research that will support career success. As this internalization process unfolds, a researcher's individual epistemology is shaped by his/her perception of the department's epistemology. Perceived behavioral control represents the extent to which an individual believes that he/she can successfully control the external factors that are necessary to successfully undertake a specific behavior. Control beliefs and perceived behavioral control reflect the ability to control important external variables, such as funding, resources, space and the cooperation of others; it is not one's internal sense of self-control or self-efficacy. An analog of this internalization in the academic setting can be found in discussions around status and interdisciplinary collaboration. The common assertion is that graduate students are not free to act as independently as other researchers in higher education, which is a function of the developmental ability of graduate students (which will vary with ability and time) and the external latitude afforded graduate students (e.g., freedom to choose research agenda, collaborators, funding, etc.). Academic status can serve as a proxy for one's perceived, and actual, behavioral control.

Behavioral attitudes develop as our understanding of how the outcomes associated with specific behaviors align with our perceptions of the higher order group norms. The alignment of behavioral outcomes with group norms and expectations will in turn lead to the development of positive or negative attitudes toward the associated behavior. If a researcher believes that interdisciplinary collaboration will slow down the achievement of tenure, then that researcher may develop a more negative attitude toward interdisciplinary collaboration and be less open to interdisciplinary research.

As these three internalized inputs come together, they coalesce into an intention to act, which immediately precedes behavior. Behavioral intention to act is the most proximal throughput of behavior; it is the springboard for behavior (Rhodes & Courneya, 2003, Ajzen & Fishbein, 2005). Intention is a forward-looking stance, or cognition, that directs us to the behavior of interest. An example of this forward-looking stance is when an individual researcher begins mapping out potential research projects and collaborators. Someone interested in pursuing interdisciplinary research may begin to consider the fit of non-departmental researchers as interdisciplinary collaborators.

Holding a specific intention does not guarantee that we will engage the target behavior, or succeed, simply that we are looking forward to the behavior. Also, there are times when an individual engages in a behavior simply because they can. Such individuals have such control over the factors that influence successful completion of a behavior, it is not necessary to formulate a forward-looking behavioral intention (Rhodes & Courneya, 2003). Instead, the individual simply does something because he/she can, not because he/she has a positive or negative attitude toward the behavior, and not necessarily because it is associated with a specific and desired outcome. Clearly there are numerous instances where behavior is automatic in nature (e.g., a habit) and does not require any specific and conscious intention to act (Aarts & Dijksterhuis, 2000), but I believe that interdisciplinary collaboration primarily falls within the domain of planned behavior.

As a behavioral framework, The Theory of Planned Behavior has had a long history of research, and is considered a viable model for explaining important facets of human behavior. When considering how the three internalized components of the Theory of Planned Behavior interact with regard to interdisciplinary research, it is important to consider the meta-analytic findings of Notani (1998) and Armitage & Conner (2001). The authors argue that the three internalized throughputs that precede intention are not equally important in the formation of behavioral intention. Ajzen & Fishbein (2005) do not dispute that there are times when specific throughputs are more relevant and suggest that people will weight the various components based on context and personal experience. Armitage & Conner (2001) found that perceived norms are often the weakest predictor of behavioral intention, due in part to problems with accurately measuring perceived norms. Armitage & Conner (2001) suggest that a reconceptualization of perceived norms is necessary, and that it may be more appropriate to explore a group level measure focused around self-identity and understanding normative beliefs an individual identifies with. Notani (1998) also found that perceived norms are not the strongest predictor of behavioral intention, and found that an individual's attitude toward a behavior is the most consistent predictor of behavioral intention, and thus his/her behavior.

The findings of the meta-analyses suggests that while the model associated with the Theory of Planned Behavior presents attitudes, subjective norms, and perceived behavioral control as equal factors in the emergence of behavioral intentions and behaviors, attitudes may be more important than other factors, and perceived norms may be too difficult to capture as it is conceptualized. These findings are important, because they do suggest a slight deviation from the equal and reciprocal relationships outlined in the Theory of Planned Behavior. The findings of Notani (1998) suggest that attitudes may be weighted more heavily than subjective norms in the development of behavioral intention.

Borrowing from the Theory of Planned Behavior model, and responding to the findings of Notani (1998), I offer Figure 4 to organize the various inputs and throughputs related to interdisciplinary research collaboration. The proposed framework is not a direct replication of the Theory of Planned Behavior as often described in the literature (e.g., Azjen & Fishbein, 2005). The reciprocal relationships between the most distal components of the Theory of Planned Behavior are not included, as the variables themselves are absent in this study. The possibility of a direct relationship between perceived behavioral control and behavior itself (bypassing intention) is not included in the framework though this point has been a focus of discussion around the Theory of Planned Behavior (e.g., Rhodes & Courneya, 2003). The role of attitude is presented as a more proximal variable than perceived norms and perceived behavioral control, which reflects an understanding that attitudes are often the strongest driver of behavioral intentions (Notani, 1998) and that often times attitude, perceived norms, and perceived behavioral control are weighted differently (Azjen & Fishbein, 2005). With these points understood, what follows is the proposed framework for understanding how interdisciplinary research emerges.

As mentioned earlier, individual epistemology is a function of an individual's experience, culture, development, and understanding of the external world. Specifically, a university level researcher's individual epistemology reflects the educational background of the individual, and the cultural expectations and epistemology of a department. As demonstrated in Biglan (1973), disciplines/departments exhibit specific epistemological tendencies toward applied or pure science, which an individual researcher can internalize as indicators of his/her discipline/department's standards around scientific research.

Path 1 in Figure 4 suggests that the nature of a department's epistemology, as a relatively static set of beliefs (e.g., pure vs. applied), will shape the individual epistemologies of the researchers within the department. An individual's epistemology reflects the subjective internalization of the disciplinary/departmental epistemology that an individual experiences, and will be less static, and more difficult to capture (Armitage & Conner, 2001), than the relatively static beliefs around the departmental epistemologies that are reflected in categorizations like Biglan's (1973).

An individual's epistemology will serve to drive two vital components of this framework. In a more direct fashion, an individual's epistemology will influence one's consideration of potential research connections (Path 2) by moving people to behave in a manner that aligns with the department epistemology of the referent group. Following along Path 1 and Path 2 suggests at indirect effect of individual epistemology on the consideration of potential interdisciplinary connections. This possibility is supported by the findings of Armitage & Conner (2001), who suggest that there may be an indirect link between normative forces, like department epistemology, and behavioral intentions such as the consideration of interdisciplinary connections.

As one's individual epistemology informs the consideration of interdisciplinary connections, it will also influence one's interdisciplinary openness (attitude) (Path 3). Specifically, as discussed above, the expectation is that a more applied individual epistemology will lead to a more open attitude toward interdisciplinary research. As with Path 1 and Path 2, there is a similar indirect effect between department epistemology and interdisciplinary openness (Path 1 to Path 3). Path 4 represents the relationship between one's interdisciplinary openness and the consideration of interdisciplinary connections that are necessary to undertake interdisciplinary research.

Beyond having an individual epistemology that is more applied, an open attitude toward interdisciplinary research is also expected to be influenced by the degree of control that one has over his/her research choices. This point is often the focus of discussions around how status within a group shapes attitude and influences the behavioral options of the group members. In particular, possessing higher levels of academic status was earlier suggested as allowing a more established individual within a group to act in a way that is more open to interdisciplinary research. This assertion suggests that academic status is directly linked to the interdisciplinary openness exhibited by an individual (Path 5).

In addition to the role that status within a group would play around interdisciplinary openness, status also establishes guidelines for tolerated behavior. This suggests that one's academic status within a group will influence the degree to which an individual can consider and then form potential interdisciplinary connections (Path 6) without being concerned about damaging one's standing within the department. Though not in the framework, it is important to restate that perceived behavioral control, as indicated by academic status in this case, can be such that it allows an individual to act without the development of behavioral intentions (Rhodes & Courneya, 2003; Ajzen & Fishbein, 2005). This suggests that established researchers within a department/discipline could be known outside of a department/discipline, and it is reasonable to believe that non-departmental/discipline others would approach high status individuals to assist in various non-disciplinary research projects. In these instances, academic status may be sufficient enough to allow an individual to participate in interdisciplinary research, absent any development of intention.

The framework outlined in Figure 4 provides several testable hypotheses.

Hypotheses and Research Questions

The first set of three hypotheses, derived from Figure 4, are focused on how departmental and individual epistemological orientations, along with academic status, is related to an individual's openness to interdisciplinary research, as well as the consideration and identification of interdisciplinary connections.

Hypothesis 1a: Departmental epistemology will exhibit a positive relationship with individual epistemology, such that individuals from applied departments will tend to report an individual epistemology that is more applied, and those from more pure departments will tend to report an individual epistemology that is less applied (Path 1).

Hypothesis 1b: Individual epistemology will exhibit a positive relationship to interdisciplinary openness, such that reporting a more applied individual epistemology will correspond with a higher degree of interdisciplinary openness (Path 3).

Hypothesis 1c: Departmental epistemology, through an individual's epistemology, will exhibit a positive and indirect relationship with interdisciplinary openness (Path 1 & Path 3).

Hypothesis 2: Academic status will exhibit a curvilinear relationship with interdisciplinary openness (Path 5), such that Full Professors will exhibit a higher openness to interdisciplinary research than Assistant and Associate Professors. Associate Professors are expected to exhibit higher levels of interdisciplinary openness that Assistant Professors. Graduate students will be the most open to pursuing interdisciplinary research, with an openness that exceeds that of Full Professors.

Hypothesis 3a: Individual epistemology will be positively related to the reporting of potential interdisciplinary connections, with a more applied epistemology corresponding with a greater likelihood that interdisciplinary connections are reported (Path 2).

Hypothesis 3b: Departmental epistemology, through individual epistemology, will exhibit a positive and indirect relationship with the likelihood of reporting interdisciplinary connections (Path 1 & Path 2).

Hypothesis 3c: Academic status will exhibit a positive relationship with the reporting of potential interdisciplinary connections (Path 6), with graduate students being least likely to report interdisciplinary connections.

Hypothesis 3d: Interdisciplinary openness will exhibit a positive relationship with the reporting of potential interdisciplinary connections, with higher levels of openness corresponding with a greater likelihood of reporting interdisciplinary connections (Path 4).

Not only are interdisciplinary openness and the related variables related to the development of interdisciplinary connections (Figure 4), but they also exhibit a relationship with the overall diversity, of reported interdisciplinary connections. Though not addressed in the model (Figure 4), the literature suggests that more applied researchers will report more diverse collaborators. Also, as an individual secures status within a department, he/she will experience less risk when collaborating with dissimilar others, which should correspond with more diverse collaborations. As interdisciplinary openness is seen as an important component related to the reporting of interdisciplinary connections, it is also reasonable to suggest that it will be positively related to the reporting of more diverse interdisciplinary connections.

Hypothesis 4a: The diversity of reported interdisciplinary connections will be positively related to academic status, with higher status individuals exhibiting greater diversity than lower status individuals.

Hypothesis 4b: Individual epistemology will be positively related to the diversity of reported interdisciplinary connections, with individuals reporting a more applied epistemology reporting more diverse connections.

Hypothesis 4c: The interdisciplinary openness of an individual will be positively related to the diversity of reported interdisciplinary connections, with more open individuals reporting more diverse connections.

The framework provides a possible explanatory model for understanding the emergence of interdisciplinary research at the level of the individual. One focus of this research is on the formation of attitudes, and how they begin to influence the development of an individual researcher’s interdisciplinary landscape. While individual outcomes are the focus of the above hypotheses, the discussion that precedes the hypotheses also focuses on the higher level influence and roles of groups, departments, universities, etc. While there are not specific hypotheses regarding the higher level social/group concerns that an individual researcher must navigate, this research also seeks to understand if there are predictable patterns or boundaries that present themselves in the pursuit of interdisciplinary research.

In particular, the second line of questioning in this research project is to examine how the interdisciplinary networks of researchers in this study coalesce. Social network analysis will provide a means of developing a narrative that will illustrate how the findings of Boyack et al. (2005) and Morillo et al. (2003), within the larger galaxy of published research, corresponds with the potential for collaboration within a single research university. The following research questions are explored:

Question 1: Will departments/disciplines that are suggested to be more interdisciplinary by design (e.g., Biochemistry) exhibit a more central role in the network of reported connections than the more foundational, or pure, sciences (e.g., Physics)?

Question 2: Will the more "social" sciences exhibit a greater degree of isolation from the other departments (e.g., Psychology and Economics)?

Once an overall image of how the various departments are defined within the larger research network is constructed, the next question will explore the type of interdisciplinary research that is occurring. As discussed previously, what constitutes interdisciplinary research is often debated. However, Morillo et al. (2003) distinguish between "big" and "little" interdisciplinary research collaborations. Instances of interdisciplinary research that are considered "little" can be identified as patterns of interdisciplinary collaborations that are shared among the members of a single department and often occur between methodological "relatives." "Big" interdisciplinary connections will present themselves as moments where the connections are truly novel and seem to stretch into new domains of research methodologies and epistemologies.

Question 3: Will the patterns of interdisciplinary research connections reflect a greater tendency toward "little" interdisciplinary research connections, with fewer instances of "big" interdisciplinary connections?

Method

The study of the above hypotheses and questions relied on secondary data analysis of data collected from previous research associated with a program funded by the National Science Foundation's Integrative Graduate Education and Research Training (IGERT) program.

Sample

The survey data provided information from 227 adults affiliated with research at a large Public University in the Southeastern United States. Relevant data was collected from participants recruited from within 15 academic departments based within three Colleges of the University. The selected departments met two relevant criteria: (1) the department's primary field was represented within the 31 divisions of the National Academy of Sciences and, (2) the department contained a doctoral program in said field. Within the departments, data was collected from participants meeting one of two criteria: (1) the individual was listed as a faculty member within one of the 15 departments or, (2) the individual was listed as a graduate student within one of the 15 departments.

Two additional comments about participant selection are relevant, data was not collected from individuals listed as research, adjunct, or emeritus faculty, and all graduate students listed within the departments' publicly available resources were contacted for participation. The decision to recruit M.S. and Ph.D. students reflected the belief that within the sciences, both degree levels are based in research, and as such both levels are embedded within the larger graduate research community.

Using the above criteria, survey data was requested from 316 Faculty (66 Assistant Professors, 93 Associate Professors and 157 Professors) and 595 Graduate Students. The collected survey data provided information from 26% of the contacted Faculty (n = 81) and 25% of the contacted Graduate Students (n = 146). Table 1 presents a table of response rates across departments and academic status.

Measures

In order to minimize redundancy for survey respondents, 30 different survey formats were developed and deployed by crossing academic status (Faculty or Graduate Student) with each of the 15 departments. The survey was presented across four WebPages, with the items on each page presented in random order. Across the 30 survey formats, participants were asked to respond to the following measures that were selected based on previous research (Knee, 2008).

Department Epistemology. In order to provide information on the epistemological standing for the departments, information from Biglan (1973) regarding the relative relationships and applied standings of the various academic departments were used to provide a score for each department. The use of Biglan’s (1973) work to assign an epistemological standing to an academic department or field is well documented (Muffo & Langston, 1981; Smart & Elton, 1982; Stoecker, 1993).

Biglan’s (1973) plot of department orientation (see Figure 2) was used to derive a Department Epistemology Score for each of the 15 departments surveyed in the study, with scores ranging from -10.00 to +10.00. Positive values indicate that a department is perceived as having a greater focus on applied science, while negative values indicate a greater focus on pure science. Ten of the 15 departments were directly represented in the plot, meaning that the name of the Department listed at the University could be found in the figure provided by Biglan (1973). One of the Departments was represented by an alternate name. Specifically, there is no field designation for Crop Soil and Environmental Sciences, yet the Department's description of its studies and that of the American Society of Agronomy suggests that Crop Soil and Environmental Sciences can effectively be considered Agronomy under the conditions of this research. The Department of Biological Sciences is represented by various fields within Biglan's (1973) mapping, specifically the cluster of microbiology, botany, zoology. As this was a tightly grouped cluster, an approximate value was derived that captures the Department of Biological Sciences. This cluster was also adequately represented within the network derived by Boyack et al. (2005), as being a set of disciplines that publish within the same domain (see Figure 3). Similarly, Plant Pathology, Physiology, and Weed Sciences did not have a direct representative, so the decision was made to place Plant Pathology, Physiology, and Weed Sciences in the same vicinity as Horticulture and Agronomy, as there is some relationship in the work that these fields do.

The final two fields, Biochemistry and Animal and Poultry Sciences, lack direct representation or correlates on the applied orientation plot. Biochemistry was placed in the cluster of fields "north" of Biology, Chemistry, Microbiology, etc., as an examination of general publication practices of Biochemistry (Boyack et al., 2005) suggests that this field is highly interdisciplinary and seems to serve as a bridge between some of the more traditional pure fields of science and rests close to more applied disciplines like medicine and veterinary sciences (see Figure 3). The department of Animal and Poultry Sciences produced a pattern of output that pairs the field with Dairy Science and in the neighborhood of Veterinary Science in the network produced by Boyack et al. (2005). Based on this trend to more applied partners in publication practices, Animal and Poultry Sciences was placed in the area of Dairy Science and Horticulture, which is also a close neighbor in the Boyack et al. (2005) network. Table 2 provides information on all of the Department Epistemology Scores that were derived from Biglan (1973) and Boyack et al. (2005).

Individual Epistemology. Based on Knee (2008) four items were designed to capture the perceptions of epistemological standing of a respondent's scientific field in terms of exhibiting an applied focus (Appendix A). A sample item is describing a field focus as "Focuses on developing pragmatic know-how." Previous research demonstrated Cronbach's alpha at 0.63 (Knee, 2008). Participants were asked to rate their level of agreement with the items on a five-point scale, with "1" indicating "Completely Disagree" and "5" indicating "Completely Agree." The four item scale did not demonstrate the same level of internal consistency or factor structure as in the Knee (2008). Factor analyses across subsets of respondents (Faculty vs. Graduate Student) did not suggest a factor difference within the sample. Further analysis suggested that a two-item scale had the highest degree of internal consistency (α =.0.51) and was used as an indicator of an individual's epistemology being more or less applied.

Interdisciplinary Openness. Five items were designed to capture the degree of openness toward interdisciplinary research (Appendix B). A sample item is "Pursuing interdisciplinary research will strengthen research in my field." Previous research demonstrated Cronbach's alpha at 0.62 (Knee, 2008). Participants were asked to rate their agreement with the statements on a five-point scale, with "1" indicating "Completely Disagree" and "5" indicating "Completely Agree." Within this sample, Cronbach's alpha was 0.71.

Interdisciplinary Connections. Participants were asked to provide information on the research connections that they have, or would consider, outside of their respective departments. In order to accomplish this, participants were asked to consider “former, current, or future non-departmental research collaborations at Virginia Tech” and then from a list of fourteen departments, not including the participant’s home department, participants selected potential departmental collaborations. From that point further instructions asked participants to “select the individuals from the department that you have research partnerships with, would consider conducting research with, or would approach for assistance with a research question.” A list of ten departmental Faculty names was presented for participants to select from, with participants also having the opportunity to add additional names to the list of people meeting the specified criteria within the selected department.

During this component of data collection, the survey used “skip-logic” to reduce the number of presented survey pages. Participants began by choosing their first choice for non-departmental research collaboration from the list of other departments being surveyed. Participants also had the options to select “I would choose none of the above.” When a participant selected a department, he/she was directed to the appropriate departmental list. After selecting individuals from the list, participants were then directed back to a list of 14 departments and asked to select their second choice for non-departmental research collaboration. The process of collaborator selection continued until a participant made selections across three departments, or indicated that there was not a department listed that they would collaborate with. This data provided a means of counting those individuals reporting potential interdisciplinary connections, and identifying those who do not perceive potential interdisciplinary connections. This count and connection data is the foundation of the social network analysis addressed later.

Diversity Impact Factor. The interdisciplinary connection counts provide a means of identifying who is reporting connections, and can also be used to demonstrate the relative importance and connectedness of each actor through social network analysis. However, the interdisciplinary connection counts, and related social network analysis, do not provide a means of capturing how similar actors conform to the interdisciplinary connections of their respective departmental cliques. For purposes of this study, cliques were defined as 3-cliques, which captured the members of the "home" department plus any non-departmental actor who received a direct link from actor(s) of the "home" department clique, so that no included actor could be more than 3 actors removed from any other actor in the clique. This configuration was limited to out-connections reported by the members of the "home" department.

The diversity impact factor was derived by examining the information related to non-departmental connections and is a standardized numerical index that describes the extent to which an individual respondent within a department has connections that are different from those of the other members of his/her department. This factor was derived using information embedded in the various 3-cliques of each respondent's department, and only for those individuals reporting interdisciplinary connections (n = 109).

The raw values of the diversity impact factor have a range from 0.00 to 1.00, with 0.00 indicating a respondent who does not report any connections and a 1.00 indicating a respondent who is responsible for all of the non-departmental connections. As the goal of the index is to allow for comparison across respondents and cliques, the value was standardized into a z-score, allowing for a relative comparison across individual respondents and departments. In the absence of standardization, a diversity impact factor of 0.25 could be low in one group, if the clique is small, or high in another, if the clique is large. Negative values indicate that, relative to the other departmental respondents, an individual has a lower impact on the person/department diversity of the clique. Positive values indicate that relative to the other departmental respondents, an individual has a higher impact on the person/departmental diversity of the clique. The sample range of the diversity impact factor was –1.60 to +3.11 (see Appendix C for calculation information).

The following example, presented graphically in Figure 5, is offered to provide an orientation to how the diversity impact factor is conceptualized. Figure 5 provides an example of a departmental clique, such that actors A1 through A4 are all associated with department group A, and actors B1 through B3 are associated with department group B, and similarly actor C1 is affiliated with department group C. To explore how removing an actor from group A will impact the diversity of the overall network, let's begin with the impact of removing Actor A1. Actor A1has a connection with one of the three actors from group B, A1 has the only connection (L1) with B1. Based on having the sole connection with B1, Actor A1 has a higher diversity impact factor than actor A3, because severing L1 will remove one unique actor from the overall network. Like Actor A1, A3 has a single connection (L4) to an actor in group B (B2). Unlike Actor A1, A3 shares the connection with another member of group A (A2), which means severing the connection (L4) would not remove any individual actors from the overall network.

Actor A2 has a connection (L2) with B2, along with A3, but also contributes a unique connection (L3) to B3. Of the three members of group A who are connected to group B, Actor A2 has the highest diversity impact factor because removing A2 from the group will remove the unique connection to B3, plus one connection to B2. Finally, of the group A actors, Actor A4 has the highest diversity impact factor, because the removal of A4's connection (L5) with C1 removes not only a unique individual, but the whole of group C's representation in the overall network.

Salton Index. The preceding metrics of interdisciplinary connections reflect the data at the level of the individual. In order to evaluate the research questions focused on departmental patterns of collaboration, the individual interdisciplinary connections need to be evaluated at the department level, which is what the Salton Index is designed to do. The Salton Index is a measure of collaboration, or interdisciplinary connections in this instance, that quantifies the frequency of interdisciplinary connections occurring between departments, as well as quantifying the frequency of specific interdisciplinary connections. Salton Index values range from 0.00 to 1.00, with a value of 0.00 indicating that there is not a connection being reported by one department to another, and 1.00 indicating that the two departments only have connections with one another. As described in Nagpaul (2002), the calculation of the Salton Index as follows:

$$S(i,j) = C_{ij} / \sqrt{C_i\, C_j}\ ,$$

where

$S(i,j)$ = Salton index for cell (i,j)

C_{ij} = Number of connections reported between department (i) and department (j).

C_i = Total number of connections with department i.

C_j,= Total number of connections with department j.

In order to calculate the Salton Index, each reported unique interdisciplinary connection, those going into a department and those going out from a department, was given a value of one. Within each department, the values are tallied to represent the total number of interdisciplinary connections within each department, providing the values for C_i and C_j. Within this sample, the total number of interdisciplinary connections within a department ranged from 2 to 125, with an average of 58 interdisciplinary connections within a department. The individual counts were then collapsed within each departmental pairing to provide a count of how many interdisciplinary connections were reported within each departmental, which provided the respective values for C_{ij}. In instances where an interdisciplinary connection was reciprocal, Actor A reported a connection with Actor B, and Actor B reported a connection with Actor A, the two connections were counted as one connection when evaluating the number of connections occurring between the two respective departments. Within this sample, the number of interdisciplinary connections between departments ranged from zero to twenty-eight, with an average of 4.14 connections reported between departments.

Within this research sample, the Salton Index values ranged 0.00, indicating no reported relationships, to 0.57, indicating a strong tendency for one department to direct its connections to toward one specific department. Morillo et al. (2003) used a matrix of Salton Index values to detect patterns of collaborations between various research fields, and as a means of distinguishing between instances of "small" interdisciplinary collaboration and the less frequent instances of "big" interdisciplinary collaboration.

Demographic and supplementary information. Academic status (i.e., Graduate Student, Assistant, Associate, and Professor) information was collected from publicly available websites. Graduate students were also asked to provide information on their field of Undergraduate study, their field of Graduate study, and how long they had been at the University (in years).

Procedure for Data Collection

Survey participants were initially contacted via an introductory letter (See Appendix D). The introductory letter was delivered via campus mail to the departmental mailboxes of targeted participants. The letter outlined the nature of the request, the nature and value of the study, as well as information on the processes designed to ensure response and participant confidentiality. Targeted participants were instructed to expect an e-mail containing information about completing the survey.

After the introductory letter was disseminated; e-mails were sent to the University registered e-mail accounts of the targeted participants. The first e-mail attempt failed due to the campus spam filter, so a second e-mail was mailed individually to each targeted participant (Appendix E). The e-mail included the recipient's name, instructions on how to complete the survey, as well as the individual's unique link to the survey. Members of the target population who chose to participate in the study accessed the survey via a department specific link supplied in the e-mail invitation; opening the internet-based survey via SurveyMonkey.com.

The first webpage of the survey provided a general orientation to the survey and a confirmatory statement (Appendix F). Faculty participants agreeing to participate in the survey were directed to the first page of the survey which presented participants with six survey items from the 27 items representing the Epistemological and IDR attitude items. Graduate Student participants were first directed to a supplementary page that collected information on education background, and then to the first page of 27 survey items. Upon completion of the Epistemological and IDR Attitude items, participants were given information on the research connections component section of the survey and asked to provide information on how long they had been at the University. When a participant selected the "I would choose none of the above" option, or completed a third department, he/she was directed away from the survey, and thanked for their time and perspective. Participants choosing not to participate in the survey were directed away from the survey to a University website.

Results

Respondent data was coded to remove any direct references to the names of individual respondents, or individual departments. The recoding process assigned each respondent a unique five digit participant number. The first two digits provide departmental information; while the third digit indicates the departmental standing of the respondent (see Appendix G for a list of department codes). In addition to the department based codes, individuals within each department and status were assigned a two digit number between 01 and 99. The final two digits were provided in order to assist in the proper maintenance of the data. Participant numbers were assigned to each member of the target population prior to the start of data analysis.

After recoding respondent and target population information, an Interdisciplinary Openness value was calculated for each respondent by reverse coding the appropriate items and averaging across the responses. Individual Epistemology was calculated by averaging across each individual's responses to the two included items. Additionally, Academic Status was coded as follows: 1 = Graduate Student; 2 = Assistant Professor; 3 = Associate Professor; 4 = Professor. Interdisciplinary research connection information was formatted into a relationship matrix, with "0" indicating no reported relationship, "1" indicating a reported connection, and "2" indicating an interdepartmental connection. Diversity impact factor values were calculated for the respondents who reported potential interdisciplinary connections. As described above, Salton Index values were calculated by collapsing the individual relationship matrix into departmental groups and using the respective interdisciplinary connection counts.

Descriptive statistics and correlations for the dependent variables and independent variables are presented in Table 3. There were numerous significant correlations among the variables of interest. Of particular interest are the positive and significant correlations between interdisciplinary openness and individual epistemology, interdisciplinary openness and department epistemology, and interdisciplinary openness and the reporting of interdisciplinary research connections. The negative correlation between status and interdisciplinary openness is also of interest, but based on the assumption that a curvilinear relationship may exist, the correlation should not be interpreted at face value. One final comment on the correlations is that a positive and significant correlation between an individual epistemology and department epistemology was observed, which meets the expectation that individual epistemology is influenced by department epistemology. In addition to the correlation matrix, histograms of the interdisciplinary openness scores, individual epistemology, and diversity impact factor, are provided in Figures 6 through 8 respectively. An examination of the histograms revealed a particularly strong positive skew in the diversity impact factor, which was addressed during the testing of hypotheses 4a, 4b, and 4c.

Hypothesis Tests

Hypotheses 1a through 1c sought to understand how department and individual epistemology are related to one another, as well as their relationship with interdisciplinary openness. Hypotheses 1a through 1c were tested using the multiple regression approach for testing mediation (Baron & Kenny, 1986). As demonstrated in Table 4, Step 1 found a significant and positive relationship between a department epistemology and an individual's interdisciplinary openness score ($\beta = .20$, $p < .01$), such that a one standard deviation increase in department epistemology, toward and applied orientation, corresponded with a .20 standard deviation increase in interdisciplinary openness.; this finding was required to test for the indirect relationship hypothesized in 1c. Step 2 found a significant and positive relationship between department epistemology and individual epistemology score ($\beta = .21$, $p < .01$), where a one standard deviation increase in department epistemology, toward an applied orientation, corresponded with an increase of .21 standard deviations in an individual's applied epistemology focus; this supports Hypothesis 1a. In Step 3, individual epistemology was found to have a significant and positive relationship with interdisciplinary openness ($\beta = .19, p > .01$), such that a one standard deviation increase in an individual's applied epistemology corresponded with a .19 standard deviation increase in an individual's interdisciplinary openness; which supports Hypothesis 1b. Step 4, in conjunction with the preceding steps, suggests individual epistemology ($\beta = .16, p > .05$) is operating as a partial mediator between department epistemology ($\beta = .16, p > .05$) and interdisciplinary openness as both predictors were significant and positively related to interdisciplinary openness ($R^2 = .06, p < .01$) which supports hypothesis 1c.

Hypothesis 2 suggested a curvilinear relationship between academic status and interdisciplinary openness. To test for the presence of a curvilinear relationship between academic status and interdisciplinary openness, linear and quadratic terms for academic status were regressed onto interdisciplinary openness (Table 5). As both the linear ($F(1,225) = 5.52, p < .05$) and quadratic model ($F(2,224) = 5.03, p < .01$) were statistically significant, and the increase in R^2 ($R^2\Delta = 0.19, p < .05$) between the linear and quadratic model was statistically significant, the quadratic model appears to be a more appropriate fit for the data. This finding supports the assertion the relationship between academic status and interdisciplinary openness is curvilinear. Estimated marginal means of interdisciplinary openness for the four academic status groups are presented in Figure 9. In addition, Figure 10 provides boxplots of the interdisciplinary openness measure for each group, and Figures 11 through 14 offer histograms of each academic status group's interdisciplinary openness score distribution.

Table 6 presents the results of three planned contrasts that align with the group specific predictions of Hypothesis 2. However, no significant differences among the various faculty statuses were noted. The lack of significant differences across the four academic status groups does not provide full support for Hypothesis 2.

The third set of hypotheses focused on the role of individual epistemology (a), department epistemology (b), academic status (c), and interdisciplinary openness (d), in determining the reporting of interdisciplinary connections. As hypotheses 3a-d focused on the reporting of interdisciplinary connections, logistic regression was used to determine if either of the hypothesized variables increased the likelihood of reporting interdisciplinary connections. Of the 227 respondents, 109 reported at least one non-departmental connection, respondents in this group were coded as "1", with the 118 remaining respondents being coded as "0" for not reporting non-departmental connections. The logistic regression was carried out in four blocks, with the results presented in Table 7. As department epistemology was hypothesized to be positively related to the reporting of interdisciplinary connections, through individual epistemology, department epistemology was entered in the Block 1. Department epistemology did not reveal a significant and positive relationship with the ability to predict whether an individual reported interdisciplinary connections (Model χ^2 (1) = 1.59, $p > .05$), and Hypothesis 3b was not supported.

Block 2 added individual epistemology to the model. In order for hypothesis 3a to be supported, individual epistemology orientation must have a significant and positive relationship in the prediction of who reported interdisciplinary connections. Logistic regression demonstrated that for every unit increase in individual epistemology the odds factor increased by 1.57 in the reporting interdisciplinary connections (Wald = 9.77, $p < .01$). The addition of individual epistemology also significantly improved the prediction model for the reporting of interdisciplinary connections (Step χ^2 (2) = 9.77, $p < .01$). Hypothesis 3a was supported.

Block 3 entered weighted dummy coded variables comparing the three faculty levels against the graduate student level. The addition of these variables significantly increased the odds of predicting the reporting of interdisciplinary connections among the respondents (Step χ^2 (5) = 18.90, $p < .001$). In order for hypothesis 3c to be supported, logistic regression analysis must have demonstrated a significant and positive increase in the model's ability to predict interdisciplinary connections beyond the graduate student status, which was found. Compared to graduate students, being an assistant professor corresponded with an increase in the odds factor of reporting interdisciplinary connections by a factor of 2.96 (Wald = 5.51, $p < .01$), while being an associate (Wald = 9.56, $p < .01$) or full professor (Wald = 6.00, $p < .01$) corresponded with an increase in the odds of reporting interdisciplinary connections by 8.41 and 2.54 respectively.

Block 4 entered interdisciplinary openness into the prediction model and exhibited a significant and positive increase in the model's ability to predict the reporting of interdisciplinary connections. The fourth block demonstrated that a unit increase in interdisciplinary openness was found to correspond with a 1.73 increase in the odds factor of reporting interdisciplinary connections (Wald = 5.87, $p < .05$). This finding provides support for Hypothesis 3d. In addition to the blocks described above, table 7 also provides information on the full logistic regression model. As can be seen in Table 7, with the full model, all of the variables entered in earlier blocks maintain significance and demonstrated an increase in odds factor.

The final set of hypotheses were not indicated in Figure 4, and focused on understanding the relationship of the above variables with the diversity impact factor. The diversity impact factor is a characteristic of the survey subset that reported interdisciplinary connections (those coded as “1” in the previous Logistic Regression). The final set of hypotheses stated that diversity of interdisciplinary connections will be positively related to one’s academic status (4a), individual epistemology (4b), and interdisciplinary openness (4c).

As indicated previously, the reporting of interdisciplinary research connections was related to individual epistemology, an individual’s academic status, and interdisciplinary openness. The previous findings provide tentative support to the assertion that individual epistemology, academic status, and interdisciplinary openness do have a shared relationship with the reporting of interdisciplinary connections. In order to fully test hypotheses 4a, 4b, and 4c, the analyses focused on the diversity impact factor of only the respondents reporting connections (N = 109). Descriptive statistics and correlations for the respondents reporting non-departmental connections are presented in Table 8. Remember that the diversity impact factor is an index that indicates how diverse the connections of a respondent were when compared to his/her departmental peers. The presence of diversity reflects connections with individuals that are unique in terms of the individuals selected for collaboration, and also in terms of connecting with collaborators from different and unique departments.

One interesting finding within the Table 8 correlations is the now negative relationship between interdisciplinary openness and academic status. This shift of direction within this subgroup suggests that graduate students, the “lowest” status reporting interdisciplinary connections, are more likely to have higher levels interdisciplinary openness when compared to professors reporting interdisciplinary connections. This point supports the idea that with higher status individuals, attitude toward a behavior may not be as important as simply having the ability to act. With this shift in relationship in mind, a multiple regression analysis was carried out to determine what variables may be responsible for distinguishing between those who report "big" interdisciplinary connections, and those who report "little" interdisciplinary connections.

Multiple regression analysis (Table 9) indicated that among those reporting interdisciplinary connections, associate professors reported more diverse connections than graduate students ($\beta = .25$, $p < .05$), as did full professors ($\beta = .32$, $p < .01$). Assistant professors did not demonstrate a significantly higher diversity impact factor than graduate students ($\beta = .13$, $p > .05$). These results provide support for hypothesis 4a. Additionally, the inclusion of individual epistemology ($\beta = .01$, $p > .05$) and interdisciplinary openness ($\beta = .07$, $p > .05$) in the model did not reveal a significant positive relationship with diversity impact factor. Hypotheses 4b and 4c were not supported by these results. Overall, the model explained twelve percent of the variance in the diversity impact factor ($R^2 = .12$, $p < .05$). The findings of the multiple regression analysis suggest that what corresponds with more diverse interdisciplinary relationships is status, more than any other variable discussed thus far.

Post-hoc Analysis

In order to understand how those reporting interdisciplinary connections differed, from those who did not, in terms of interdisciplinary openness and individual epistemology, a series of post-hoc *t* tests were conducted. A *t* test of interdisciplinary openness differences between the graduate students who reported interdisciplinary connections (M = 4.08, SD = 0.54), and those who did not (M = 3.73, SD = 0.72) revealed a statistically significant difference, $t_{graduate}(144) = 3.13$, $p > .01$. A similar finding existed with regard to a difference in individual epistemology, $t_{graduate}(144) = 2.20$, $p > .05$, between graduate students reporting connections (M = 3.04, SD = 1.04) and those who did not (M = 2.69, SD = 0.96). Additional t tests failed to reveal statistically significant differences among the three faculty groups, when evaluating differences in interdisciplinary openness between those who reported interdisciplinary connections and those who did not, $t_{assistant}(24) = 1.02$, $p > .05$; $t_{associate}(13) = 0.00$, $p > .05$; $t_{full}(38) = 0.43$, $p > .05$. Significant differences in individual epistemology were noted among Assistant Professors ($t_{assistant}(24) = 2.20$, $p < .05$) and Full Professors ($t_{full}(38) = 2.53$, $p < .05$), but not Associate Professors ($t_{associate}(13) = 1.79$, $p > .05$), when examining differences in who reported connections. Table 10 presents the mean differences between all of the groups, within the subset of respondents reporting interdisciplinary connections, and Figure 15 presents a box plot of the score distributions by academic status for the same subset.

Research Questions

In order to answer the research questions posed earlier, social network models were derived from the reported interdisciplinary connections information and compared with the connection patterns presented in the Matrix of Salton Index values (Table 11). The research questions sought to understand the patterns observed in the non-departmental interdisciplinary research connections, with the first focused on understanding whether there are specific departments/disciplines that operate as hubs of interdisciplinary, or non-departmental, connections within the overall research network. Using the social network idea of betweenness centrality provided some insight into the first research question.

In order to derive the social network models that were used to answer the first research question, and those that follow, social network representations were created using Analytic Technologies' Ucinet version 6.181 (Borgatti, Everett & Freeman, 2002) and NetDraw version 2.074 (Borgatti, 2002). Specifically, the relational data provided by survey respondents was entered into a relational matrix of the non-departmental others that respondents reported as possible or actual research collaborators. The data was entered so that each survey respondent and individual reported as a possible research connection was represented by a row and a column. Moving row by row, each survey respondent's data was entered across the columns, with a "1" indicating that an actual or potential relationship was reported, and a "0" indicating that the survey respondent did not report a connection. As each respondent, who provided connection information, could link to more than one person outside of his/her department, the number of possible connections and individuals accounted for in the final network is much greater than the number of survey respondents providing connection information.

A tally of the reported connections resulted in a non-symmetrical 353 x 353 matrix of relational nodes. Within the 353 individuals represented in the social network matrix, individuals without any reported connections (Isolates) were dropped from the network analyses, resulting in a non-symmetric 269 x 269 matrix. Within the 269 individuals sending and/or receiving links to another person, there were 920 reported unidirectional connections in which the survey respondents are connected to other individuals, but not necessarily in a reciprocal fashion (though this is possible if the individual who was reported as a connection also responded to survey and then reported a connection with the individual who reported them as a connection).

Once the initial data was entered into the matrix, additional data was entered into the matrix that placed connections between all members of the same department. The addition was not based on actual data provided by survey respondents, but on the idea that de facto connections existed between all members of a department. The operating rationale was to assume that most individuals could conduct research with others in their respective departments. Imposing this assumption of interdepartmental connections provided a means of visualizing the social network representation as an indicator of departmental patterns, and not just individuals.

In the absence of the departmental connections assumption, the derived network representation treated each respondent as “context-free” with regard to department. Meaning that, without the assumption, it was possible for members of the same department to not exhibit any form of indirect connection to one another when graphically represented in a network layout.

The original network layout was arranged using Spring Embedding with Node Repulsion, which is an iterative process that attempts to arrange the nodes in space until a "better" fit is found (Figure 16). This approach draws the network with a focus on orienting the nodes in 2-dimensional space by grouping the nodes with similar others and pushing less similar nodes away (repulsion) (Hanneman & Riddle, 2005). This provided a network visualization that was appropriate for examining how directly linked departmental cliques were, and which departmental cliques operate as hubs of interdisciplinary collaboration. Table 12 provides the network matrix of potential interdisciplinary collaborators.

A calculation of network statistics revealed that the density of the network, indicating the ratio of actual connections reported to possible connections within the network, was calculated at an average of 0.15, with a standard deviation of 0.52. As a density values increase from 0.00 to 1.00, the overall connectivity within the network increases, with a value of 1.00 indicating that all of the actors in a network are directly connected to one another. The interdisciplinary connection network density of 0.15 was relatively low, suggesting a low level of direct connections between all of the actors in the network. In addition to the density value, the network centrality value was also calculated. The centrality of the network indicates the extent to which all of the connections are directed to one central individual (or a small group of central individuals). The possible values for network centrality range from 0 to 100. With network centrality, larger values indicate a higher degree of network centrality and lower values indicating that the network is not centered on one particular actor. The outdegree centrality of the network reflected the extent to which one central actor was sending out a large number of the connections within the network (e.g., the really outgoing person in a group of friends).

For the interdisciplinary connection network, the outdegree centrality was calculated as 3.91%, indicating that on average the connections were being sent out by a large portion of the actors in the network, and not just a few nodes. In addition to the outdegree centrality, the indegree centrality was also calculated and represents the popularity of a specific node, or the degree to which a relatively small number of actors were being connected to by others. The network demonstrated an indegree centrality of 4.33%, which indicated that there was not a particular node that was overwhelmingly selected by everyone in the network.

While Figure 16 presents the possible interdisciplinary connections that were reported, it is a visually dense figure, and because of the number of edges in the figure, it was difficult to discern the patterns of connections reported between departments. In order to overcome the visual density of the figure and develop a better understanding of how the links between departments emerged, a second network visualization was derived that focused on the departments as single nodes in a network of respondents. In order to accomplish this department level visualization, the various connections of each respondent were collapsed within their respective departments. The collapsed connections within a department were then entered into a matrix representing the number of connections being sent out by department respondents, and those being received by department members. As mentioned earlier, Table 12 shows the relationship matrix between the 15 departments; values in the cells indicate the number of possible research connections that were reported between the two intersecting departments.

A department level network was created using NetDraw (Figure 17). The department level network visualization indicates the degree of betweenness centrality of the departments by varying the size of the department nodes. A larger node represents a department with a higher degree of betweenness centrality. Edge thickness (the connecting lines) indicates the frequency of connections between departments (how many people are targeted in a specific department). Outdegree and indegree centrality were also calculated with an average outdegree centrality of 17.40 (SD = 8.70) and an average indegree centrality of 17.40 (SD = 11.60). The overall level of outdegree network centralization was 8.77% and the indegree network centralization was 17.81%, this difference suggests that there were more preferred receivers of connections than more central senders of connections. Table 13 presents the centrality measures for each department, as well as the frequency of survey respondents and those who reported non-departmental connections.

In order to answer the research questions, the first step was to explore the department level network. A visual examination of Figure 17 showed that Biological Sciences (BIO), along with Agricultural and Applied Economics (AAG), exhibited the highest degree of betweenness centrality. Biological Sciences and Agricultural and Applied Economics were followed by Biochemistry (BIOCHM), Biological Systems Engineering (BSE), Civil and Environmental Engineering (CEE), and Crop Soil and Environmental Sciences (CSES). Taken on its own, Figure 17 suggests that the interdisciplinary hubs rest with Biological Sciences and Agricultural and Applied Economics.

Figure 17 also suggests that Psychology (PSYC) and Economics (ECON) rest on the periphery of the interdisciplinary connections, being connected with a total of three departments. With regard to the core “physical” sciences and the engineering fields, it was noted that the thickest edges were found within three specific triangles. The thicker edges indicate a higher frequency of connections between departments. The first triangle connected Biological Sciences (BIO), Chemistry (CHEM), and Physics (PHYS). A similar triangle connected Biological Sciences (BIO), Biochemistry (BIOCHM), and Chemistry (CHEM). The third triangle connected Biological Systems Engineering (BSE), Crop and Soil Environmental Sciences (CSES) and Agricultural and Applied Economics (AAE).

Expanding on the patterns observed in Figure 17, an examination of the rows and columns the Matrix of Salton Index values (Table 11) revealed that there are 49 reported departmental pairings out of 105 possible departmental pairings. On the low end, Economics was only paired with Agricultural and Applied Economics as an interdisciplinary collaborator. On the high end, Biochemistry was paired with 12 of the 14 departments available for interdisciplinary collaboration. Biochemistry was followed closely by Biological Sciences with interdisciplinary connections across 11 of the 14 departments available for collaboration. Another noteworthy observation is that Biological Sciences and Biochemistry had a Salton Index value of 0.38, which is one of the larger values. As these two departments were frequent collaborators with one another, as indicated by the Salton Index value, and that these two departments accounted for almost half of the 49 pairings reported in this sample, Biochemistry an Biological sciences appear to be interdisciplinary hubs within the observed interdisciplinary network. This evaluation corresponds with the greater betweenness centrality values of Biochemistry and Biological Sciences noted in Figure 17.

With regard to the role of the Agricultural and Applied Economics Department as a hub, an examination of the Matrix of Salton Index values (Table 11) revealed that Agricultural and Applied Economics was paired with six departments, but none of them were Biological Sciences or Biochemistry. An examination of the pairings, and the magnitudes of the Salton Index Values, suggests that while Agricultural and Applied Economics is an important collaborator for some departments, the span of connections was not as great as those demonstrated by Biological Sciences and Biochemistry. The higher betweenness centrality value of Agricultural and Applied Economics, when examined alongside the Salton Index values, shows a department that connects a large cluster of departments together, but did not exhibit a high level of diversity outside of that core group.

The three triangles mentioned above are also supported by patterns of departmental pairs observed within the Salton Index values. The Salton Index Matrix had a mean value of 0.06. The Biological Sciences – Chemistry pairing had a Salton Index of 0.18, the Biological Sciences – Physics pairing had a Salton Index of 0.21, and the Chemistry – Physics pairing had a Salton Index of 0.38. These high values, shared across the three pairings correspond with the first triangle described as a central core of the interdisciplinary research network. Similarly, the triangle between Biological Sciences, Biochemistry, and Chemistry was also supported by the presence of higher Salton Index values (Biological Sciences – Biochemistry = 0.38; Biochemistry – Chemistry = 0.25). The third and final triangle between Biological Systems Engineering, Crop and Soil Environmental Sciences, and Agricultural and Applied Economics was supported by higher than average Salton Index values (Biological Systems Engineering – Crop and Soil Environmental Sciences = 0.33; Biological Systems Engineering – Agricultural and Applied Economics = 0.27; Crop and Soil Environmental Sciences – Agricultural and Applied Economics = 0.18).

The final observations were derived from an examination of the outdegree (M = 17.40; SD = 9.00) and indegree (M = 17.40, SD = 12.00) of each department. Table 13 provides a means of evaluating which departments were reporting a large number of connections, and which departments were the most popular in terms of receiving the most connections. The most immediately identified pattern was the relative lack of interdisciplinary connections identified, in either direction, from the Psychology Department and the Economics Department. This suggests that the “social” science fields are more peripheral in terms of interdisciplinary collaborations, which is in line with earlier observations.

Chemistry, with the largest number of survey respondents, exhibited the third lowest outdegree, suggesting that the respondents did not readily identify potential collaborators outside of their department. Civil and Environmental Engineering, along with Physics, exhibited high outdegrees, suggesting that the respondents in the department were more apt to identify potential collaborators outside of their departments. Biological Sciences and Entomology also exhibited relatively high outdegrees, as well as high indegrees, suggesting that the respondents were aware of potential interdisciplinary collaborators, but also that members of the department were popular targets for interdisciplinary collaboration.

The above observation suggests that Biological Sciences and Entomology may act as hubs of interdisciplinary collaboration within the university. The final department of note is Biochemistry. Biochemistry was suggested to be a hub of interdisciplinary connections, when evaluated in terms of being the most frequently requested collaborators, demonstrating the second highest indegree value. The high indegree value suggests that Biochemistry was indeed a popular potential collaborator for other departments.

With regard to the first research question, and based on the above patterns, it seems that there are departments/disciplines that tend to be more interdisciplinary, and that serve as more central players within interdisciplinary collaborations. Across the three examined sources,

Figure 17, along with Tables 11 and 13, Biological Sciences and Biochemistry consistently appear as hubs of interdisciplinary connections by exhibiting a high proportion of connections being directed toward these departments. While Agricultural and Applied Economics and Entomology were also discussed as possible hubs, these two departments seem to be more strongly connected to a specific subset of departments. With regard to the second research question, within this sample, the patterns of collaborations suggest that the "social" science departments of Psychology and Economics were relatively disconnected from the interdisciplinary network of the "physical" sciences and the engineering fields.

With regard to the third question focusing on the preference for "little" vs. "big" interdisciplinary research, while there were a good deal of reported connections across multiple disciplines, the patterns suggest a preference for "like" others in terms of interdisciplinary connections. A concrete example is found in examining the triangle that was observed between Biological Systems Engineering (BSE), Crop and Soil Environmental Sciences (CSES) and Agricultural and Applied Economics (AAE) (Figure 17). The three departments describe very similar goals in terms of being focused on sustainable and sound use of natural resources, so the reported collaborations may be more natural than others. Only a couple of disciplines exhibited a trend toward "big" interdisciplinary research, those were Biological Sciences (BIO), and Biochemistry (BIOCHM), which were connected with almost all other departments.

Discussion

Evaluation of the hypothesis tests offers the following perspective on the formation of an open attitude toward interdisciplinary research. Overall, the results of this research align with the process that is suggested by the Theory of Planned Behavior (Ajzen, 1985; Ajzen, 1987) and the model derived from the theory (Figure 4). One interesting observation from the research is the role of academic status as an influential factor in the emergence of interdisciplinary connections.

To begin with, it is clear that there are multiple sources of influence on one's interdisciplinary openness. As has been suggested in other research (Sung et al., 2003), graduate students tend to be more open toward interdisciplinary research as an idea, while faculty members tend to exhibit an attitude that is slightly less open. In addition to the influence of one's academic status, a more applied epistemological orientation (McNeill, 1999) exhibited a more direct influence on the emergence of interdisciplinary openness. Not surprisingly, as suggested by the Theory of Planned Behavior (Ajzen, 1985; Ajzen, 1987) and the model presented in Figure 4, the department epistemology that an individual is embedded in exerted an indirect effect on one's interdisciplinary openness.

As for the formation of interdisciplinary connections, which the study captured by evaluating the reporting of potential interdisciplinary connections, department epistemology did not result in an increase in the likelihood of reporting interdisciplinary connections. What did increase the likelihood of reporting interdisciplinary connections was an increase in individual epistemology toward a more applied perspective, as did the reporting a greater degree of interdisciplinary openness. As Notani (1998) suggests that attitude is a stronger predictor of behavioral intention than perceived norms, it is interesting to note that having a more applied individual epistemology increased the likelihood of reporting interdisciplinary connections to a greater extent than having a more open attitude toward interdisciplinary research. In this case, it appears that Azjen's (1987) assertion that the three inputs can exert a similar degree of influence on behavioral intention is supported. Finally, possessing a higher academic status increased the likelihood that someone would report interdisciplinary connections, with graduate students less likely to report interdisciplinary connections.

The final hypotheses examined how the diversity of interdisciplinary, or non-departmental, connections was impacted by the individual level variables of individual epistemology, interdisciplinary openness, and academic status. With regard to diversity, it was demonstrated that having a full or associate professor faculty status would increase the reporting of more diverse interdisciplinary connections, with full professors exhibiting the most diversity compared to graduate students. Assistant professors did not exhibit greater diversity in the reporting of connections, when compared to graduate students. The diversity of one's interdisciplinary connections was not increased by individual epistemology or interdisciplinary openness.

The above finding lends support to the suggestion that sometimes one of the most influential components of behavior is simply the ability to engage in the behavior (Rhodes & Courneya, 2003; Ajzen & Fishbein, 2005). As is evidenced by this result, once the variables that precede the behavioral intention were accounted for in the consideration of interdisciplinary connections, what mattered most was academic status. This finding is not surprising given the observation that individuals of lower academic status are going to have their behaviors shaped by the expectations of others within the department (Golde & Gallagher, 1999; Stokols et al, 2003).

The research questions sought to understand the reported patterns in the network of non-departmental connections. What was observed was that the overall network of actors, while visually dense, was not dense relative to the number of possible connections that could have existed in the overall network of actors. So, within the research network, the actors were not all connected to one another, and there were relatively few direct connections among all of the actors. Similarly, there was not a high degree of network centrality among the various actors, or respondents, within the network. So, there was not a single person who overwhelmingly served as a go-between for other individuals, meaning an individual "hub" did not appear within the network.

Evaluating the research connections at the level of the departments provided a means to more clearly understand how the various departments came together within the network. Within the pattern of connections at the departmental level, there did appear to be a preference to send research connections to specific "hub" departments. This pattern is observed graphically (Figure 17) and also by examining the Salton Index values (Table 11). Across the two sources, it appears that Biological Sciences and Biochemistry do indeed serve as departmental "hubs" for research connections (Boyack et al., 2005; Morillo et al., 2003). The presence of these two departments is not surprising considering the stature of these departments in science, and at the university. Biological Sciences covers such a broad expanse of science, ranging from studies focused on the micro-level to studies focused on a macro-level (e.g.: Evolutionary Biology) so, the breadth of questions that are explored in Biological Sciences is great and the department's role as potential collaborator is not surprising. Biochemistry, by design, is a science that is working at the interface between Biology and Chemistry. Within Biochemistry we find a broad expanse of knowledge and techniques across the core sciences, and technologies and techniques that are useful in a large number of domains, which explains the presence of Biochemistry as a hub. Though not officially designated as a "hub" in this discussion, it is important to acknowledge that the Agricultural and Applied Economics Department was a key department in connecting some of the less central departments.

While there were apparent "hubs" of interdisciplinary activity within the observed network, there were also some obvious "outsiders" observed within the network, these departments had few connections with other departments in the research network and were less connected overall. As the research question suggests, these "outsider" departments are the more "social" of the sciences, specifically Psychology and Economics, and as such may have a lower status in the overall research community that was explored. While I could quite easily list the possible collaborations that might exist between the Psychology Department and other sciences and engineering, as well contributions that Economics could make to the other departments, the stature of these departments is obviously less than those in the so called "hard" sciences and engineering.

To the final research question, which asked whether or not or interdisciplinary connections are "big" or "small," it appears that "small" interdisciplinary connections were the norm. While I find the labels of "small" and "big" interdisciplinary research to be useful, I understand that some may find them to be judgment laden labels. Interdisciplinary research of any sort should serve to expand our knowledge, so whether it is "small," "big," or disciplinary in nature, research that is undertaken with a clear purpose and proper execution is a vital part of the overall process of understanding our world. What is important within interdisciplinary research is pushing the boundaries and finding new technologies and techniques to address the concerns of our world. "Big" interdisciplinary research will require the biggest stretch in knowledge, it will require the biggest risk, and ask people to really step outside of their "comfort zone" in terms of their knowledge and area of expertise. Remembering that Morillo et al. (2003) made a similar discovery, the fact that the connections needed to support the "big" interdisciplinary collaborations are less frequent in the observed network is not surprising. Instead, it is to be expected that the “little” connections are more prevalent, given our nature as people to not put ourselves in a position where the chance for failure is greater.

Limitations

While the above observations generally support the hypotheses and the suggestions in the literature, the generalizability of the findings must be tempered by the fact that the study was conducted within a single institution, and may reflect a cultural/organizational influence that is not found in other research universities. However, it is reasonable to suggest that given other commentaries and research on these issues derived from observations at other institutions, the concern that the observed patterns is idiosyncratic and untenable at other research universities is minimal.

A common concern with research that relies on survey based data is the impact of common method variance (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). As both the applied epistemological measure and the interdisciplinary openness measure relied on the same survey method and were collected at the same time, one may be reasonably concerned about common method variance. To address the concerns around common method variance, respondents were assured that their responses would not be identified individually and data would only be presented in the aggregate, which should minimize the influence of social desirability factors (Podsakoff et. al., 2003). Additionally, the measures were not presented as separate measures of two constructs, but were counterbalanced in presentation so that within each subset of items respondents responded to items assessing applied epistemology and interdisciplinary openness, thereby reducing the likelihood that a previous item provided a specific response context for an item that followed (Podsakoff et. al., 2003), this may have contributed to the lower reliability of the scales when compared to earlier samples (Knee, 2008).

Finally, the relevant variables in the overall study were not all based on the same scale or survey approach, so common method variance should not be seen as a concern that permeates the entire data set.

Another reasonable concern is the low reliability associated with the sample measurement of applied epistemology. Admittedly, the reliability of the measure is much lower than what is standard, however, as reliability is related to the number of items, the low reliability can partially be explained by the fact that the current measure consists of only two items.

One final comment on a potential limitation is related to the collection of the non-departmental research connections. As one survey respondent suggested, there are other people within the university that someone may work with, but the department may not have been available on the list. The concern that the connections within the research network were artificially truncated by the presentation of a predetermined set of departments is legitimate. A reasonable suggestion is that there may have been a larger and more diverse constellation of research connections if the respondents were able to indicate non-departmental connections without restriction. To that point, I suggest that the core observation of the collected network is not undermined by the absence of a few other departments, but that the overall theme of the presented network is still notable and an important observation of tendencies that are exhibited within the departments represented in the study.

Conclusion

As the idea of interdisciplinary research continues to evoke our aspirations to push the boundaries of science and technology, we need to be mindful of how interdisciplinary research emerges and thus how it may succeed. Interdisciplinary research should serve as more than a funding "buzzword" and should truly be pushing the boundaries of what, and how, we know our world. The findings of this research have demonstrated that a good deal of the anecdotal evidence and ideas around the development of interdisciplinary collaboration hold true.

What this research suggests, or reinforces, is that the structure provided within the Theory of Planed Behavior (Ajzen, 1985; Ajzen, 1987) seems to hold true. The more proximal variables of interdisciplinary openness and individual epistemology play an important role in the emergence of interdisciplinary research, yet the most important variable appears to be status. The power to set one's path, to deviate from the norm, to take chances and not be concerned that failure will derail one's career in academia, is an essential component to the development of interdisciplinary collaborations. The power to engage in behaviors, simply because one can, is not unrecognized as a potential means of bypassing interdisciplinary openness and individual epistemology under the Theory of Planned Behavior (Rhodes & Courneya, 2003; Ajzen & Fishbein, 2005) it is simply not the focal point, nor should it be the sole focus here.

As the diversity of interdisciplinary connections will influence the boundaries that can be pushed, it is important to recognize that status is an important barrier to pursuing the diversity desired in interdisciplinary research. However, while the individuals choosing to pursue interdisciplinary research who have reached a higher degree of status may be more successful, attitudes toward interdisciplinary research appear to be more open and flexible within graduate students (Sung et al., 2003). The value of graduate students as the frontier of interdisciplinary research is still great. What is obvious is that successful fostering of interdisciplinary research is active engagement from senior faculty members, who have the means to bridge the gaps that might ordinarily exist for graduate students and less senior faculty members (Rhoten & Parker, 2004; Frost & Jean, 2003).

Returning once again to the topic of funding, with there being a greater demand than supply for funding of interdisciplinary research, it is important to consider what should be expected from interdisciplinary research in the future. Should interdisciplinary research be any program that pulls individuals from different departments and disciplines, or should it be research that truly steps outside of the norms of our departments and disciplines? My hope is that the funding agencies will continue to reward those who conduct "big" interdisciplinary research whenever possible. While it may be a personal judgment to say "big" interdisciplinary research is more valuable, if the partnerships that would support "big" projects are less frequent, then it seems appropriate to defer to the less frequent research partnerships when evaluating a research proposal.

Future Research

First and foremost, future research should attempt to replicate the relationships and patterns found in this research by exploring the relationships at other universities. An interesting component in further research is to examine how power and influence unfolds in the development and success of interdisciplinary research. In this study, status was assumed as a proxy for the power that could be exerted by graduate students and faculty when considering potential collaborators. Future research on the topic may consider actually measuring perceptions of power within the context of research in general.

An individual's ability to form interdisciplinary connections, beyond exhibiting openness toward the activity, should require the ability to direct the behavior, intentions, and attitudes of others (power) along with the ability to actually exert their power on others (influence) (Aguinis, Nesler, Quigley, Lee, & Tedeschi, 1996). So, while a senior faculty member may have the power necessary to engage others in interdisciplinary research, could it be that he/she may not have the ability to influence non-departmental others based on the status of his/her department/discipline? Additionally, what is the outcome when a power differential exists within interdisciplinary research groups? Could it be that interdisciplinary research groups in which a single individual holds a disproportionate degree of power are more functional, but less creative, which is the true gem of interdisciplinary research?

Future research may also benefit from exploring how organizational social capital influences the formation of interdisciplinary research collaborations. Organizational social capital is that collective goal orientation of an organization's members that supports the behaviors of individuals within the organizational network and directs them toward actions that benefits the larger organization (Leana & Van Buren, 1999). Based on the above idea, one may ask if colleges and universities that foster a greater degree of organizational social capital more likely to achieve success in interdisciplinary research? Also, do individuals who pursue interdisciplinary research perceive a greater collective goal orientation or are they more individually focused in their goals?

Additional research at the organizational level should seek to identify the value of the interdisciplinary "hubs." Could it be that the methodologies of the "hubs" are flexible and broad enough that other disciplines are able to adapt more readily into the paradigm of the "hub" discipline? Are the "hub" disciplines broader in scope and thus act as more effective go-betweens for dissimilar departments? Is it possible to identify the structural holes within a research network, such that we could identify effective disciplinary go-betweens for future interdisciplinary initiatives?

Admittedly this research has only scratched the surface of empirically uncovering the variables that underlie interdisciplinary collaboration. However, I believe that the finding of this research provides direction for future research into interdisciplinary research. As funds for research become scarcer, and the questions more pressing, it will become even more important to be able to develop, support, and identify the interdisciplinary research programs that are most likely to succeed.

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Table 1

Survey Response Percentages by Department and Academic Status

Department	Graduate Student	Faculty	Total
Agricultural and Applied Economics	0.45	0.30	0.37
Animal & Poultry Sciences	0.25	0.19	0.22
Biochemistry	0.33	0.16	0.26
Biological Sciences	0.23	0.18	0.21
Biological Systems Engineering	0.21	0.22	0.21
Chemistry	0.15	0.40	0.19
Civil and Environmental Engineering	0.30	0.26	0.29
Crop and Soil Sciences	0.31	0.26	0.28
Dairy Sciences	0.36	0.15	0.25
Economics	0.04	0.29	0.13
Entomology	0.41	0.13	0.30
Geosciences	0.29	0.19	0.25
Physics	0.20	0.30	0.23
Plant Pathology, Physiology, and Weed Science	0.33	0.33	0.33
Psychology	0.33	0.42	0.35

Table 2

Departmental Epistemology Scores as a Function of Biglan (1973) and Boyack et al. (2005)

Department/Discipline	Department Epistemology
Agricultural and Applied Economics	4.00
Animal & Poultry Sciences	3.00
Biochemistry	- 2.75
Biological Sciences	- 4.75
Biological Systems Engineering	5.50
Chemistry	- 4.25
Civil and Environmental Engineering	5.50
Crop and Soil Environmental Sciences	3.00
Dairy Science	3.00
Economics	- 1.50
Entomology	- 4.25
Geosciences	- 4.25
Physics	- 4.00
Plant Pathology, Physiology, and Weed Science	- 3.00
Psychology	- 3.75

Note. Negative values indicate a more pure approach to science and positive values a more applied approach.

Table 3

Descriptive Statistics and Spearman's Rho Correlations

Measure	Sample Size	Mean	SD	Status	Interdisciplinary Openness	Individual Epsitemology	Department Epsitemology	Interdisciplinary Connections
Status								
Graduate Student	146							
Assistant Professor	26							
Associate Professor	15							
Full Professor	40							
Total	227			--				
Interdisciplinary Openness	227	3.76	0.71	- 0.19*	(0.71)			
Individual Epsitemology	227	2.78	1.00	- 0.02	0.18**	(0.48)		
Department Epistemology	227	- 1.39	3.90	0.07	0.19**	0.16*	--	
Interdisc. Connections	227	0.48	0.50	0.24**	0.14*	0.22**	0.04	--
Diversity Impact Factor	109	0.00	0.93	0.35**	- 0.02	- 0.00	0.02	0.77**

Note. *p < .05, **p < .01; parenthetical values on diagonal represent alpha coefficients

Table 4

Multiple Regression for Prediction of Interdisciplinary Openness and Mediation Analysis

Variables	B	SE	β	t
Step 1 – Prediction of Interdisciplinary Openness from Department Epistemology				
Constant	3.81	0.05		
Department Epistemology	0.04	0.01	0.20	2.90**
Step 2 – Prediction of Individual Epistemology from Department Epistemology				
Constant	2.86	0.07		
Department Epistemology	0.05	0.02	0.21	3.16**
Step 3 – Prediction of Interdisciplinary Openness from Individual Epistemology				
Constant	3.38	0.14		
Individual Epistemology	0.14	0.05	0.19	2.94**
Step 4 – Test of Individual Epistemology as a Mediator of the Department Epistemology and Interdisciplinary Openness Relationship				
Constant	3.48	0.14		
Department Epistemology	0.03	0.01	0.16	2.37*
Individual Epistemology	0.11	0.05	0.16	2.42*

Note. n = 227.

Step 1 R^2 = .04. F(1,225) = 8.40, p < .01.

Step 2 R^2 = .05. F(1,225) = 9.96, p < .01.

Step 3 R^2 = .04. F(1,225) = 8.64, p < .01.

Step 4 R^2 = .06. F(2,223) = 7.21, p < .01.

*p <.05. **p < .01.

Table 5

Quadratic Regression Model for the Prediction of Interdisciplinary Openness from Academic Status

Model	Variable	R^2	$R^2\Delta$	B	SE	β	t
Linear		.024					
	Constant			3.93	0.09		
	Academic Status			- 0.09	0.04	- 0.16	- 2.35*
Quadratic		.043	0.19*				
	Constant			4.47	0.27		
	Academic Status			- 0.73	0.30	- 1.20	- 2.40*
	Academic $Status^2$			0.13	0.06	1.05	2.11*

Note. n = 227. Linear: $F(1, 225) = 5.52$, $p < .05$. Quadratic: $F(2, 224) = 5.03$, $p < .01$. *$p < .05$.

Table 6

Interdisciplinary Openness Planned Contrasts for Academic Status Groups

			95% CI for Difference	
Group	Contrast Groups	Contrast Value	SE	t
Graduate Student	All Professors	0.95	0.31	3.10**
Assistant Professor	Assoc. and Full Professor	- 0.20	0.35	- 0.57
Associate Professor	Full Professor	- 0.10	0.21	- 0.48

Note. **p <.05.

Table 7

Logistic Regression for Prediction of Interdisciplinary Connections

		B	exp B	Wald	Step χ^2	Model χ^2	Cox &Snell	Nagelkerke
Block 1	Department Epistemology	0.04	1.04	1.58	1.59	1.59	.01	.09
Block 2	Individual Epistemology	0.45	1.57	9.77**	10.31***	11.90**	.05	.07
Block 3	Assistant Professor	1.09	2.96	5.51**	18.90***	30.80***	.13	.17
	Associate Professor	2.13	8.41	9.56**				
	Full Professor	0.93	2.54	6.00**				
Block 4	Interdisc. Opennness	0.55	1.73	5.87*	6.19**	36.99***	.15	.20
Full Model	Department Epistemology	0.00	1.00	0.00	6.19**	36.99***	.15	.20
	Individual Epistemology	0.53	1.70	11.13**				
	Assistant Professor	1.32	3.74	7.41**				
	Associate Professor	2.40	10.99	11.34**				
	Full Professor	1.11	3.03	7.86**				
	Interdisc. Opennness	0.55	1.73	5.87*				

Note. n = 227. Cox & Snell and Nagelkerke are measures of R^2. *p <.05. **p < .01. ***p < .001

Table 8

Descriptive Statistics for Individuals Reporting Interdisciplinary Connections

Measure	Sample Size	Mean	SD	Status	Interdisciplinary Openness	Individual Epistemology	Department Epistemology
Status							
Graduate Student	57						
Assistant Professor	15						
Associate Professor	12						
Full Professor	25						
Total	109						
Interdisciplinary Openness	109	3.84	0.68	-.28**			
Individual Epistemology	109	3.08	0.97	.03	.24*		
Department Epistemology	109	-1.06	4.01	.11	.15	.15	
Diversity Impact Factor	109	0.00	0.93	.35**	-.02	.00	.02

Note. *p <.05. **p < .01.

Table 9

Multiple Regression for Prediction of Diversity Impact Factor

Variables	B	SE	β	t
Constant	- 0.69	0.59	--	- 1.18
Individual Epistemology	0.01	0.09	0.01	0.09
Assistant Professor	0.33	0.27	0.12	1.25
Associate Professor	0.73	0.29	0.25	2.48*
Full Professor	0.75	0.22	0.34	3.37**
Interdisciplinary Openness	0.10	0.14	0.07	0.68

Note. $n = 109$. $R^2 = .12$. $F(5,103) = 2.89$, $p < .05$. *$p < .05$. **$p < .001$.

Table 10

Academic Status Mean Differences Between Those Reporting Interdisciplinary Connection and Those Not Reporting Interdisciplinary Connections

		Interdisciplinary Openness			Individual Epistemology		
	n	M	SD	*t*	M	SD	*t*
Graduate Students							
Connections	57	4.08	0.54	3.13**	3.06	1.04	2.20*
No Connections	89	3.73	0.72		2.69	0.96	
Assistant Professors							
Connections	15	3.61	0.49	1.02	2.67	0.94	2.20*
No Connections	11	3.31	1.00		1.86	0.90	
Associate Professors							
Connections	12	3.53	0.95	0.00	2.75	1.01	1.79
No Connections	3	3.53	0.83		1.67	0.29	
Full Professors							
Connections	25	3.67	0.77	0.43	3.24	0.78	2.53*
No Connections	15	3.57	0.55		2.53	0.97	

Note. *p <.05. **p < .01.

Table 11

Salton Index Matrix of Interdisciplinary Connections Reported for All Pairwise Departmental Groupings

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Ag. & App. Econ.	~												
2. Animal & Poultry Sci.	0.00	~											
3. Biochemistry	0.00	0.19	~										
4. Biological Sciences	0.00	0.16	0.38	~									
5. Bio. Syst. Eng.	0.27	0.02	0.04	0.04	~								
6. Chemistry	0.12	0.01	0.25	0.18	0.05	~							
7. Civil & Enviro. Eng.	0.07	0.00	0.01	0.05	0.24	0.06	~						
8. Crop & Soil Enviro. Sci.	0.18	0.02	0.01	0.02	0.33	0.00	0.26	~					
9. Dairy Science	0.00	0.57	0.05	0.05	0.04	0.00	0.00	0.00	~				
10. Entomology	0.12	0.00	0.13	0.14	0.00	0.02	0.00	0.00	0.00	~			
11. Geosciences	0.00	0.00	0.01	0.03	0.00	0.13	0.41	0.02	0.00	0.00	~		
12. Physics	0.00	0.00	0.01	0.21	0.00	0.38	0.06	0.00	0.00	0.00	0.16	~	
13. Plant Pathology, Phys., & Weed Sci.	0.03	0.00	0.11	0.07	0.04	0.00	0.00	0.27	0.00	0.25	0.00	0.00	~

Note. Salton: Econ. – Ag. & App. Econ. = .44; Psych. – Animal & Poultry Sci. = .09; Psych. – Biochem. = .06

Table 12

Department Level Connection Matrix Indicating the Number of Individuals Targeted Within Departments

Dept. Number	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
20		0	0	0	0	3	0	1	6	0	0	1	2	0	3
25	0		7	0	3	0	1	0	1	0	0	0	0	0	0
30	0	2		0	4	0	5	0	0	0	0	0	0	0	0
35	0	0	0		1	0	9	0	0	6	11	0	1	0	0
40	0	0	3	0		0	9	0	1	0	4	0	0	0	0
45	0	0	0	0	2		2	0	0	0	0	0	0	0	0
50	0	2	3	0	10	3		0	2	0	4	0	2	0	1
55	2	0	0	0	0	0	0		0	0	0	0	0	0	0
60	4	1	1	0	2	0	1	0		0	0	0	2	0	6
65	0	0	0	1	1	0	2	0	0		6	0	3	0	1
70	0	0	1	4	10	1	10	0	2	2		0	0	0	0
75	0	0	0	0	3	3	3	0	1	0	0		0	0	6
80	1	0	0	1	1	0	2	0	3	6	3	0		0	5
85	0	0	1	0	0	0	1	0	0	0	0	0	0		0
90	4	0	1	0	1	0	1	0	5	0	0	4	1	0	

Note. Rows indicate outgoing connections. Columns indicate incoming connections.

Table 13

Departmental Count for Survey Respondents, Connection Respondents and Social Network Node Degrees

	Respondents		
Department	Survey (Connects)	Outdegree	Indegree
Agricultural and Applied Economics	16 (5)	16	14
Animal & Poultry Sciences	8 (6)	18	20
Biochemistry	11 (10)	18	38
Biological Sciences	25 (15)	27	43
Biological Systems Engineering	9 (8)	19	21
Chemistry	31 (17)	7	13
Civil and Environmental Engineering	20 (9)	30	12
Crop and Soil Environmental Sciences	10 (7)	19	22
Dairy Science	6 (3)	12	12
Economics	5 (2)	2	1
Entomology	11 (3)	29	29
Geosciences	15 (5)	14	15
Physics	20 (10)	28	11
Plant Pathology, Physiology, and Weed Science	10 (7)	20	10
Psychology	29 (2)	2	0

Note. Values in parentheses indicate the number of survey respondents that provided information on non-departmental connections.

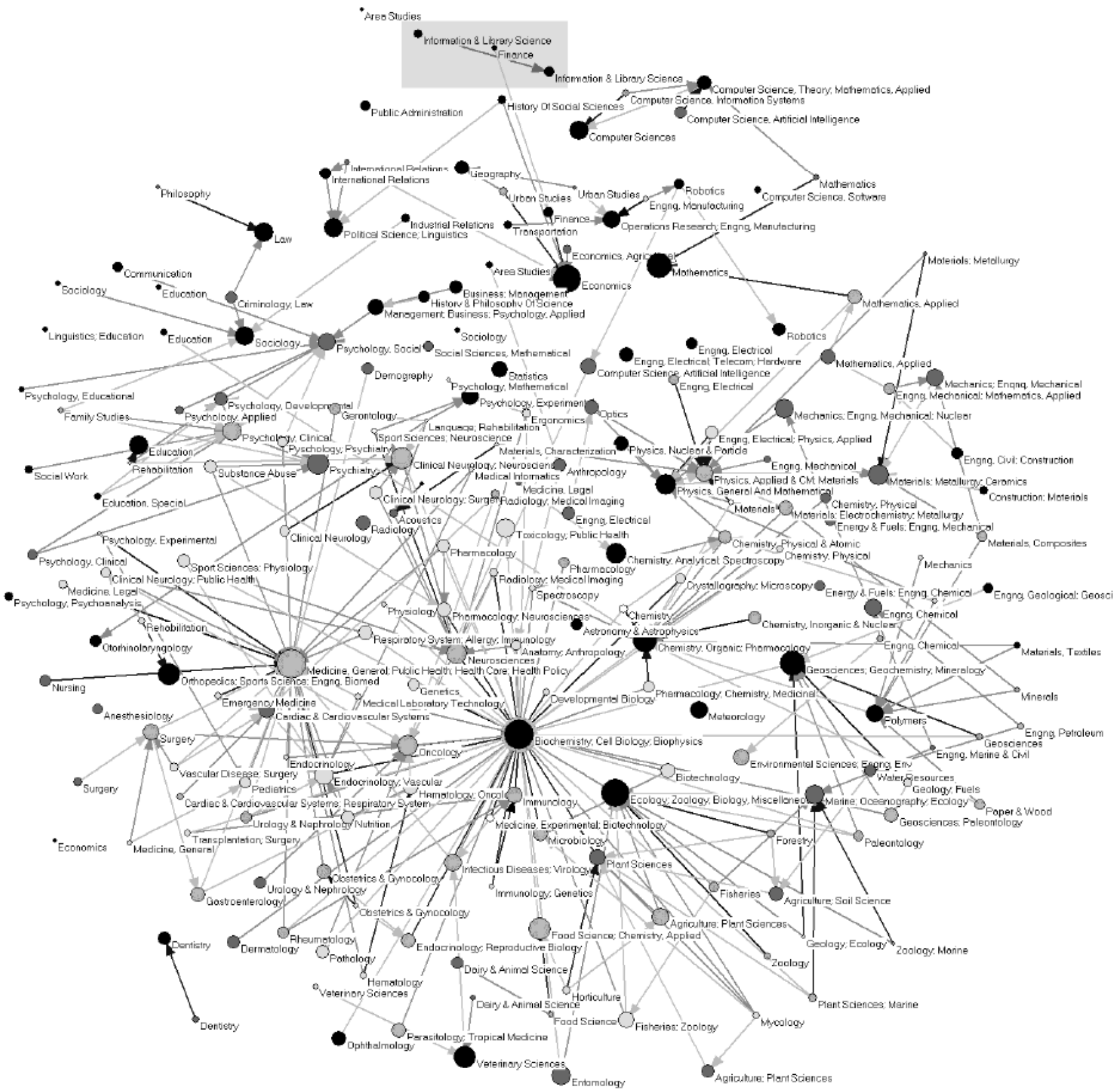

Figure 1. Map of the backbone of science from Boyack, Klavans, & Borner, 2005.

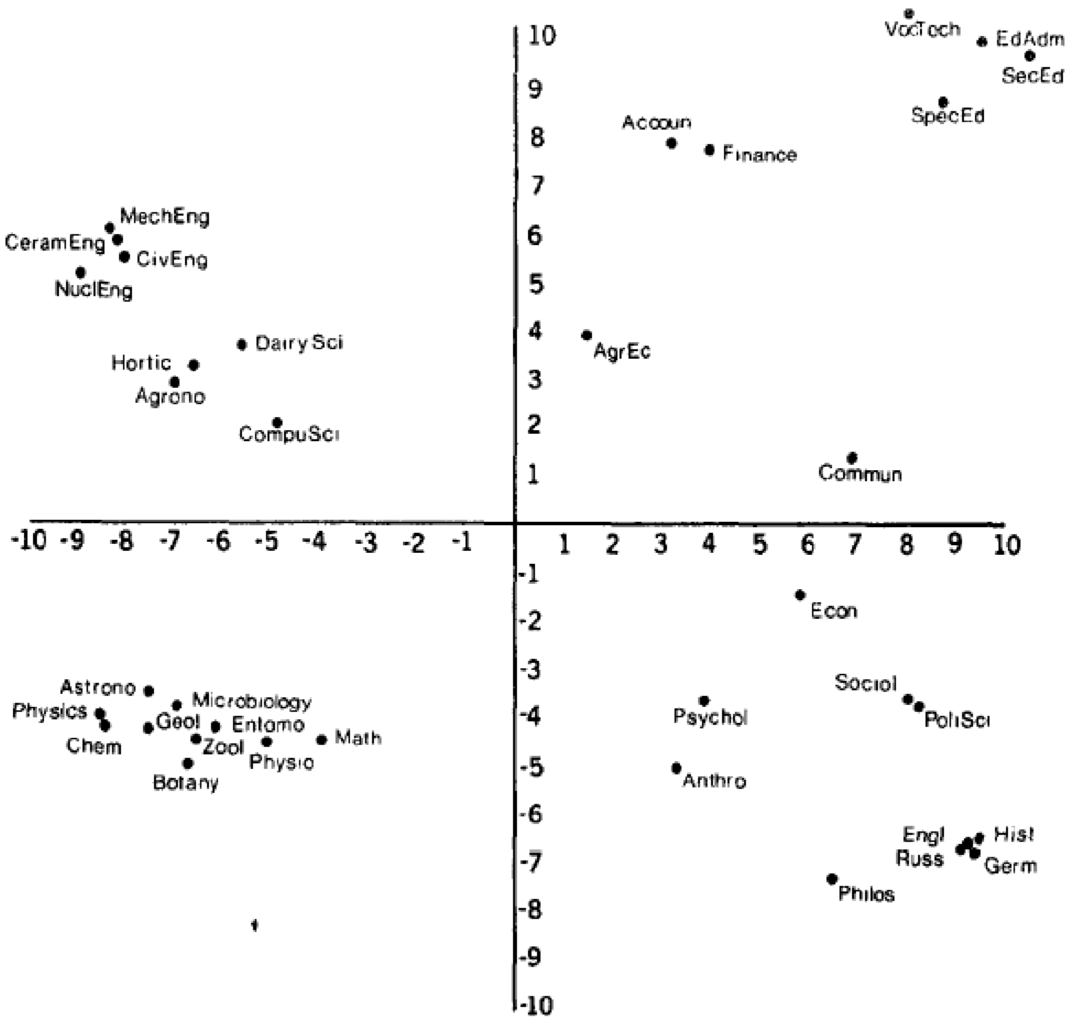

Figure 2. Plot of academic disciplines along the hard science-social science dimension (horizontal) and applied-pure dimension (vertical) from Biglan, 1973.

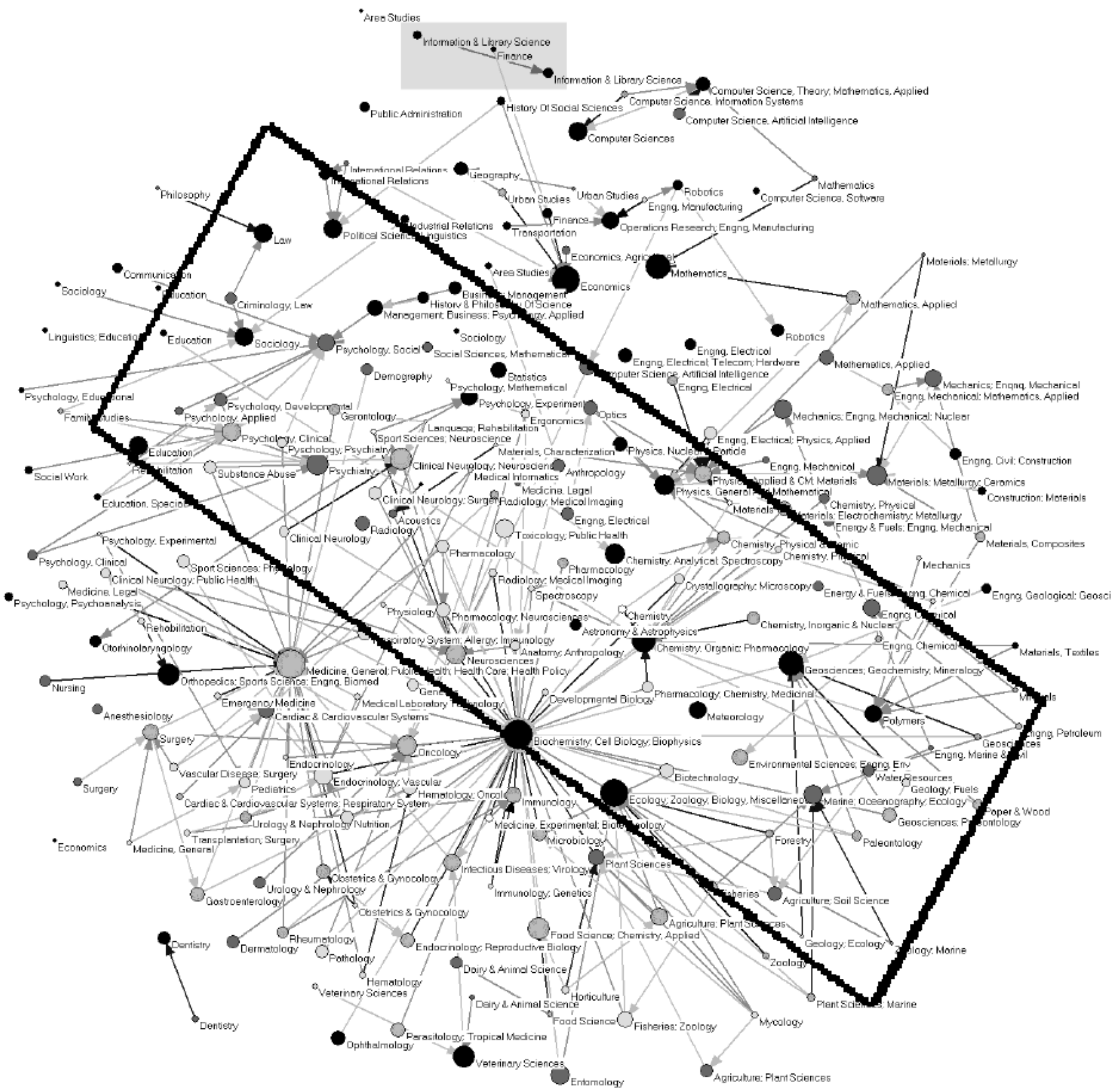

Figure 3. Map of the backbone of science (Boyack et al., 2005) with an applied band representing Biglan's (1973) applied fields.

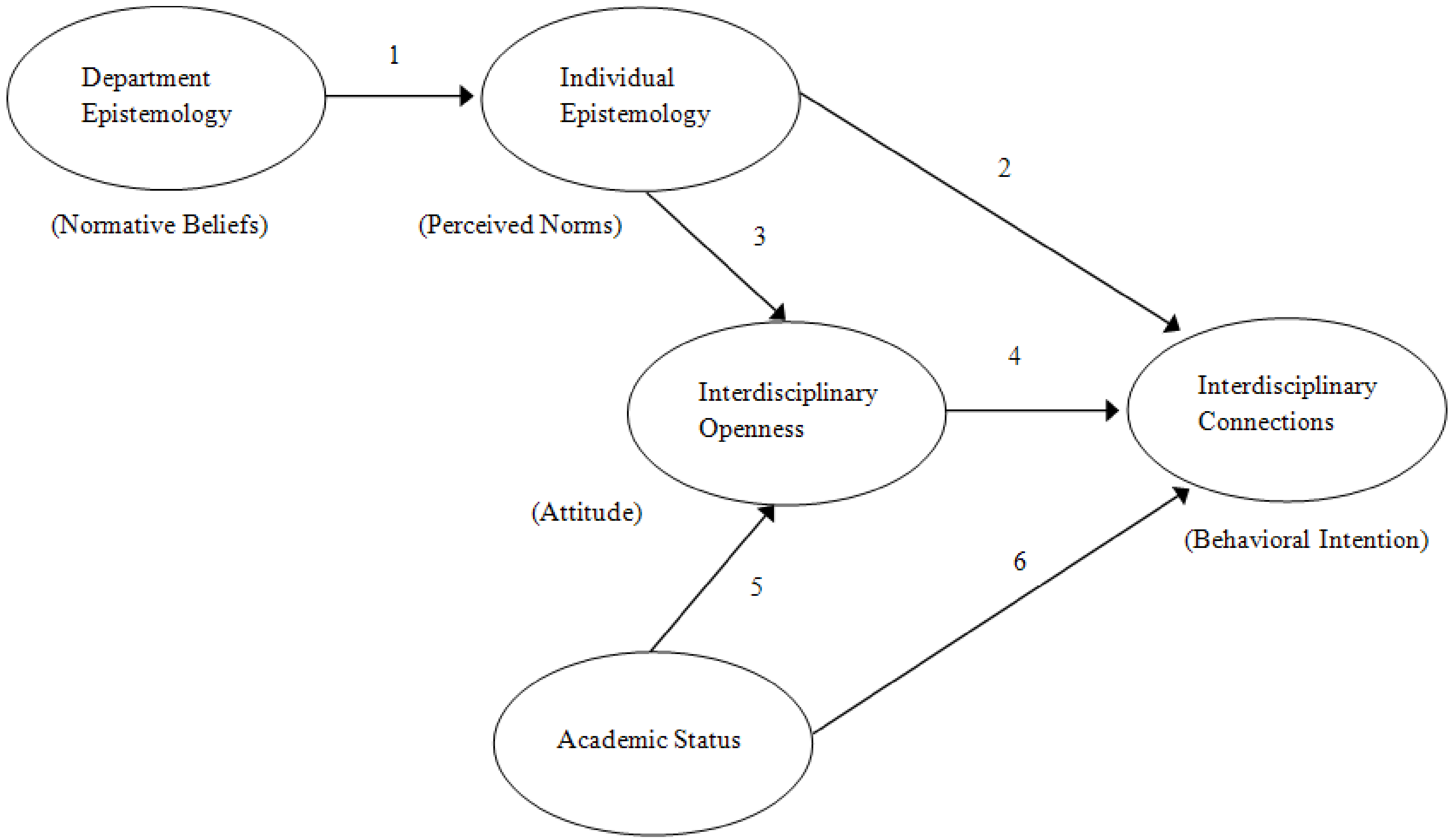

Figure 4. A framework for understanding how interdisciplinary research connections emerge derived from the Theory of Planned Behavior.

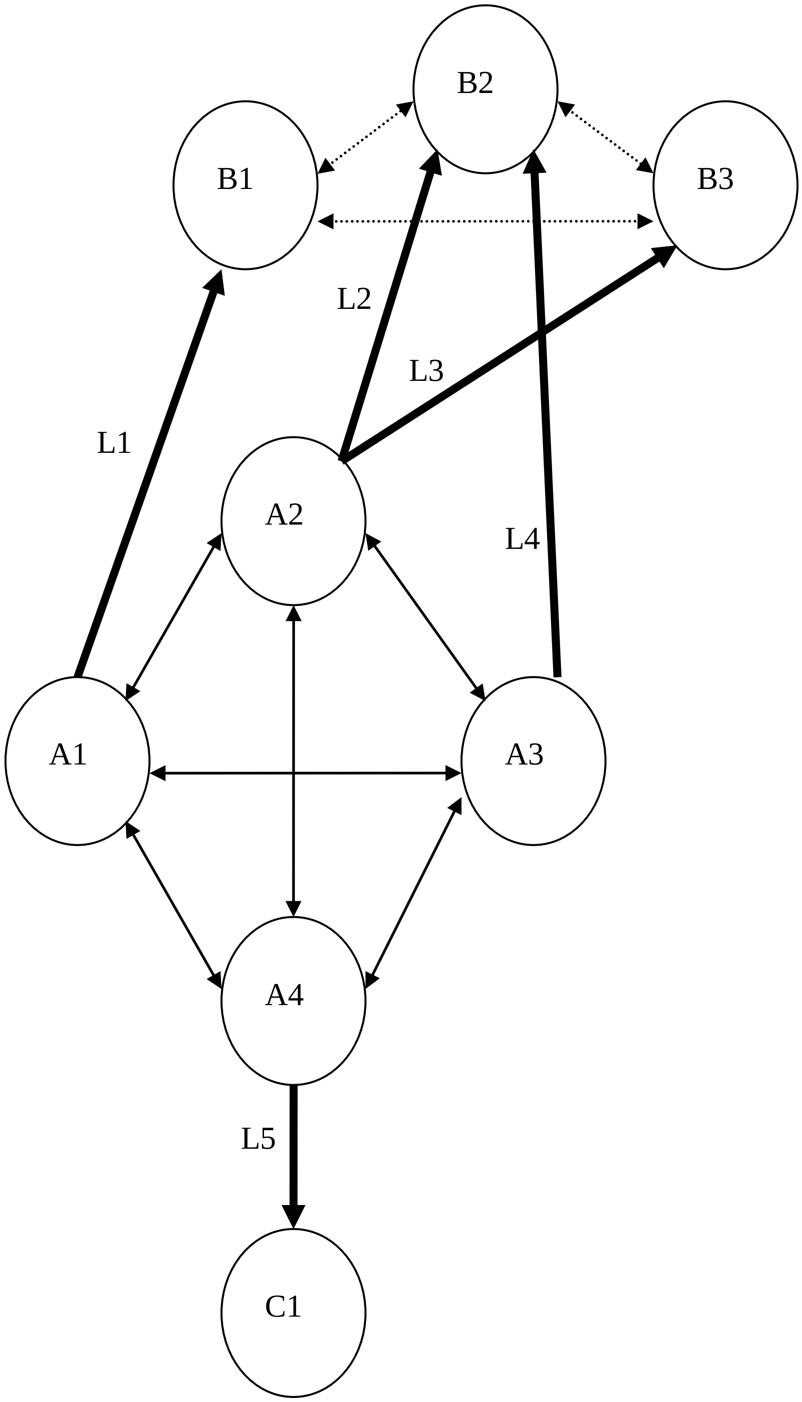

Figure 5. Diversity Impact Factor example.

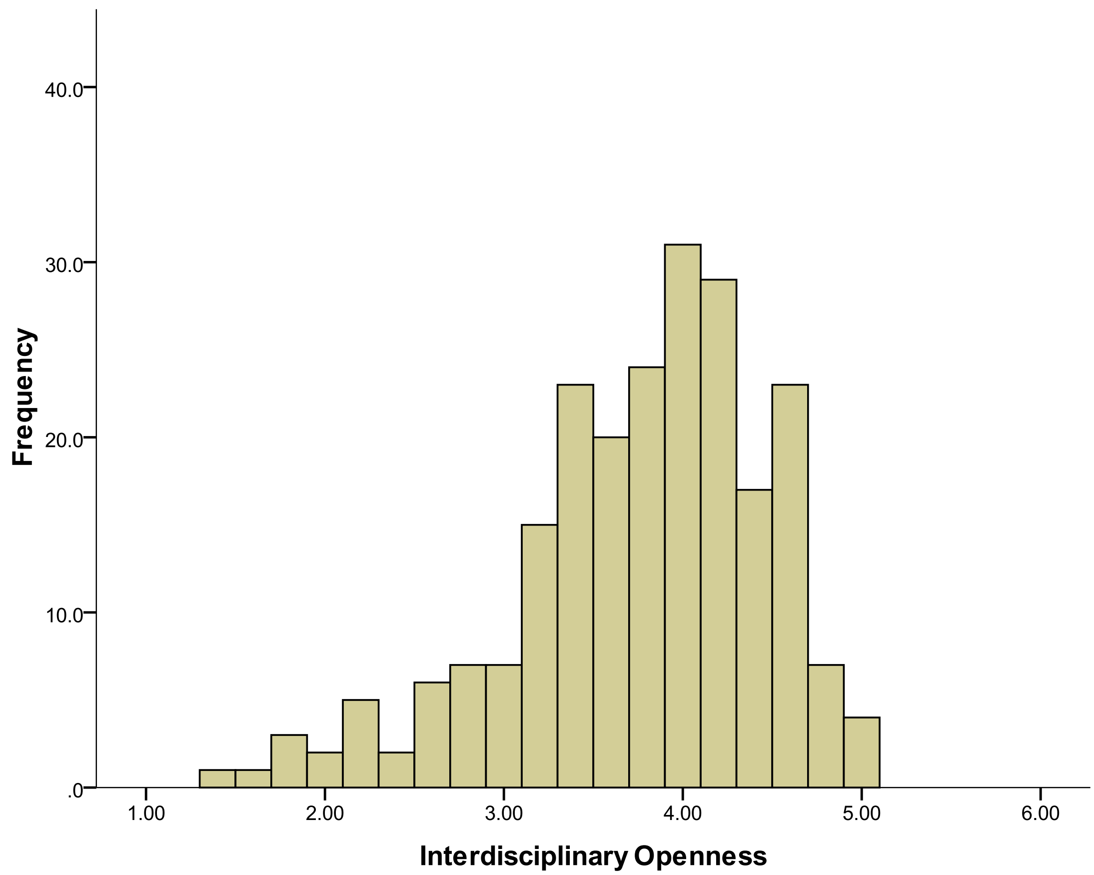

Figure 6. Histogram of Interdisciplinary Openness Scores

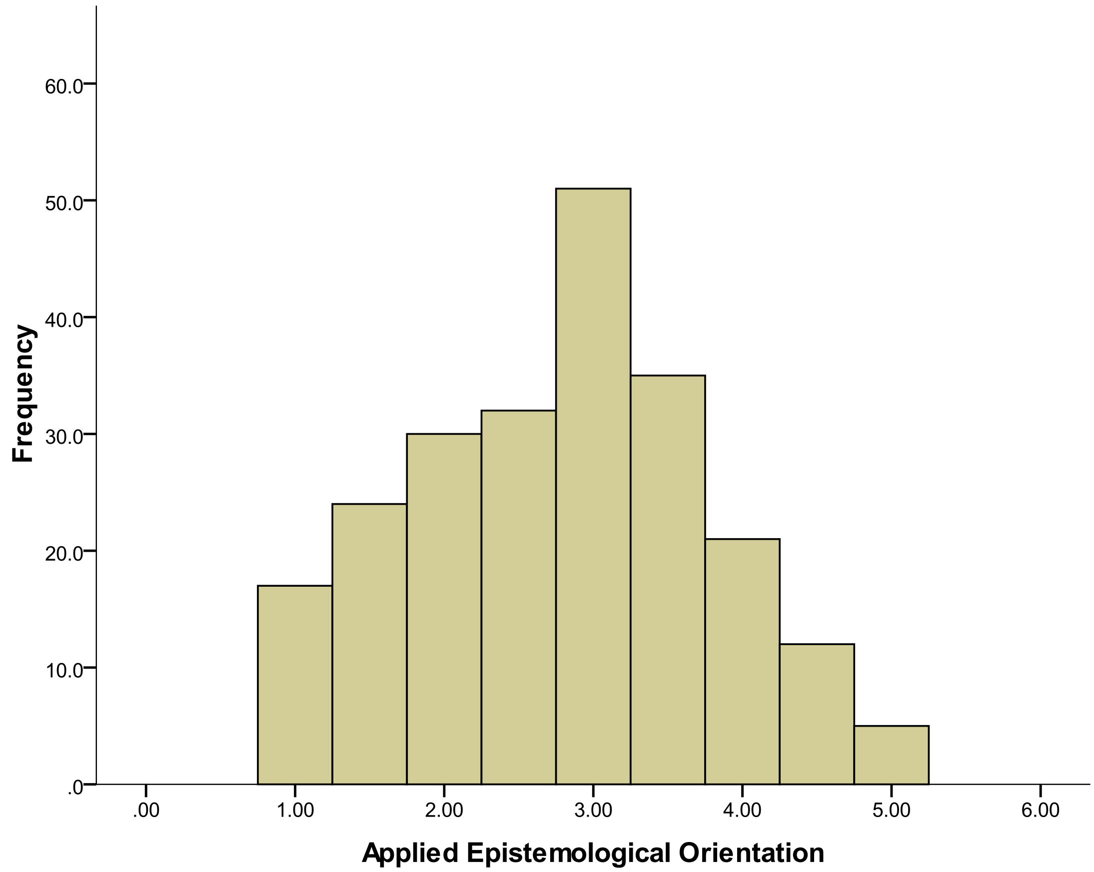

Figure 7. Histogram of Individual Epistemology

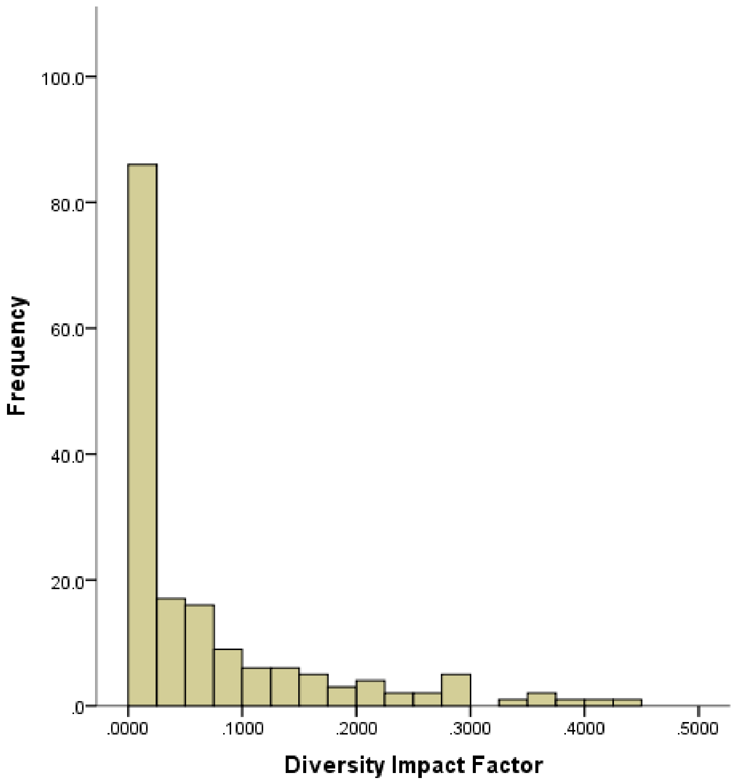

Figure 8. Histogram of Diversity Impact Factor

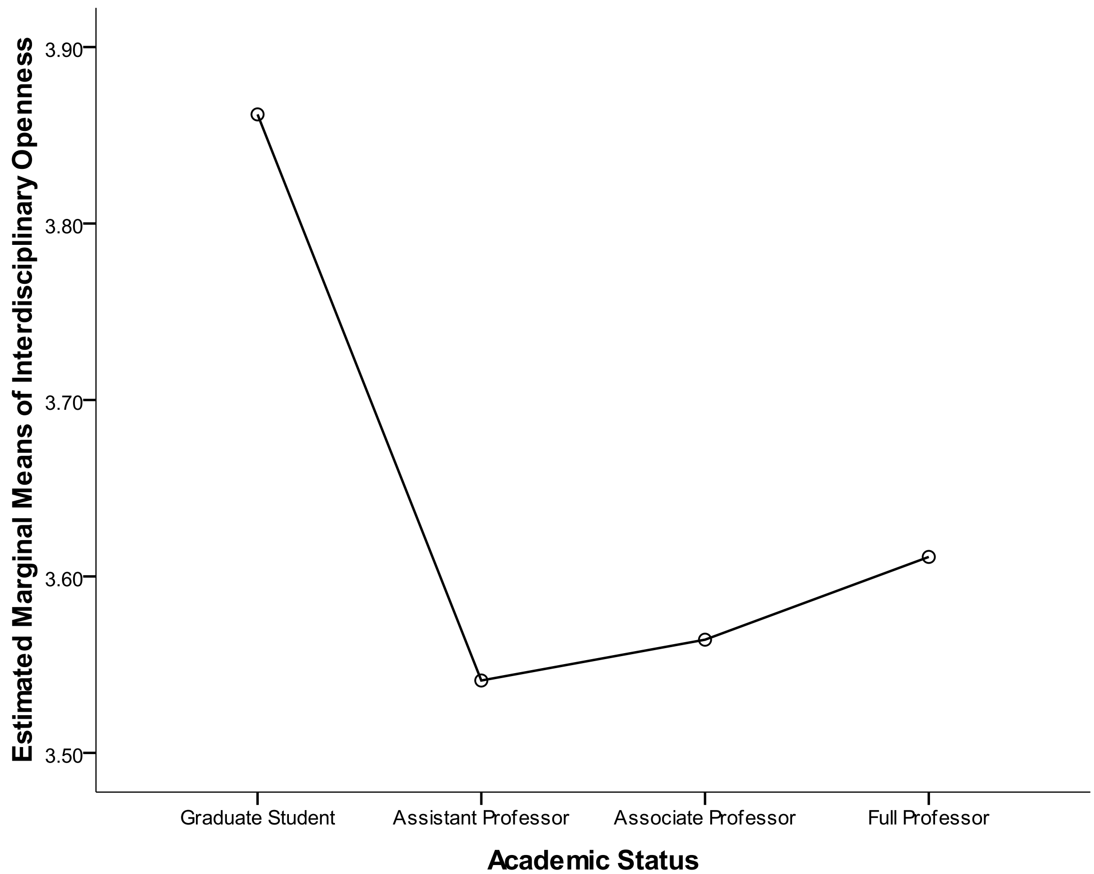

Figure 9. Analysis of Variance Marginal Means of Interdisciplinary Openness by Academic Status

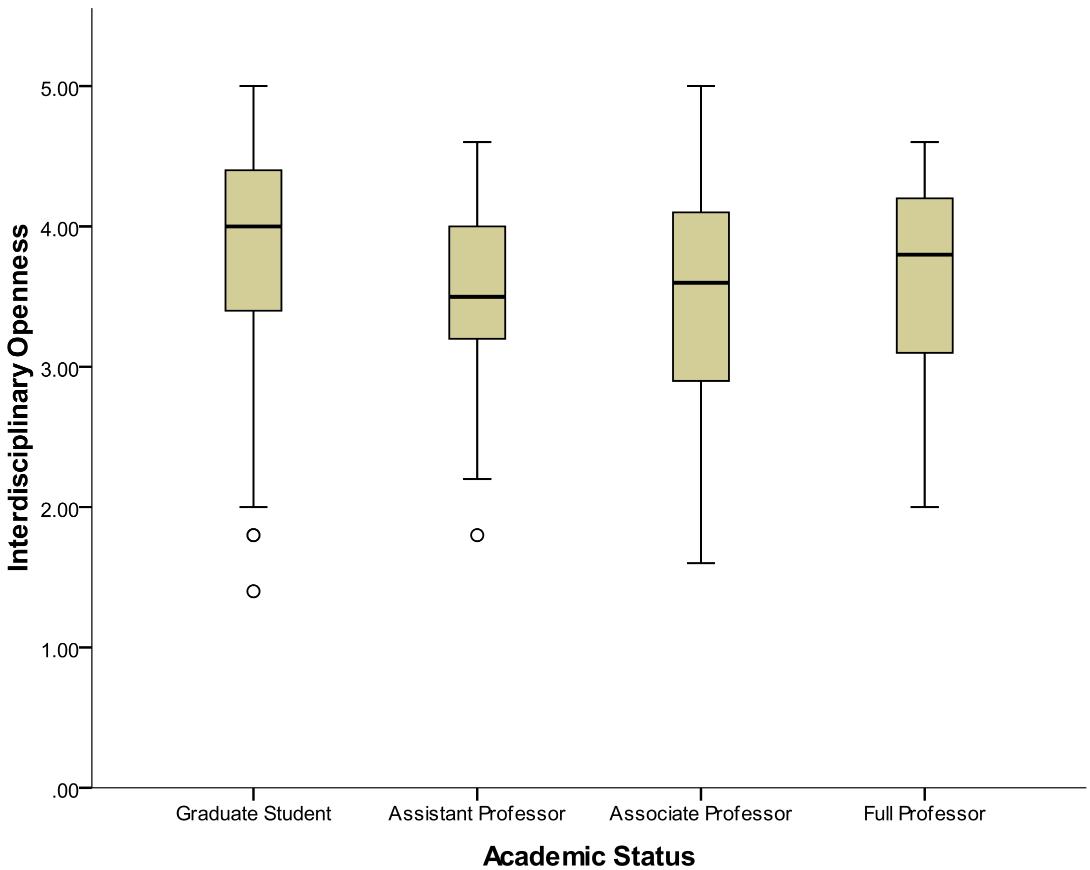

Figure 10. Boxplot of Interdisciplinary Openness by Academic Status

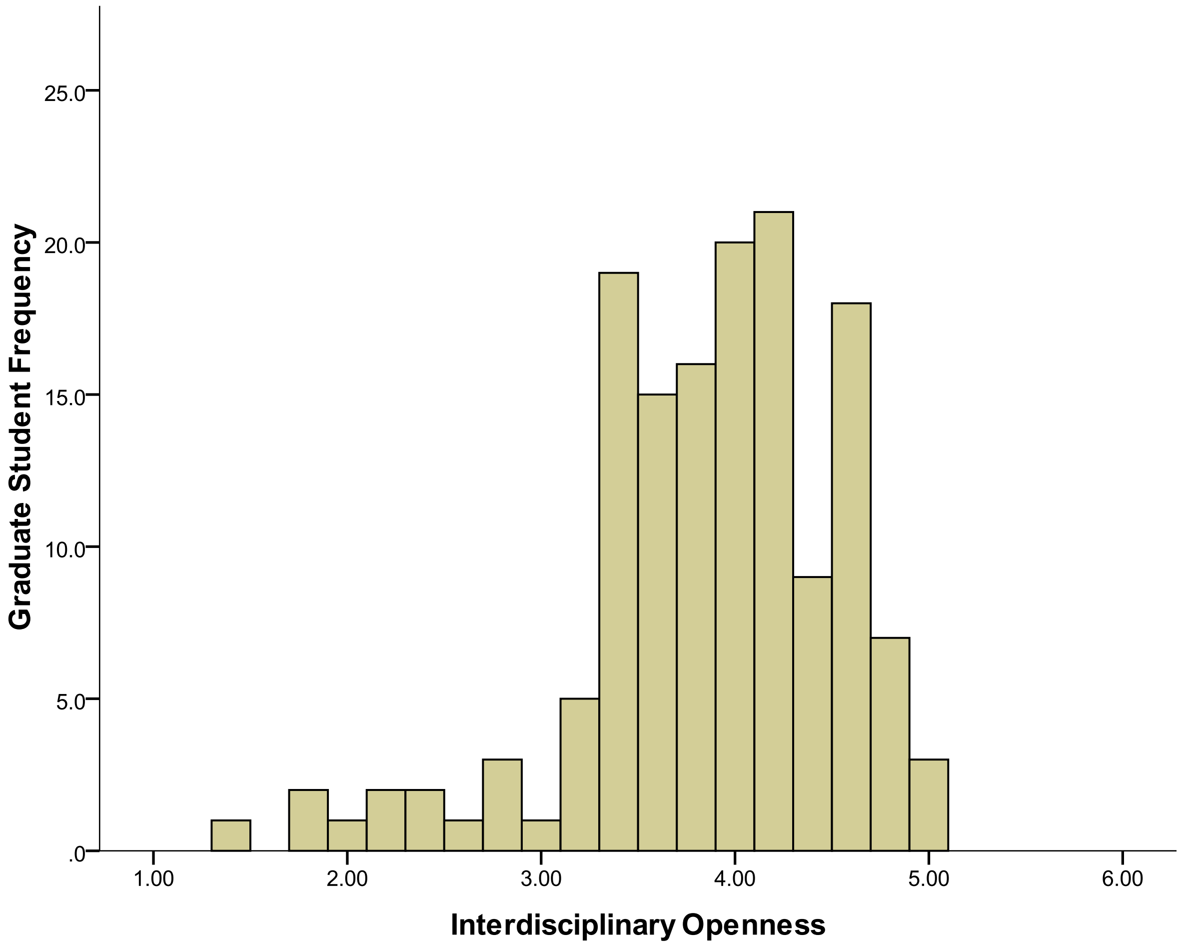

Figure 11. Histogram of Interdisciplinary Openness Scores for Graduate Students

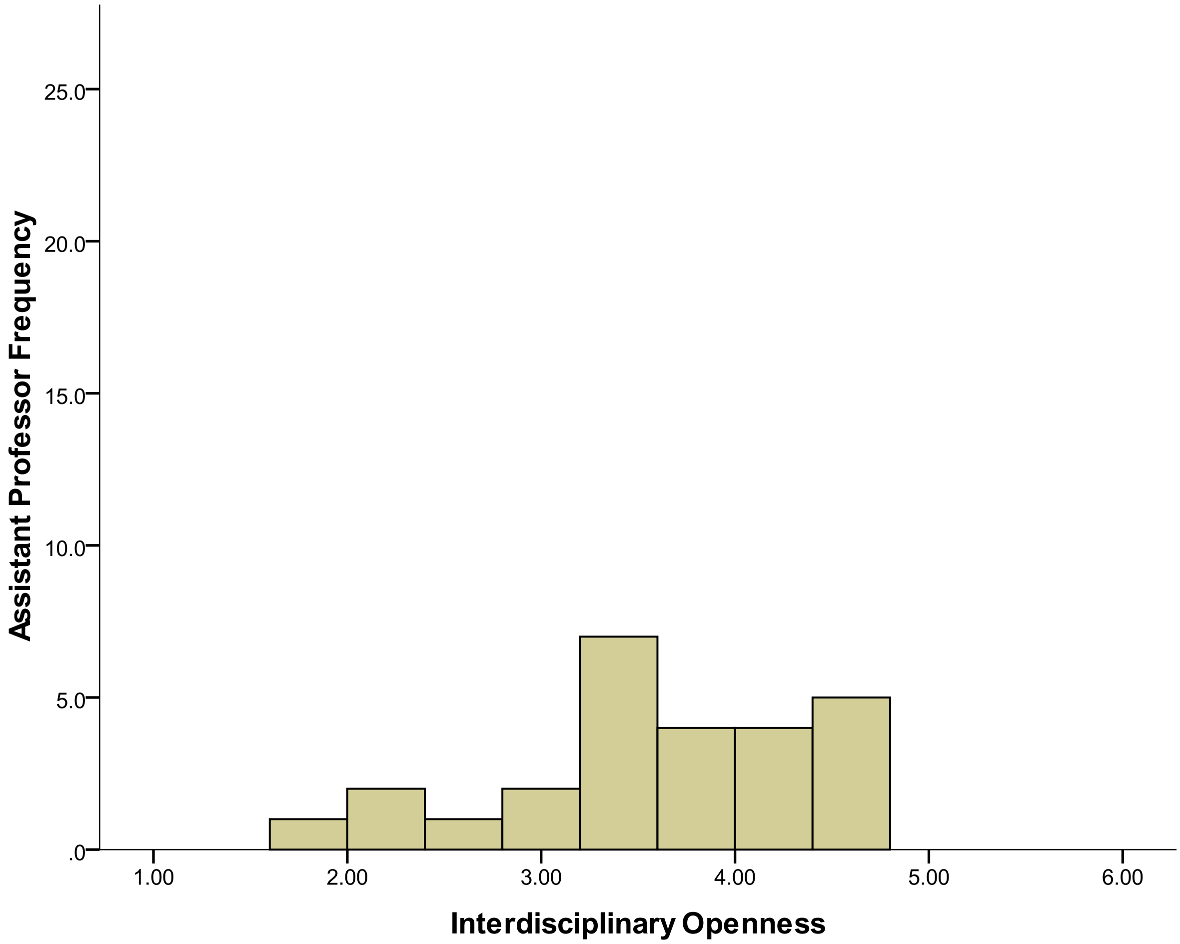

Figure 12. Histogram of Interdisciplinary Openness Scores for Assistant Professors

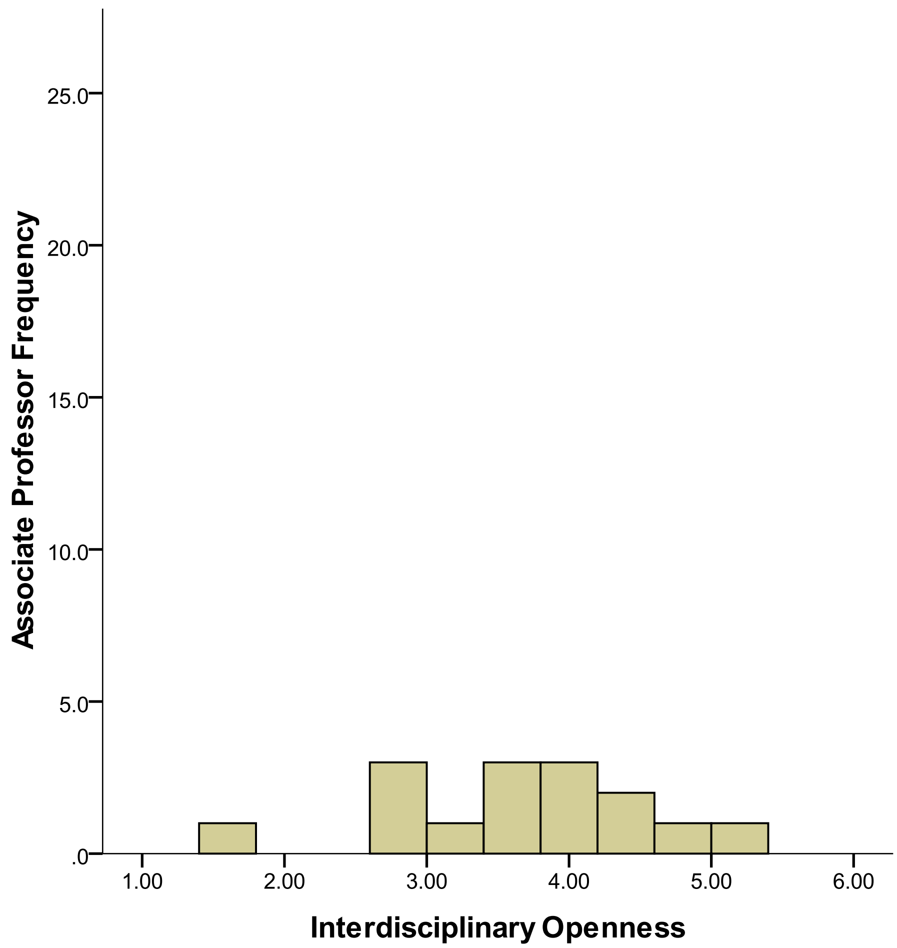

Figure 13. Histogram of Interdisciplinary Openness Scores for Associate Professors

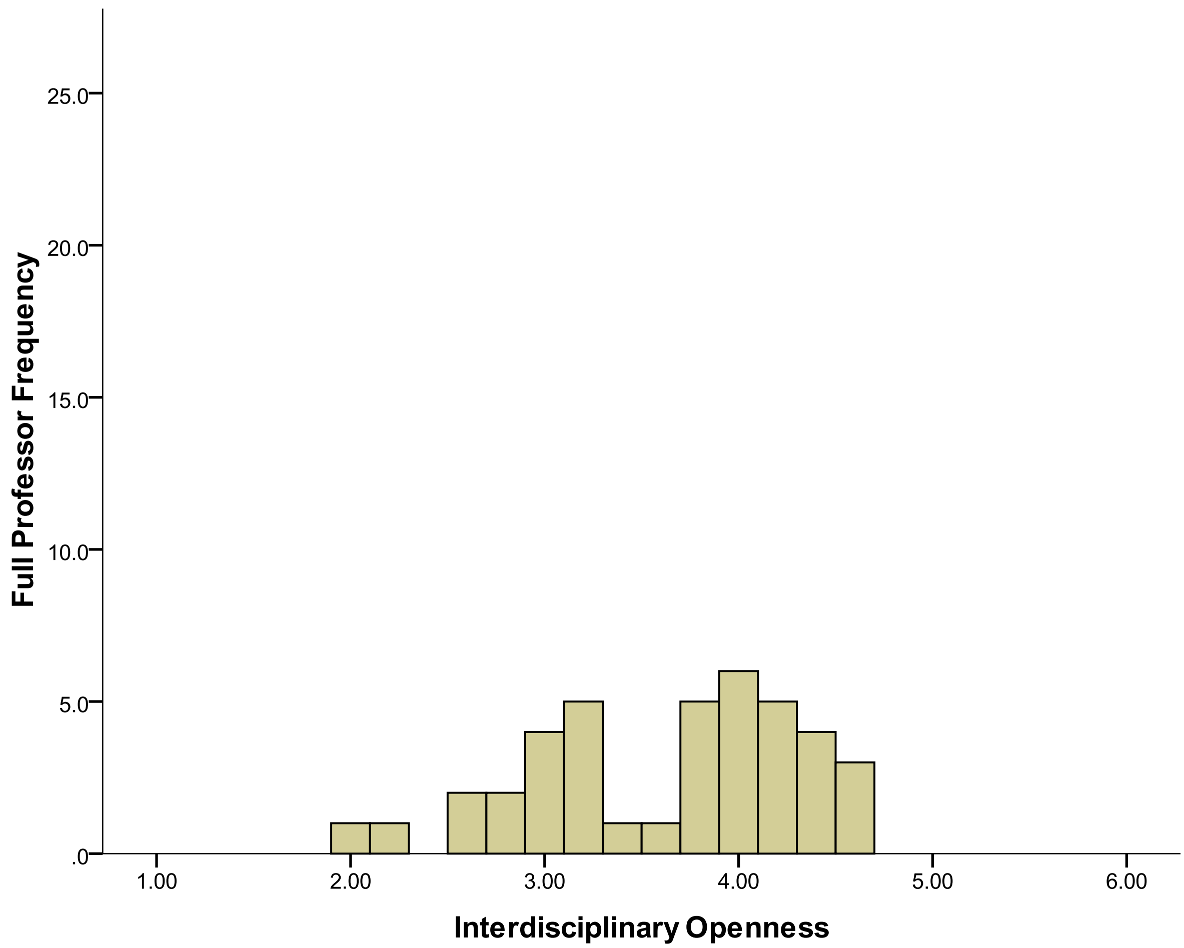

Figure 14. Histogram of Interdisciplinary Openness Scores for Full Professors

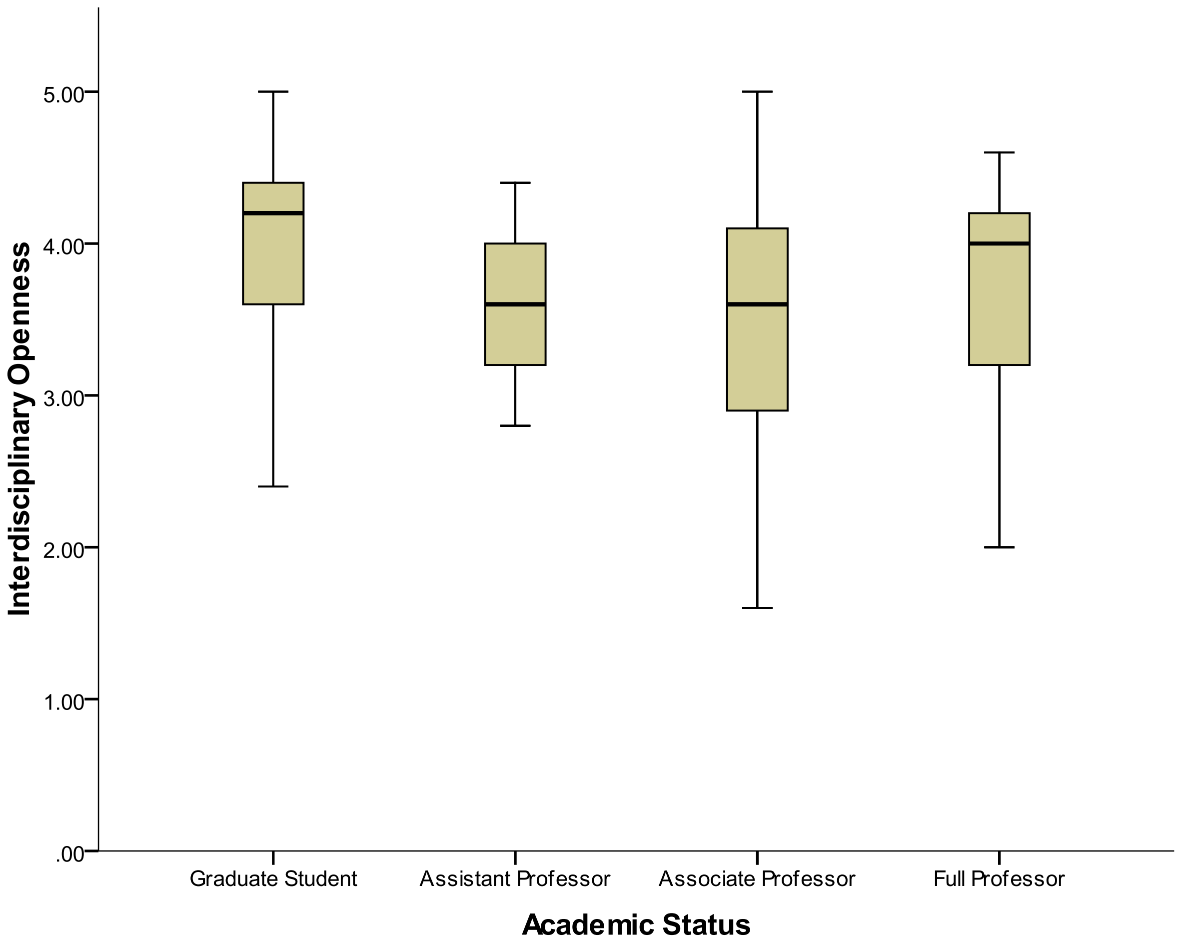

Figure 15. Boxplot of Interdisciplinary Openness by Academic Status for Multiple Regression Analysis Subsample

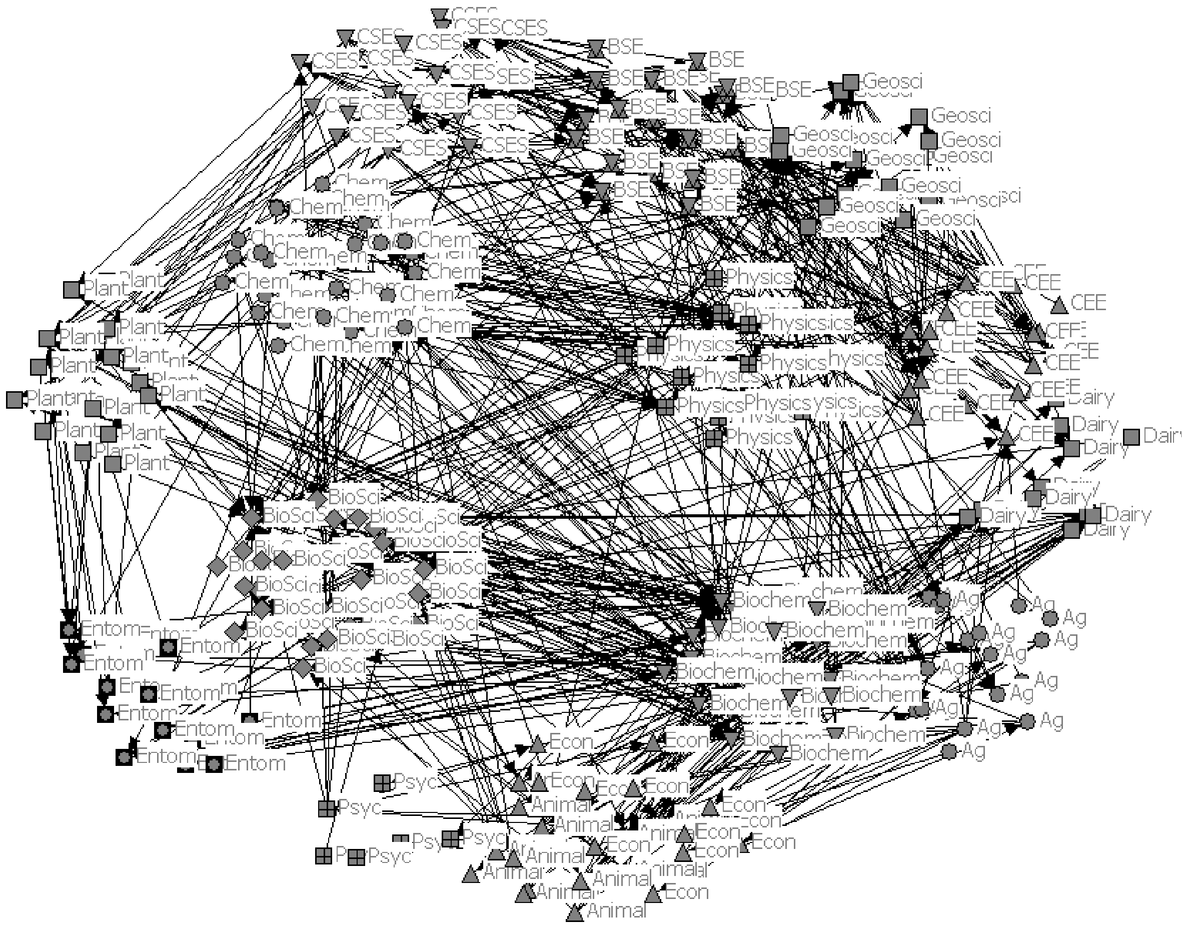

Figure 16. Total network connections for all departments

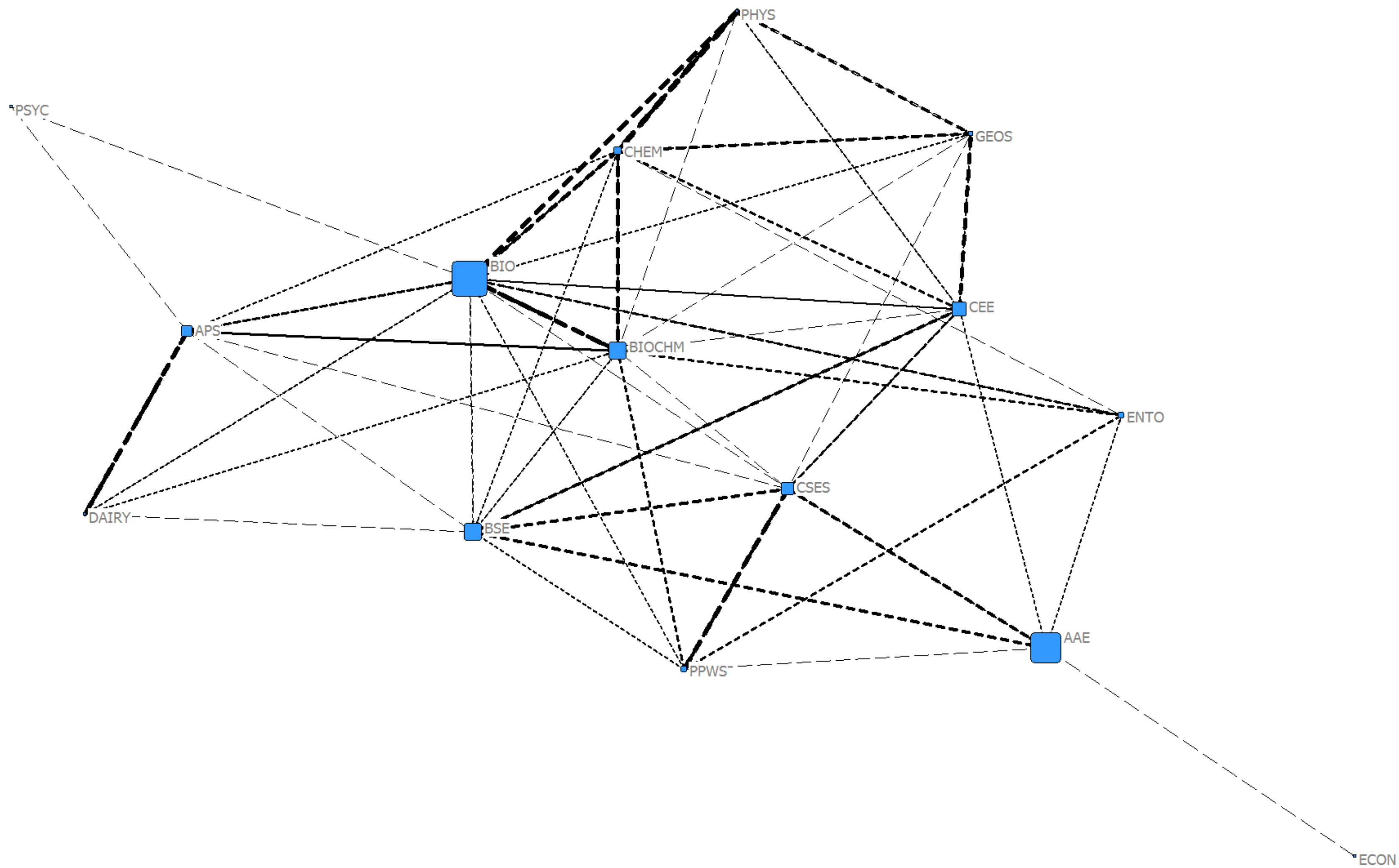

Figure 17. Research connections reported between departments

Appendix A

Survey Items for Individual Epistemology – Applied Focus

Note: Underlined items were used in the final scale.

Respondents were asked to respond to each item of the 4 items using the following scale:

“1”	“2”	“3”	“4”	“5”
Completely Disagree	Slightly Disagree	Neither Agree or Disagree	Slightly Agree	Completely Agree

- My academic discipline focuses on developing pragmatic know-how. [†]
- My academic discipline focuses on mastering the physical environment. [†]
- <u>My academic discipline is entrepreneurial.</u> [†]
- <u>My academic discipline values the development of patents.</u> [†]

[†] These items were derived from Becher, 1994

Appendix B

Survey Items for Interdisciplinary Research Attitudes

Note: Bolded item indicate reverse coding.

Respondents were asked to respond to each item of the 5 items using the following scale:

"1"	"2"	"3"	"4"	"5"
Completely Disagree	Slightly Disagree	Neither Agree or Disagree	Slightly Agree	Completely Agree

- Pursuing interdisciplinary research will strengthen research in my field.
- Interdisciplinary research is needed to advance scientific knowledge.
- Scientific research conducted within one discipline is too narrowly focused.
- **Scientific advances do not require interdisciplinary research.**
- Interdisciplinary research is more creative than disciplinary research.

Appendix C

Calculation of Diversity Impact Factor

Calculating the Diversity Impact Factor is a five step process that seeks to understand how unique a referent group member's connections are when compared to the other members of the referent group. The following outlines the steps for calculation by using the information for the network presented in Figure 4.

In step 1, all of the connection information for a specific referent group (Group A in this example) is entered into blocks, one block for each non-departmental group (Group B and Group C), with each column representing a unique member of the referent group and each row representing a unique non-departmental individual. A value of "1" indicated that a connection was reported by the respondent in the referent group, a value of "0" indicated that a connection was not reported by the respondent in the referent group.

Step 1

	A1	A2	A3	A4
B1	**1**			
B2		**1**	**1**	
B3		**1**		
C1				**1**

In step 2, the relative percentage of total diversity (100%) was calculated for each unique non-departmental group. In this example, diversity at the group level is a function of two non-departmental groups (50-50).

Step 2

	A1	A2	A3	A4		
B1	1					
B2		1	1			
B3		1			**0.500**	
C1				1	**0.500**	
					1.000	Total

In step 3, the species diversity attributable to each non-departmental group (block) was divided among the individuals within each non-departmental group. In this example, the three individuals in group B divided the 50% of the species diversity attributed to Group B into 0.1667 for each individual. The lone individual in Group C received all of the species "credit" for Group C (which reflects that individual C1 is a more rare species specimen than all of the other species specimens).

Step 3

			A1	A2	A3	A4		
	0.167	B1	1					
	0.167	B2		1	1			
	0.167	B3		1			0.500	
	0.500	C1				1	0.500	
Total	1.000						1.000	Total

In step 4, the diversity value assigned to each actor within a block was further divided among the number of reported connections to the actor. This division represents the relative frequency of a reported connection; larger numbers within a block indicate that an individual is connected to with less frequency than another actor in the same group (the connection is more unique). At this point, all of the connections reported by the members of the referent group A have been assigned a relative diversity value (or uniqueness value).

Step 4

		A1	A2	A3	A4		
0.167	B1	**0.167**					
0.167	B2		**0.083333**	**0.083333**			
0.167	B3		**0.166667**			0.500	
0.500	C1				**0.5**	0.500	
						1.000	Total

The final step (5) is to sum the uniqueness of each referent group member's connections.

Step 5

			A1	A2	A3	A4		
	0.167	B1	0.167					
	0.167	B2		0.083333	0.083333			
	0.167	B3		0.166667			0.500	
	0.500	C1				0.5	0.500	
Total	1.000		**0.167**	**0.250**	**0.083**	**0.500**	1.000	Total

These new values (0.083 to 0.500) indicate how unique the overall reported connections of an individual are when compared to the rest of his/her group. Put another way, these numbers indicate the extent to which an individual's reported connections are responsible for increasing the amount of 1) species diversity and 2) within-species diversity, now referred to as the Diversity Impact Factor.

Appendix D

Introductory Letter to University Faculty and Graduate Students

Dr. [Recipient],

I am writing to you as a member of the Virginia Tech research community to request your participation in a brief survey of scientific research perspectives at our University. This project is a component of my dissertation project, and a complement to earlier research conducted with Fellows of the National Academy of Sciences. I believe that Virginia Tech provides an exceptional opportunity to explore some of the questions facing the evolving nature of today's modern research university. Specifically Virginia Tech has the following important characteristics:

- We conduct research across the breadth of science and engineering fields represented within the National Academy of Sciences
- We have a large number of interdisciplinary research initiatives, such as ICTAS, VIGEN and MII
- We have a large number of IGERT programs, such as EIGER, which are NSF funded programs designed to increase interdisciplinary training for Ph.D. students

While I believe that this research is important, I understand that your time is important, so the survey is designed with the following characteristics:

- The survey is designed to require no more than 10 minutes of your time
- You will be asked to respond to 27 statements using a 5 point scale
- You will be asked to select from a few lists of people that you collaborate with at Virginia Tech

In approximately one week, I will send an e-mail labeled "Disciplines and Academic Research Survey" to your Virginia Tech e-mail account. In that e-mail, you will find a link to the Disciplines and Academic Research Survey and a website that will provide additional information about the study. Please know that any survey responses you provide will be held to the highest standard of confidentiality. Thank you for taking the time to consider my request.

Respectfully,

Robert E. Knee, Jr., M.S.
Doctoral Student/IGERT Trainee
Virginia Tech

In Support of,

Roseanne J. Foti, Ph.D.
Associate Professor
Virginia Tech

Appendix E

E-mail with Survey Link

Hello [Recipient Name],

Please forgive the delay in getting this link to you. The first attempt was captured in the spam filter.

When you are ready to complete the survey, please click the following link:

http://www.surveymonkey.com/s.aspx?sm=[UNIQUE LINK INFORMATION]

Thank you again for considering my request and for participating in this research. As indicated in my earlier letter to you, this e-mail provides a link to complete a brief online survey of scientific research and disciplinary perspectives. The survey should take no more than 10 minutes.

If you did not receive the initial letter, you can view an online copy of the letter here: http://mysite.verizon.net/vze75wrq/academicresearch/id3.html

If during the course of completing the survey, or after completing the survey, you have questions or are curious about the subject matter or content of the survey, please visit: http://mysite.verizon.net/vze75wrq/academicresearch/index.html

Respectfully,

Robert E. Knee, Jr.

Doctoral Student/IGERT Trainee

Virginia Tech

Appendix F

Confirmatory Statement

This survey has been approved by the Virginia Tech Institutional Review Board (IRB #07-214).

The survey will ask you to indicate your level of agreement or disagreement with a series of statements, as well as provide information on your research connections within the University.

Some of the items will ask you about interdisciplinary research, which at a minimum, should be considered research that involves collaboration and exchange across "traditional" disciplinary boundaries and training.

When considering these items, please frame them in the context of how your university department operates. Also, there are no correct answers, so please respond with your first impression.

The three statements below explain the conditions under which the survey data is being collected.

1. You are being asked to voluntarily participate in a survey on science and research practices and you may exit this survey at any time.

2. All identifying information will be removed prior to analysis of the responses, and your name will not be shared with anyone outside of the researchers.

3. Aggregate data may be presented to other researchers, conferences, or journals.

Please select one of the following options:

I understand the above information and choose to continue with the survey.

I do not want to participate in the survey.

Appendix G

Coding Scheme for Departmental ID Numbers

Department	Code
Agricultural and Applied Economics	20
Animal & Poultry Sciences	30
Biochemistry	40
Biological Sciences	50
Biological Systems Engineering	60
Chemistry	70
Civil and Environmental Engineering	80
Crop and Soil Environmental Sciences	90
Dairy Science	25
Economics	55
Entomology	45
Geosciences	65
Physics	35
Plant Pathology, Physiology, and Weed Science	75
Psychology	85