A MIXED METHOD APPROACH FOR IMPROVING TEAMS BY REDUCING BARRIERS TO COLLABORATION, RECOGNIZING TEAM SCIENCE, IDENTIFYING EMERGING FIELDS, AND EVALUATING THEIR IMPACT ON THE PUBLIC

By

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To team science
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By
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Scientific innovation requires research collaborations across disciplines. This study analyzes team science through an ethnographic lens. A mixed method approach was used to explore how organizational culture at a university, college, and departmental level shapes its collaboration networks. These methods include social network analysis, surveys, semi-structured interviews, text analysis of secondary sources, online profile analysis, usability testing, and participant observation. This mixed-method process identified key barriers to collaboration, examined how the tenure process shapes researchers’ attitudes towards collaboration, proposed a new method for building new research teams in emerging fields, and measured the impact of science on the public. This study also proposed suggestions for promoting collaboration, identifying emergent scientific fields, increasing research impacts beyond academia, and reducing barriers to team science at universities. These findings can be applied to evaluate and improve team functioning at universities, companies, or government agencies.
CHAPTER 1
INTRODUCTION

Overview

Teams are critically important to the advancement of science and society. Scientific trends in publications and grants illustrate a clear rise in team science. Over the past fifty years, single author publications have steadily declined and multi-authored publications have rapidly increased. Previous studies have demonstrated the role of team science in improving research outcomes, scientific productivity, and progress on addressing complex problems. This study builds upon this previous work and the assumption that teams are critical to the advancement of science and society by observing and testing how teams operate in an academic environment. This assumption is based on past research in both academic and non-academic settings that highlights the role and increasing dominance of teams in the generation of new scientific knowledge. (Uzzi et al. 2013) Therefore, this dissertation begins with a brief overview of the impact that collaboration has on increasing research productivity, scientific discoveries, and other outcomes.

Previous studies have quantified the impact of collaboration by comparing the number of publications and grants produced by research teams and individual researchers. Bibliometric studies demonstrate a clear and continued increase across disciplines in the number of co-authored publications. (Sonnenwald, 2007; Hunter & Leahey, 2008; Cronin, 2005; Cronin, Shaw, & La Barre, 2003, 2004) Other studies have also demonstrated that co-authored publications have higher citation rates and scholarly impact in their fields. (Persson, Glanzel, & Danell 2000; Uzzi et al., 2013) As a result of these trends, research funding agencies like the National Institutes of Health (NIH) and...
National Science Foundation (NSF) have significantly increased their financial support for team science over the past decade.

Collaboration also increases the speed of the research process, scope of the project, and reliability of its findings. Across disciplines, scientific collaboration has become more necessary due to the increases in the complexity of scientific problems, size and availability of data, research specialization, cost of equipment, and speed required to identify solutions to these problems. (Katz & Martin, 1997) Certain research problems, especially those in the health sciences, often necessitate a team approach. Collaboration also often enhances a project’s academic rigor and research productivity, which positively impacts the quality and speed of science. Team based science can also help to increase the project’s societal impacts and student’s job placement.

Research is increasingly becoming more team-based in academic, industry, and government settings. This team focus requires new tools for improving collaborations between researchers and removing organizational barriers. Researchers experience many challenges throughout the collaboration process. The process of transitioning from forming a new team to generating and disseminating research findings requires high levels of team functioning, clearly defined roles, and soft skills like communication and empathy. Most universities and disciplines do not emphasize these types of skills in their graduate training. Thus, mentors play an important role in modelling collaboration norms behaviors for their students. New approaches can help to increase organizational performance, team functioning, and individual productivity. Organizational culture, disciplinary training, advice from mentors, and individuals’ past experiences working in teams also shape researchers’ desire to collaborate and team’s outcomes.
This dissertation identifies variables that promote and inhibit team science. This study builds on the assumption that teams are critical to the advancement of science. We are interested in examining collaboration because previous literature has shown that it leads to increased productivity and better research outcomes. For example, many studies have found that coauthored publications are correlated with higher citation rates. Other studies have found correlations between team science and increases in publications, patents, and grants. In addition, teams are necessary to solve particular problems, especially complex multi-faceted research issues.

These variables are broken down into four chapters that each look at different aspects of scientific collaboration within a single university. This case study examines team science holistically. It also enabled me to identify the role that organizational culture plays in shaping researchers’ attitudes towards team science. My goal for this dissertation was to improve researchers’ experiences collaborating and translating their findings to a broader audience. I address this goal by examining how a university’s organizational culture shapes scientific collaboration practices and identifying the norms and processes that incentivize or dis-incentivize team science and public engagement. This question has great scientific importance because research collaboration networks are a crucial channel for the diffusion of knowledge and innovation across scientific fields and between academia, government, and industry.

This dissertation combines four studies that examine researchers’ experiences working in teams, applying for tenure and promotion (T&P), identifying new collaborators, and disseminating their findings. It adopts a mixed method approach for analyzing the role that organizational culture plays in shaping scientific collaboration.
networks and individual researcher’s experiences working in teams. Combining qualitative and quantitative methodologies, data sources, and theories from the traditions of ethnography and social network analysis adds new dimensions to the field of team science. The results of these studies can be used to improve universities’ recognition of teams, encouragement of scientific collaboration, construction of teams in emerging fields, and prioritization of public engagement.

Social networks play an important role in shaping the structure and norms of team science. A researcher’s position within their organization’s scientific network shapes their choice of collaborators, access to information, and utilization of resources. Researchers located in the center of their organization’s collaboration network typically have increased options and access to more resources than those located in the periphery. This can have implications for organizational retention and faculty engagement. Organizational culture also plays a major role in setting the parameters of what practices and achievements are recognized and rewarded by the university.

In this dissertation, I will present the results of four studies that propose new methods for identifying barriers to collaboration, recognizing team science in the T&P process, creating teams in emerging scientific fields, and evaluating faculty engagement with the public. The primary goal of this dissertation is to understand the collaboration landscape on a particular campus in order to extrapolate this knowledge to improve team dynamics in other settings. These studies’ results and recommendations can be translated to improve team dynamics and performance evaluation at universities and other organizational settings. They also provide a mixed method research template for studying teams within an organization. This work contributes to the fields of team
science, social network analysis, translational science, evaluation science, and user experience (UX) research by presenting new approaches for assessing how organizational culture shapes team dynamics and researchers’ collaboration experiences. On a broader level, it highlights the role that teams play in the production of scientific knowledge. It also demonstrates the role that social networks play in shaping scientific norms.

**Team Science**

Over the past fifty years, there has been a major shift in scientific norms. Teams dominate the current research landscape of most scientific fields. Teams rather than individuals are also increasingly responsible for most major scientific discoveries and high-impact publications. (Börner et al., 2010) This means that across all disciplines larger teams are publishing more frequently and producing new types of scientific knowledge. (Jones et al., 2008) This has also caused an increase in the development of new methods, concepts, and types of interdisciplinary collaborations. (Dhand et al., 2016) Scientific teams naturally bring together different theories of knowledge and methodological expertise from each collaborator’s discipline and specialty within that discipline. Therefore, it is more likely that teams will combine different types of knowledge than single authors. (Wuchty et al., 2007)

There has also been a huge growth in the interdisciplinary study of collaboration and team dynamics. These changes led to the development of a new field centered around studying the science of team science (SciTS). (Stokols et al., 2008a; Stokols et al., 2008b; Börner et al., 2012; Falk-Krzesinski et al., 2011) However, research on scientific collaboration is not new. In 1944, Brozek and Keys published one of the first articles on this topic in *Science* and wrote that,
"The interdisciplinary approach is becoming one of the prominent characteristics of [science] and represents a synthesizing trend which focuses the specialized research techniques on problems common to a number of separate disciplines. Such cooperative research has to overcome serious obstacles when operating within the existing departmentalized framework of the universities. It appears that real progress in this direction will be made in institutions which are organized on a permanent and frankly cooperative basis. Psychologically, interdisciplinary research requires not only abstract, theoretical intelligence…, but also 'social intelligence.' Cooperative work is a social art and has to be practiced with patience."

This article was one of the first to highlight the challenges of organizational structure and interpersonal differences. It emphasizes the role that universities' tacit norms, individually focused reward structures, and departmental focus serve in creating institutional barriers for interdisciplinary scientific collaboration.

**Collaboration Thresholds**

Granovetter's threshold model of collective behavior can help to examine the dramatic cultural shifts in scientific collaboration norms in disciplines and universities over the past fifty years. (Granovetter 1978) Granovetter's threshold model can be applied to the specific decision of whether or not to collaborate with another researcher because it is binary decision where the potential costs and benefits are dependent upon the number of other scientists who decide to collaborate (Figure 1-1). Granovetter defines an individual's threshold as "the proportion of the group he would have to see join before he would do so." (Granovetter 1978: 1422)

On one side of the spectrum, an innovator or radical researcher has a low threshold. This means that they will be one of the first researchers to collaborate because they emphasize the potential benefit of producing innovative research findings over the potential costs of not being recognized by their peers or university. These
individuals are the early collaborators who started collaborating far before federal funding agencies started emphasizing scientific collaboration.

On the other side of the spectrum, a conservative researcher has a high threshold. This means that they will be one of the last researchers to collaborate because they emphasize the potential costs of not being recognized by their peers or university over the potential benefit of producing innovative research findings. These individuals are the late or non-collaborators. Late collaborators typically start collaborating after seeing funders or universities start to prioritize scientific collaboration. Non-collaborators continue not to collaborate either due to a lack of rewards for collaboration from their university or due to no personal interest in collaborating. Those who do not see the value of scientific collaboration regardless of the circumstances have a threshold of 100%. It would be difficult to create incentives to get these researchers to collaborate. However, researchers with a high threshold that is lower than 100% could be convinced to collaborate if provided the right circumstances and incentive structures. Thus, these individuals should be the primary target of organizational programs to promote and reward collaboration.

Each of these positions are rational based on the individual's perception of the aggregate costs and benefits of collaborating with other researchers. However, researchers’ differential weighting of the combination of their perceived costs and benefits causes them to make different decisions. This means that each group of researchers will start collaborating during distinct time frames. Many researchers fall somewhere in between these two ends of the spectrum. Differential collaboration thresholds occur due to differences in pre- and post-doctoral training and mentorship,
disciplinary norms, organizational norms, social network structure, tenure status, career level, gender, race, and personality traits. All researchers who collaborate share the belief that the sum of the team is greater than the individual. However, each researchers’ specific motivations for joining a particular team at a certain time are distinct and highly individualistic.

Once a researcher decides to collaborate, they must also make a series of non-binary decisions. For example: Who will I collaborate with? How frequently will I collaborate? What types of projects will I collaborate on? What will be my level of collaboration? What will be my role in this collaboration? How will our team resolve conflict over authorship and other critical decisions? These decisions are driven by a combination of a series of individual beliefs, group norms, and institutional limitations.

This dissertation examines the collective patterns which have emerged from the literature on this topic and identifies strategies to increase the perceived benefits of scientific collaboration among researchers with high, but not absolute thresholds in order to promote collaborative activities. While I do not explicitly measure thresholds in this dissertation, I used this threshold concept to determine who to interview for these studies and categorize interviewees’ level of collaboration and attitudes towards team science. This dissertation will also provide suggestions for offering resources and services to faculty members to assist them in making these types of decisions.

**Disciplinary Collaboration Norms and Interpersonal Barriers**

Working in interdisciplinary teams can provide researchers with greater access to resources, more funding opportunities, higher productivity levels, and access to a broader range of knowledge sources. Federal funding agencies including the National Science Foundation (NSF) and National Institutes of Health (NIH) have also recently
increased their support for interdisciplinary research. As a result of these changes in funding and the increase in specialization of research skills, science is increasingly becoming more interdisciplinary. (Sonnenwald, 2007; Katz and Martin, 1997) However, differences in disciplinary norms, values, communication styles, training, and terminology can present barriers to interdisciplinary collaborations.

Levels of collaboration vary greatly by disciplines due to different disciplinary training and cultural norms. Researchers in disciplines in the humanities tend to collaborate less, publish more single author books, and place less emphasis on grant funding. Their graduate training and mentorship norms often emphasize solo research where graduate students develop their own research agenda and apply for their own funding.

Researchers in natural or basic science disciplines are typically based in a lab setting. As a result, they tend to collaborate more, have greater specialization, contribute to multiple author publications, and have a greater emphasis on federal grant funding with multiple investigators. Graduate training in the basic sciences typically emphasizes collaborative research within and between labs. Graduate students typically develop their own research project within the larger agenda of the primary investigator (PI) of the lab. They also usually have funding through their advisors’ grants and often apply for grants with their mentors. Some disciplines in the natural sciences have traditionally been better at engaging in interdisciplinary collaborations than others due to the nature of their research, training, and disciplinary culture. (Dhand et al., 2016) Disciplines in the social sciences often combine a mixture of these two approaches. In
these disciplines, the mentor’s scientific orientation often determines whether they train their graduate students in the humanities versus the natural sciences model.

Interpersonal differences can also lead to team conflict. Previous studies on reducing interpersonal barriers to collaboration have found that high levels of patience, strong communication, training in conflict management, and social intelligence can help to reduce interpersonal barriers and enhance a team’s effectiveness. (Kozlowski & Ilgen, 2006) Reducing barriers to interdisciplinary scientific collaboration requires simultaneous action on an organizational, disciplinary, and interpersonal level.

**Differences Between Single-Author and Team Publications**

Team publications differ from single authored publications in multiple ways. Single authored work is typically more theoretical, whereas experimental research often requires collaborations due to the requirement of different specializations and costly equipment. (Katz & Martin, 1997) Other studies have found that co-authored publications are more likely than single authored papers to be published in high impact core journals and have longer durations of citation relevancy. (Sonnenwald, 2007; Beaver, 2004) However, many teams disband prior to publishing their findings. (Cummings & Kiesler, 2008) Disciplinary differences, interpersonal conflict, geographical distance, and other factors pose significant challenges for teams.

Collaborating with a team on a research project also often influences the writing process and audience of the publication. Teams conceptualize and approach problems differently than individual researchers do. (Salas & Fiore, 2004) As Sonnenwald (2007) writes,

Co-authors contribute different types of knowledge and collaborative work may foster more rigorous review of the papers, thus increasing the quality of the final publication. Moreover, co-authors can increase the visibility of
a paper when they share information about it in conference and workshop presentations, discuss it informally with colleagues, and distribute preprint to colleagues. This increased visibility may also lead to higher citation rates.

These differences can influence who cites the paper, what fields circulate the findings, how the results are referenced in these fields, and how often other scientists cite it.

The increased visibility of team science publications due to the network multiplier effect plays a major role in determining the impact of an article. This means that when scientists collaborate on a project each collaborator shares their findings with members of their research network who in turn share it with their network. As a result, many more researchers are aware of the article than if the project was conducted by one researcher. This added awareness and diffusion of scientific findings typically leads to additional citations and the perception of a higher impact paper. Scientists who collaborate are also more likely to cite each other’s collaborators, as well as their network of colleagues and mentors. Therefore, the odds of producing a high impact paper increase as the number of collaborators increase. This also relates to the Matthew effect, which highlights the role that laws of power play in increasing disparities in recognition for scientific discoveries between well established and relatively unknown researchers. (Perc, 2014)

**Collaboration and Anthropology**

The field of anthropology has not traditionally examined the topic of scientific collaboration. Collaboration norms in anthropology departments have also varied greatly by subfield. Most of the anthropological literature on collaboration focuses on the topics of collaborative ethnography, participatory action research, and other types of engagement with stakeholders in their research site. (Rocheleau, 1994; Dickson &
Green, 2001; Williams & Lykes, 2003; Lassiter, 2001; Mohatt, 2004; Lassiter, 2005) This type of research aims to bridge the power gap between researchers and the communities in which they work by adopting collaborative approaches for designing and conducting research in the field.

Other work by anthropologists uses critical theory to examine the nature of science and technology and its influence on society. (Latour, 1987; Haraway, 1991; Pfaffenberger, 1992; Downey & Dumit, 1997; Traweek, 2009; Latour, 2012; Latour & Woolgar, 2013) This research seeks to provide a cultural critique of science by describing the lives of scientists and questioning its objectivity. However, my studies are distinct from these two traditions in that they analyze how organizational culture shapes scientific collaboration with the aim of generating solutions that will reduce barriers to collaboration, translational research, and innovation at universities.

Anthropology can contribute a cultural and people-centered perspective to the study of scientific collaboration. Many studies of scientific collaboration focus on using big data (authorship, citation, and grant data) to analyze scientific collaboration networks or surveys to learn about teams. (Uzzi et al., 2013; Sonnenwald, 2007) These methods provide valuable data and are an excellent starting point, but when used alone they are not able to tell the entire story of scientific collaboration. The cultural aspects of collaboration are largely absent from the literature on this topic.

One of anthropology’s greatest strengths is that it helps explain the messiness of human behavior and culture in ways that other disciplines like organizational behavior often ignore. As Czarniawska-Joerges (1992) writes,

An anthropologically inspired organization theory would be.... an interpretation of organizational processes from the standpoint of the actors
involved, collected and retold by the researcher (also representing a certain standpoint). It would be a polyphony of voices from inside rather than an aerial picture taken from the outside. (4)

This worldview helps anthropologists address complex organizational problems. Ethnography emphasizes the role of researchers fully immersing themselves into a culture to get to the root of complex cultural processes. This approach requires anthropologists to listen to the perspectives of multiple stakeholders, compare responses, and be open to try different approaches to address complex issues in a variety of organizational contexts.

Adopting an ethnographic approach can help to broaden the study of scientific collaboration. This approach can add to existing studies by analyzing the role that organizational culture, disciplinary training, and personal preferences play in shaping these processes. This type of ethnographic understanding of networks is critical to developing interventions to increase scientific collaboration. (Valente et al., 2015) Ethnographic perspectives and methods can help the field verify whether network visualizations represent real collaborations, explain what is missing from the current models, and identify alternative collaboration metrics. They can also create more complete networks of scientific influence through understanding factors that shape individual practices and organizational norms around team science and analyzing the underlying cultural processes that are shaping scientific collaborations.

Research Setting

The University of Florida (UF) is a large public research university based in the southern United States. The campus spans 2,000 acres with over 900 buildings. The colleges of medicine and agricultural and life sciences also have many researchers located across the state of Florida due to their clinical and extension research
appointments. There are 5,136 full-time faculty members, 2,616 of which are tenured or tenure-track, and approximately 50,000 students. The university has 16 colleges and 132 departments. The colleges vary in size from nursing’s 11 to agricultural and life sciences’ 444 tenured or tenure-track faculty members. They also vary significantly in their missions, research emphasis, and metrics for evaluating faculty members’ achievements and team science.

The university’s large size and broad research scope has created a competitive yet highly collaborative research environment with many opportunities for interdisciplinary engagement. However, this organization’s large size and diverse administrative requirements and procedures at the department, college, or academic unit level can create barriers to scientific research and collaboration, as well as differential access to resources and services. Integration into this large scientific research community can be especially overwhelming for new faculty members, those trying to create a new research team, or those seeking collaborations across colleges.

Recently, many efforts have been made at UF to increase scientific collaboration and innovation. Specifically, the university has devoted financial resources to support team science through creating a preeminence program to hire interdisciplinary faculty members and an informatics institute to support innovations in data science. The UF Clinical Translational Science Institute (CTSI) was also established in 2008 as a result of funding from the National Institutes of Health (NIH) National Center for Advancing Translational Sciences (NCATS) program. This institute provides resources for increasing the translation of scientific findings from researchers’ laboratories to clinicians’ practice and patients’ communities, as well as reducing barriers to
interdisciplinary collaboration. The institute has played a major role in increasing research collaboration in the health sciences at UF. UF has also provided seed grants and increased access to shared resources to encourage new collaborations between researchers. Tenure and Institutional Review Board (IRB) taskforces were also established to examine administrative processes, identify potential barriers, and provide recommendations for more appropriately recognizing team science.

Through the efforts of these recent initiatives, scientific collaboration has increased at UF. (Vacca et al. 2015) This project occurred as a result of a need to evaluate progress on these fronts, as the university acknowledges that many barriers to collaboration still exist. Our goal was to identify key barriers to research and collaboration in order to help the university better address and minimize these challenges in future initiatives. This paper will also help to expand the conversation around team science at UF and other universities, develop new efforts to reduce the barriers highlighted in this dissertation, recognize researchers for their scientific collaborations, and reward research impacts beyond academia.

**Methodological Overview**

This dissertation uses data from twenty months of participant observation, two surveys (n=914, n=514), social network analysis of publication and grant data (nodes: ~28,000, ties: ~189,000), thirty-two semi-structured interviews, and textual analysis of secondary sources to analyze how organizational culture shapes scientific collaboration at universities. This mixed method approach allowed me to compare findings, verify the insights gained from each method, and eliminate mono-method bias. (Creswell & Clark 2011; Bernard 2006; Kline 2008; Messick 1989)
This approach also helped me answer different types of questions about the nature of scientific collaborations at research universities. All of the data collected for my project was observational. However, it has laid the groundwork for a network intervention with an experimental design (described in chapter 4) that my collaborators in the UF CTSI network science group and I have designed for the CTSI pilot award distribution and other projects. This combination of methods allowed me to cultivate multiple perspectives on scientific collaboration norms among researchers at the UF.

**Dissertation Overview**

Chapter 2 highlights the major barriers to research and collaboration at universities. Chapter 3 examines how faculty reward systems at universities evaluate team science. Chapter 4 explains how network ethnography can be adopted to identify emerging research fields and create new research teams. Chapter 5 explores methods for increasing engagement between scientists and the public. Chapter 6 provides a discussion of these results and suggestions for implementing these findings at other universities.

![Scientific collaboration thresholds](Figure 1-1. Scientific collaboration thresholds)
CHAPTER 2
IDENTIFYING BARRIERS TO RESEARCH AND SCIENTIFIC COLLABORATION AT UNIVERSITIES

Overview

Scientific research has shifted towards a team based approach. The literature on team science (Stokols et al., 2008b; Börner et al., 2010; Falk-Krzesinski et al., 2010; Vacca et al., 2015) emphasizes the role that collaborative interdisciplinary research can play at addressing complex multidimensional problems. High levels of interdisciplinary collaboration between laboratory, clinical, and applied scientists have led to increases in scientific innovation and translation. Research collaborations require scientists to share resources (e.g. knowledge, funding, equipment, staff) and work together toward a common goal (e.g. grant, paper, research finding). Scientific collaborations vary greatly by the length of time researchers spend working together, the scale of the project, each team member’s role, and their level of contribution. (Katz & Martin, 1997)

Scientific collaborations require additional resources and coordination between researchers. This causes researchers to experience additional research barriers, especially communication failures. The literature on scientific collaborations (Brozek & Keys, 1944; Beaver & Rosen, 1978; Beaver & Rosen, 1979; Chompalov et al., 2002; Barabási et al., 2002; Hara et al., 2003; Bozeman & Corley, 2004; Sonnenwald, 2007; Leahey, 2016) has explored some of the barriers to collaborative research. These barriers center around issues related to distance (Olson & Olson, 2003), communication (Sonnenwald, 1995), coordination (Montoya-Weiss et al., 2001), regulations (Axelsson & Axelsson, 2009), funding (Beaver, 2001), and disciplinary distinctions. (Thompson, 2009; Van Rijnsoever & Hessels, 2011)
Organizational culture also plays a major role in shaping a university’s collaboration culture. The field of organizational culture has its roots in both anthropology and business, but also draws from sociology, psychology, and other disciplines. (Schein, 2010) All of an organization’s shared knowledge, rules, norms, stories, myths, rituals, jargon, physical arrangements, humor, politics, and relationships come together to form the organization’s culture. (Martin, 2001; Schneider et al., 2013) As Martin (2001) explains,

When organizations are examined from a cultural viewpoint, attention is drawn to aspects of organizational life that historically have been ignored or understudied, such as the stories people tell to newcomers to explain ‘how things are done around here,’ the ways in which offices are arranged and personal items are or are not displayed, jokes people tell, the working atmosphere the relations among people, and so on. (3)

This combination of items, symbols, and relationships creates a complex picture that can be difficult to decipher.

Organizational cultures are the distinct product of the people, practices (formal and informal), and processes (both micro and macro on daily, quarterly, yearly, or other scale) that make an organization. Though many similarities can be drawn between organizations, each one is different in its own way. These cultural differences result from an organization’s history, administrative processes, goals, and location in combination with the backgrounds, perspectives, preferences, and experiences of its current and past employees. Studying an organization’s history and culture helps researchers understand its current priorities, decisions, and issues and plan for the future. In this study, I combined an organizational survey with interviews with faculty members to ethnographically examine the university’s organizational culture in order to describe its research and collaboration culture.
This paper identifies barriers to research and scientific collaborations in university settings. It also analyzes how these barriers vary across colleges within a university and uses survey data to examine their organizational prevalence. This paper analyzed data gathered from an online survey (n=913) and semi-structured interviews with researchers and administrators (n=32) to identify key barriers to research and scientific collaboration at a large public university. The findings and themes identified in this in-depth case study can also be extrapolated or replicated by other colleges and universities.

First, I provide an overview of the methods used in this paper and explain why I chose this approach. Second, I examine how barriers to research vary by college using an ANOVA analysis of respondents’ research barriers scores. Third, I analyze the seven categories of barriers identified in this study, identify subcategories, examine their prevalence, use quotes from respondents to highlight key trends, and provide suggestions for reducing these barriers. Finally, I conclude the paper with a discussion of the study’s results and suggestions for minimizing these barriers at universities.

**Methodology**

This paper is part of a larger ethnographic study of scientific collaboration and organizational culture at a large public university in the United States. I used data from an online organizational survey and semi-structured interviews to identify barriers to research and scientific collaboration.

The university’s annual research collaboration and barriers survey was distributed through Qualtrics to 2,380 researchers based at the same university in September 2015. This survey collected data on respondents’ knowledge of institutional programs and services, as well as their research and collaboration experiences. There
were 913 survey respondents between September 8th and 30th (810 completed the survey and an additional 103 completed at least one question) with a response rate of 38.5%. (AAPOR Response Rate 2, 2016)

I conducted semi-structured interviews with thirty-two researchers and administrators from eight colleges and three campuses about their experiences with scientific collaboration and research barriers. These researchers were selected using social network analysis (SNA) of collaborative grant funding data (approximately 5,000 researchers, 189,000 collaborative connections between scientists) using UCINET and NetDraw between the period of January 2010 and November 2015 (n=25) or recommendations from interviewees (n=7). SNA allowed me to compare colleges' collaboration network structures and identify researchers from each college with the highest number of collaborative grants during this period to interview for this project.

This approach allowed me to incorporate insights gained from survey data into the study’s interview questions. Each respondent was asked questions on the same general themes, but the interviews varied in depth, length, and focus based on their answers. Participants were interviewed for approximately an hour about their current and previous scientific collaboration experiences. These interviews were focused on the themes of past decisions about choosing potential collaborators, reaching out to potential collaborators, finding mentors, forming teams, setting team goals, coauthoring grants and publications, maintaining team communication, completing interdisciplinary projects, assigning credit for collaborative research, managing team conflicts, and dealing with a variety of other issues that arise when researchers engage in team
science. These conversations helped me to cultivate a better understanding of the intersections between barriers to research and scientific collaboration.

Quantitative Survey Results

The survey found that the majority of respondents felt they had sufficient opportunities to collaborate with other researchers across the university. Yet, they were overwhelmingly interested in building new research collaborations. Most respondents were interested in using a “matchmaking” service to identify potential collaborations. However, this percentage was 24% less than those interested in building new research collaborations (Table 2-1). This means that “matchmaking” services could be a promising means of promoting scientific collaboration, but additional options need be identified.

Researchers’ ideal level of collaboration was higher than their current level of collaboration. Most respondents identified their current level of collaboration as working with a few researchers from different departments across the university but their ideal level of collaboration was working with a large number of researchers from this and other institutions or organizations (Tables 2-2 and 2-3). This means that on average researchers would like to be collaborating more than they currently do.

The survey also asked respondents to rate a series of five potential barriers to collaboration on a five point Likert scale, with one being strongly agree and five being strongly disagree (Table 2-4). The statement with the highest mean score was “the [university’s] business model poses financial barriers to collaboration.” Respondents from the college of education identified this statement as the greatest barrier to collaboration (Table 2-5). This highlights the role that organizational culture plays in
collaboration norms and practices. This finding concurs with the qualitative survey analysis which I will explore later in this article.

Data Analysis of Barriers to Research by College

A one-factor analysis of variance (ANOVA) with fixed effects was used to examine whether a research barriers score is a function of college. The independent variable college represented nine colleges: 1) agricultural and life sciences (AG), 2) dentistry (DN), 3) education (ED), 4) engineering (EG), 5) public health and health professions (HP), 6) liberal arts and sciences (LS), 7) medicine (MD), 8) pharmacy (PH), and 9) veterinary medicine (VM). The samples from the other seven colleges were too small for analysis (n < 20), so they were not used in this model.

The research barriers score based on faculty members’ perceptions was rated on a summed scale of 10 to 50. This series of questions asked respondents “To what degree is each of the following a barrier in conducting your research?” Respondents rated the barrier on a five point Likert scale, with one being not a barrier and five being an extreme barrier. Human subjects (IRB) submission and approval was rated by respondents as the highest barrier to research (Table 2-6).

A one-factor analysis of variance (ANOVA) with fixed effects was also used for each question to examine whether each of the ten barriers are also a function of college. The results indicate a statistically significant difference in perception of barriers for all ten questions between the nine colleges. Researchers from colleges in the health sciences (DN, HP, MD, PH, VM) had the highest mean research barriers score (Table 2-7). Table 2-8 provides the mean and standard deviation for each college’s research barriers score, the total number of respondents from each college who had a research barriers score, and the number who completed the survey. In order to have a research
barriers score, the respondent must have responded to all ten questions about barriers to research.

My hypothesis is that barriers scores vary across colleges.

H0: \( \mu_{AG} = \mu_{DN} = \mu_{ED} = \mu_{EG} = \mu_{HP} = \mu_{LS} = \mu_{MD} = \mu_{PH} = \mu_{VM} \)

H1: At least one \( \mu \) is not equal to \( \mu \) of the other colleges

This model examines the mean differences in barriers score between colleges. The ANOVA model allowed me to partition the variance in the data into two parts: variance associated with mean differences between groups (between-group variability) and variance not associated with differences between groups (within-group variability).

Results of ANOVA

The tests for normality indicate that the data were approximately normally distributed. All survey participants were assigned to one and only one college and the sampling of these participants was independent. Therefore, the assumptions of independence have also been met. However, Levene’s test showed that the homogeneity of variance assumption was not met (\( F(8, 616)= 2.83, p=.004 \)). Therefore, I performed a Welch test. This provided a more robust test of equality of means.

The Welch test indicates that there is a statistically significant difference in barriers scores somewhere between the nine groups (\( \eta^2 =0.15, F(8, 122.567)=14.07, p<.001 \)). This means that approximately 15% of the variation in perception of research barriers score is attributable to differences between the nine colleges. Therefore, I reject the null hypothesis and conclude that barriers score varies, in part, as a function of college.

Tahame and Dunnett T3 post hoc tests were conducted, and both were in agreement of the following pairwise differences between colleges. AG had a statistically
significantly lower mean barriers score than HP, MD, and VM. DN did not differ significantly in mean barriers scores from the other colleges. ED did not differ significantly in mean barriers scores from the other colleges. EG had a statistically significantly lower mean barriers score than HP, MD, and VM. HP had a statistically significantly higher mean barriers score than AG, EG, and LS. LS had a statistically significantly lower mean barriers score than HP, MD, and VM. MD had a statistically significantly higher mean barriers score than AG, EG, and LS. PH had a statistically significantly higher mean barriers score than LS. VM had a statistically significantly higher mean barriers score than AG, EG, and LS.

These findings reveal that research barriers vary significantly across colleges. They also revealed two separate groups of colleges that experience similar barriers to research. Faculty in the health sciences (HP, MD, PH, and VM), with the exception of DN, report experiencing the highest average research barriers score (Table 2-8). This difference may be partially explained by the increased regulatory requirements of the Institutional Review Board (IRB), Institutional Animal Care and Use Committees (IACUC), Research Administration and Compliance (RAC) office, and ClinicalTrials.gov for health-related research, especially in clinical trials. Faculty in AG, EG, and LS report experiencing the lowest average levels of research barriers. DN and ED appear to experience unique levels of research barriers. This may occur due to their small sample size and large standard deviation.

I then examined whether colleges that experienced higher levels of research barriers also had higher levels of collaboration. A one-factor analysis of variance (ANOVA) with fixed effects was used to examine whether current level of collaboration
is a function of college. The only difference between this model and the previous model was that the dependent variable was their current level of collaboration. Respondents self-reported their current level of collaboration by rating themselves on a scale from 1 to 6 (Table 2-2). This model did not find a statistically significant difference between the groups’ current level of collaboration.

In addition, I examined whether colleges that experienced higher levels of research barriers had higher ideal levels of collaboration. A one-factor analysis of variance (ANOVA) with fixed effects was used to examine whether ideal level of collaboration is a function of college. The only difference between this model and the previous model was that the dependent variable was the respondent’s ideal level of collaboration. Respondents self-reported their ideal level of collaboration by rating themselves on a scale from 1 to 6 (Table 2-3). This model did not find a statistically significant difference between the groups’ ideal level of collaboration.

Qualitative Data Analysis

An inductive grounded theory approach was used to analyze open-ended responses to the survey question ("What other barriers to collaboration (if any) have you encountered?") and interview questions about barriers to collaboration. (Glaser & Strauss 2009; Ryan and Bernard 2003) Three hundred thirty-six survey respondents provided a response to this open-ended question and thirty-two researchers were interviewed about this topic. Survey responses were read and sorted into categories and subcategories based on the repetition of themes in MAXQDA (qualitative data analysis software).

Survey respondents’ open-ended response lengths were not restricted and varied from one word to a few paragraphs. Many respondents identified barriers from
multiple categories. Therefore, the code distribution percentages are not equal to 100%.

All interviews were recorded. I took notes during the conversations and listened to the audio recording after the interview to identify common themes. Quotes that highlighted common themes were transcribed. The introduction of each quote in the results section differentiates between whether it came from a survey respondent or interviewee.

**Qualitative Results**

I identified seven barrier themes common across survey and interview data: 1) administrative regulations, 2) institutional structures, 3) interpersonal communication failures, 4) time allocation, 5) funding restrictions, 6) disciplinary divides, and 7) geographical proximity. Figure 2-1 illustrates the distribution of barriers identified by survey respondents. Figure 2-2 provides a visualization of barriers to collaboration by their codes to highlight common themes and sub-themes within these seven categories.

The following sections are broken down by category of barriers to collaboration. Each section will provide an overview of the category, list the prevalence of these responses, highlight the main themes within the categories, analyze example passages from survey and interview respondents, and offer suggestions for better addressing these barriers. There were no observable college level differences in barriers identified in the open-ended questions. The quotes will not list the college name to preserve respondents’ anonymity.

**Administrative Regulations**

Administrative regulations play an important role in shaping an organization’s norms and collaboration culture. Previous literature identified administrative bureaucracy as a major barrier to collaboration in health care settings (Axelsson & Axelsson, 2009) and transformation in the public sector. (Maddock & Morgan, 1998)
One hundred and seventy-one survey respondents discussed how administrative regulations served as barriers to collaboration in their responses. These responses were divided into two main categories: administrative bureaucracy (n=68) and institutional research subjects review boards (IRB for human subjects and IACUC for animal subjects) (n=13). One respondent discussed the challenges presented by conflicting indemnification laws.

Administrative regulations were identified as a key barrier to collaboration by many respondents. One survey respondent wrote that the biggest barrier to collaboration was the,

Undue burden of [university] administrative processes and regulations; untrustworthy administration that does not trust faculty; administration-driven intellectual agenda instead of support for faculty research initiatives.

This response emphasizes the respondent’s perceptions of the lack of trust between researchers and administrators. It also paints a picture of a research climate in which researchers feel their thoughts and initiatives are not supported by the university administration. Rather they see administrative requirements as part of an “other” group that dictates policy and places tremendous administrative burdens upon them without recognizing the important role that their research plays in the success of the university.

Responses like this highlight the need for increased interaction between researchers and administrators. Initiatives to increase communication and emphasize the shared goals between these two groups could play an instrumental role in reducing the otherness between these groups and fostering a culture of mutual respect.
Changing regulations also present barriers to research, especially in the health sciences. A researcher coordinator I interviewed described regulations as the greatest barrier to her research. She said,

Research regulations change and they change often. Research is a living breathing animal…So it is evolving and you have to keep up with the ways it is evolving. You have to constantly be communicating with the IRB because even their standards for the same things change from month to month. If there is a different interpretation of a rule that now has to go into effect, what you did two weeks ago is wrong and you now have to correct it…but it’s kind of exciting and it’s all for human subjects’ protection.

This response highlights the challenges that ever-changing human subject regulations present for medical research. Later in the interview, she also highlighted the additional challenges these university and national regulations present when working with collaborators at other universities, especially those based in other countries. However, she also saw this barrier as an opportunity to continuously make scientific research more ethical and better serve human subjects. She explained that it is essential to develop strong relationships of mutual respect and open lines of communication between researchers and administrative staff both within the team and in the IRB and RAC offices.

**Institutional**

University level policies and college and department level divisions play an integral role in shaping the cultural context of scientific collaborations. Literature on university-industry collaborations has identified variation in university’s institutional policies and organizational attitudes as a potential barrier to collaboration and knowledge transfer. (Bjerregaard, 2009; Bruneel et al., 2010; Siegel et al., 2003) One hundred and thirty-nine survey respondents referenced institutional level barriers to collaboration in their responses.
These responses were divided into five main categories: lack of institutional support for collaboration (n=29), challenges identifying collaborators with necessary skills (n=15), college level boundaries (n=14), the tenure and promotion (T&P) system (n=11), and difficulty connecting with other researchers (n=9). In addition, respondents discussed the challenges of sharing data with collaborators, finding adequate neutral space to collaborate in, collaborating as equal partners when principal investigator status made the team inherently unequal, finding collaborators with knowledgeable expertise on their research topic, sharing information with team members, and protecting their research time from other commitments. One respondent listed each of the following barriers to collaboration: culture of “risk aversion,” difficulties assessing the percentage of effort of each team member, logistical challenges, disconnect between college requirements and funding agencies, newness to the university, and lack of integration between basic and translational research.

Respondents that discussed lack of support for collaboration identified four key areas for improvement. Improvement in these areas requires increased administrative (n=10), technical (n=7), grant proposal preparation (n=5), and hiring (n=5) support on an institutional level. Other respondents cited lack access to resources, issues with Animal Care Services (ACS) organization and services, and lack of customer service for grants and contracts as barriers to collaboration.

Departmental dynamics play a central role in shaping how their faculty collaborates both within and outside of their college. Ten respondents described their department’s administration as unsupportive of collaboration. The type of collaboration their department was unsupportive of varied by respondent. A few said that their
department was not supportive of interdisciplinary collaborations. One respondent described their department as actively discouraging international collaborations whereas another said that their department did not support collaboration within their department. These responses illustrate a strong desire for recognition and support of their collaborative efforts from their department’s administration.

Technology plays an important role in how researchers collaborate. Collaborations require additional remote contact by email, teleconferences, or other electronic means between team members to make group decisions. Some respondents said that more technical support was needed, a few respondents specified that their team required additional technical support staff and more reliable collaboration technology to reduce barriers to collaboration. Respondents also mentioned the need for the Office of Technology Licensing (OTL) to be more supportive of writing licenses for research investigators. These respondents emphasize the critical role that institutional technical support plays in supporting scientific collaborations at a variety of different scales and stages within the research process.

Some respondents identified the need for additional support staff and hiring faculty in key areas such as statistical methods to better support scientific collaboration. Another researcher also made the case in an interview that the university should be prioritizing the candidate’s potential for collaboration in their hiring decisions. He said,

Every time we hire the best scientist in the group we generally have the worst collaborator in the group, because they don’t need any help. They don’t need you. They have got their ideas, and they’re good ideas. And these people have gone on to build massive programs…But they’re almost like a vortex…You just keep feeding that black hole… Nobody can work with them.
This response illustrates the importance of thinking about potential scientific collaborations during the hiring process. It is difficult to get faculty members to work together because as this researcher said earlier in the interview many researchers have “alpha” personalities. These strong personalities often make collaborations challenging. Therefore, hiring committees need to consider a candidate’s ability to collaborate with others in addition to looking at their individual research agenda and achievements.

Five respondents said that they required additional grant proposal preparation support. Identifying collaborators with necessary skills (n=15) and connecting with other researchers (n=9) were also identified as key barriers to research. For example, one survey respondent wrote,

The main barrier is just finding out what other scientists do and their interests. I do have a cadre of collaborators, but I know there are others that I could collaborate with but I don’t know what they do.

This response highlights the need for a database for identifying potential collaborators or online collaboration matchmaking service. Targeted network interventions could help to introduce faculty members working on similar research problems or requiring different types of research skills. Websites like DIRECT2Expert (2011) can help researchers identify collaborators, but targeted university approaches like those resembling Northwestern University’s team recommender (2015) could streamline the process on an institutional basis. Addressing these issues requires allocating additional administrative resources towards meeting these needs.

The university also needs to address college level boundaries to collaboration. One survey respondent wrote that the greatest barrier to collaboration that they experienced were the,
Boundaries that exist between colleges (e.g., COM and PH) making it difficult to optimize certain programs.

This response highlights the division between colleges that was discussed in the previous section of the paper on administrative regulations. Researchers who are interested in interdisciplinary research face higher levels of barriers and less support from the institution. More focus on bridging rather than further accentuating these divisions between colleges needs to occur at the university level.

The tenure process also varies greatly across the university. Eleven respondents highlighted the need for greater institutional support for collaboration in the T&P process. These responses reflect the fact that each college has its own unique guidelines for T&P. Seven of the colleges also have department level guidelines for some or all of their departments. The colleges of fine arts, health and human performance, liberal arts and sciences, and design, construction, and planning specify that each department sets their own T&P guidelines. The colleges of business administration, education, and engineering have mixed level T&P guidelines. This means that some departments within the college strictly follow college level T&P guidelines, whereas other departments set their own department level T&P guidelines. The colleges of agricultural and life sciences, dentistry, journalism and communication, law, medicine, nursing, pharmacy, public health and health professions, and veterinary medicine follow college level T&P guidelines. This diversity in T&P guidelines plays a major role in shaping who participates and how collaborative research occurs across the university.
Interpersonal

Communication plays a major role in shaping team dynamics. Previous studies have found that interpersonal communication, trust, and mutual respect is critical to team success. (Cheruvelil et al., 2014; van Dogan et al., 2016) Sixty-two survey respondents highlighted interpersonal barriers to collaboration in their responses. These responses were divided into three categories: communication issues (n=9) other researchers’ lack of interest in collaboration (n=6), and lack of recognition from collaborators (n=5). Respondents also discussed the interpersonal challenges presented by power differentials between researchers, their own personal limitations, different collaborator expectations, politics within the team, other researchers’ lack of interest in their research, inability to get in touch with people via email, making collaboration appealing to young investigators, faculty territoriality, recommendations against collaboration from mentors, challenges with team coordination, willingness of others to collaborate, willingness of other researchers to collaborate, disrespect for others’ research, and the additional effort that collaborative research requires.

Collaboration at any scale requires excellent communication between stakeholders. Communication failures occur when there is insufficient planning and allocation of roles within a team. Nine respondents highlighted this issue in their responses. One survey respondent wrote,

Lack of communication between departments and between researchers. People tend to stay in silos.

This response highlights the need for additional communication at an individual and departmental level. Lack of communication was emphasized by three respondents. Seven respondents also discussed communication issues specific to interdisciplinary
collaborations. Addressing these communication failures will require additional team science support and training at an institutional level.

Fostering research collaborations also requires sufficient interest and recognition. Six respondents felt that their peers were not interested in collaborating. Five respondents said that they did not receive sufficient recognition from other researchers for their contributions to the project. One survey respondent wrote that the greatest barrier to collaboration was,

Lack of interest in my focus, and lack of credit for input I give to others’ research grants or projects.

This response highlights both of these interpersonal issues tied to communication failures on the part of individual researchers and the institutional in which they work. In order to generate interest in collaboration, universities need to do a better job of evaluating and rewarding team science. Individuals researchers also need to do a better job of recognizing their team members for their ideas and research efforts. This can begin by asking each collaborator about the type of recognition they would like to receive for their work on the project. Each researcher has different goals for the project, so aligning the team’s goals from the onset will make the project more successful and valuable to each participant. This will increase their desire to actively participate in the project and accomplish their individual tasks.

Time

Time is a scarce resource for many faculty members. Research, teaching, service, patient care, and administrative duties take up the majority of their time. Collaborations require frequent meetings and coordination between team members to be successful. (Gardner, 2005; Cheruvelil et al., 2014; van Dogan et al., 2016) Thus,
busy schedules often serve as a barrier to collaborative research. Fifty-five survey respondents talked about how their busy schedules limited their opportunities to collaborate with other researchers in their responses.

Respondents referenced both their own and other faculty members lack of time. For example, one survey respondent said that,

Nobody has time. If someone is good, they are busy.

This response illustrates a shared cultural belief among researchers that time is valuable and extremely limited among researchers. It directly ties faculty members’ level of busyness to the quality of their research. This discourse is commonly used across colleges. As a result, lack of time is treated as a valid excuse for not being able to or wanting to participate in an activity. Citing a lack of time to devote to the project allows researchers to decline an invitation to collaborate on a project without losing face amongst their peers or providing a clear reason why they do not want to participate. Lack of time often serves as a proxy for lack of interest.

Financial

Thirty-two survey respondents highlighted financial barriers to collaboration in their responses. These responses were divided into two categories: external funding (n=18) and internal funding (n=9). Three respondents discussed the challenges of accessing resources like salary funding and tissue samples and one respondent mentioned the lack of funding for graduate students.

Scientific research requires external funding from governmental and industrial stakeholders. These stakeholders’ priorities and interests shape every stage of academic research. Reductions in federal research funding budgets have made many grant application processes more competitive and raised the stakes of conducting
academic research with well-defined goals and clear broader impacts. Survey responses highlighted the, “poor funding environment and resulting difficulty landing grants.” In particular, respondents referenced the increased difficulty of receiving a National Institutes of Health (NIH) RO1 grant. This type of funding is often essential in gaining tenure in colleges in the health sciences. Respondents who participated in interdisciplinary collaborations also discussed the difficulties of selecting a funding agency that would be equally recognized by all of the collaborators’ departments and colleges. Adding many collaborators, especially from different colleges, to a grant was also identified as a challenge due to budget sharing issues.

Budget sharing issues were identified as a major internal funding barrier. Universities use different systems to manage their budgets. This university uses a Responsibility Center Management (RCM) budget system. This system decentralizes budget decisions to college, division, center, or department units. This budgetary division often makes it difficult for collaborators to share funding across colleges and departments because each unit wants to maintain access to the facilities and administrative (F&A) rates or indirect costs (IDC) from the grant to fund their programs.

Respondents expressed frustration with the “lack of cost sharing incentives for collaborations between departments and or colleges” and “funding from department and institution.” They also described the difficulties of accessing funding for statistical or other services in the planning stages and deciding what each collaborator pays for throughout the project. One respondent discussed the challenges of arranging international sub-contacts. These internal funding barriers are tied to the institutional and administrative regulations described in previous sections.
Research funding typically plays a central role in bringing individual researchers together for larger more collaborative projects. However, it can also force dysfunctional teams to stay together in order to complete a project when the best course of action would be disbanding the team. In an interview, a researcher highlighted the role that the sunk costs fallacy played in a recent collaboration that had failed due to poor communication, different goals, and lack of intellectual investment from his collaborators. He said,

This isn’t related to science… They keep trying to change the plan even though we agreed on [X]…It puts me in a very challenging situation… Essentially what it’s going to (you know) mean is once I finish this (you know) I’m not going to continue to interact with these people, which is a shame because (you know) there are a lot of things you could do that would be interesting to work on… I think this is the first time I worked with a very large lab and I think that could be one of the factors there. I think the other lesson that I learned is there needs to be someone within the other group that is intellectually invested into the project because basically (there were) it was nobody’s project there and they were trying to get it done on the side with other people and you know techs and so forth and that that was not successful.

Though he had determined early on in the project that the collaboration was not successful, he said that he was in a difficult situation due to the large financial investments he had made in the project. Though there was an official contract attached to their grant funding, he said that it is difficult to enforce with collaborators. As a result, he decided the best course of action would be to hire his former students to work with the collaborator’s lab to get the results he needed and not collaborate with this lab again. Strategic flexibility is essential to mitigate sunk costs in collaborative projects. However, the extensive planning and budgetary rigidity required by external research funding agencies makes cutting ties with collaborators difficult if team members become harmful to the team’s progress toward its goals. (Minor & Housman, 2015)
Disciplinary

Interdisciplinary collaboration is often associated with increased levels of research barriers. Disciplinary differences in training, terminology, experiences, goals, and T&P requirements play a central role in shaping scientific collaborative research. (Brozek & Keys, 1944; Thompson, 2009; Van Rijnsoever & Hessels, 2011) Each category of barriers analyzed in this paper was shaped by the challenges of interdisciplinary collaboration in some way. Twenty-eight survey respondents directly mentioned interdisciplinary barriers to collaboration in their responses. These responses were divided into four categories: differences in clinical settings (n=11), cultural differences between disciplines (n=7), interdisciplinary issues (n=4), and lack of interest in collaboration with industry (n=3). One respondent referenced how differences in disciplinary training shape team dynamics and another lamented the lack of respect for basic scientists.

Researchers working in clinical settings have different schedules, less time for research, and additional duties related to patient care. These differences can create significant barriers to collaborative research. One clinical faculty member explained in their survey response,

The non-medical faculty do not understand how medicine is financed. There are many language issues about how we deal with different items. We see patients all day and the non-medical faculty want to meet at 10:00 AM or some time like that.

This response highlights the cultural and linguistic barriers that exist between clinical and non-clinical researchers. It also highlights the differences in their daily schedules and work. Clinical researchers have less time to allocate to focusing solely on research
and use different methodological approaches. These differences can cause challenges, but they can also present opportunities for more patient-centered research approaches.

Many non-clinical faculty members have an interest in working with clinical researchers, but also experience significant barriers. In an interview, a non-clinical researcher highlighted the role that clinicians played in his research by saying,

I often need physicians to help me to categorize patients or to help address medical issues.

When asked about how differences in clinicians’ schedules influenced his collaborations with clinical researchers. He said,

I think that has been a barrier occasionally, especially when physicians really express interest in research, but they have so many clinical demands on their time. I tend to try to be more supportive of their efforts recognizing that they’re more likely to fail because it’s very hard to compete against full time researchers when you are 20% time researcher…So that’s a challenge.

His response illustrates the important role that physicians can play in research. However, it also reflects some of the challenges of having less time to allocate to research. These challenges directly contribute to the high failure rate associated with these types of clinical-basic science collaborations. He also discussed the importance of establishing roles when trying to develop effective collaborations. This can be especially challenging when clinical researchers see their roles differently than the non-clinical researchers they are working with. For example, he said,

I think a lot of (especially) physician investigators are interested in research and have ideas and patients…they think, I’ve got the idea, I’ve got the patients, all you people go make it happen because I think many of them are used to directing clinics in that way (right?). Ok you set up my schedule. You call the patients to remind them. You do this, you do that. I walk into the room and see that patient. And research doesn’t work that way, in my experience. And so it can sometimes be a sort of important education and communication process to figure out how it’s going to work.
This response focuses on the role that strong communication between team members plays in setting and sticking to a shared timeline and project goals. This is particularly important when working with clinicians who have limited time to allocate to research collaborations.

Disciplinary differences present a variety of challenges. Seven respondents focused on the cultural differences between disciplines, four identified other interdisciplinary issues, and three discussed the lack of interest in collaboration with industry in their department/college. One respondent said that the greatest barrier was,

Cultural barriers in terms of different expectations and attitudes towards work.

Another survey respondent experienced a barrier to collaboration due to,

The differential emphasis placed on single-authored articles/books in the humanities, and on grant funding in the social/behavioral/biomedical sciences makes it difficult to collaborate. The university sets us up to pursue different goals.

These responses illustrate the cultural diversity between academic disciplines. Researchers in different departments and colleges have different goals, expectations, and attitudes regarding collaboration. These differences can lead to heightened perception of interdisciplinary barriers and cause researchers to work individually rather than in teams. It is important for interdisciplinary teams to address these issues early on in their collaboration to avoid conflict and communication failures.

Geographical

Geographical distance can serve as a major barrier to research collaborations, especially when team members have not collaborated with one another before. Previous literature has shown that close proximity leads to higher levels of scientific collaboration. (Knoben & Oerlemans, 2006; Ponds et al., 2007; Lee & Bozeman, 2005;
Fifteen survey respondents highlighted geographical barriers to collaboration in their responses.

The university has a satellite campus located approximately two hours from the main campus. Nine researchers at this campus described experiencing additional barriers to collaboration because of their distance from the main campus. These survey responses, as well as interviews with researchers located outside of the main campus, highlight the lack of communication and scientific isolation many researchers feel when working in these satellite locations. An interview with a researcher located outside of the core and satellite campuses referenced similar issues of isolation. However, this researcher reported that he had a small but strong team of core collaborators that he worked with at his location.

Respondents also said that this distance presented additional challenges for identifying potential collaborators, contacting experts and mentors, accessing research services, being aware of new programs or initiatives, and completing administrative tasks like getting contracts approved. The university has started to address these issues, but further work needs to be done to increase communication between the two campuses and provide additional administrative, mentorship, research services to faculty members located in the satellite campus. Interviews with faculty members in the college of agricultural and life sciences revealed that many researchers with extension appointments experience similar challenges.

A research university’s large size can also lead to heightened barriers related to physical distance between collaborators. Some respondents discussed how their distance from other researchers across the large campus created barriers to forming
new collaborations. The main geographic barrier referenced in survey responses and interviews was a small but steep hill that geographically separates researchers in the health sciences from other colleges. This hill presents challenges for researchers walking or biking when the weather is warm. Access to parking also varies greatly by campus location with most of the colleges in the health sciences requiring a different colored parking decal than those positioned on the rest of campus. Survey responses emphasized both the geographic and disciplinary divide between researchers and clinicians in the health sciences and other researchers from the other colleges.

**Gender and Race**

The themes introduced in the previous sections were reported in both survey and interview data. The topics of gender and race were not mentioned in the open-ended survey responses. However, these topics were discussed in great detail in interviews and conversations with female faculty, as well as faculty members of color.

There was a stark contrast by race and gender in faculty members’ perceptions of how race and gender shaped their research and collaboration experiences, as well as their service on committees. White male faculty members did not discuss race or gender in their interviews. Female faculty members and faculty members of color described multiple experiences where they believed that their gender and/or race explicitly or implicitly shaped their research and collaboration experiences.

Though service is a burden for all faculty members, some female faculty members and faculty members of color reported increased requests for their service on committees. They perceived that this was due to their diversity status and they saw it as an undue burden on their time. These ethnographic insights from interviews and informal conversations with faculty members illustrate the role that perceptions of race
and gender can play in shaping research and collaborations. However, the lack of reporting on these issues in the survey data suggests that faculty may not feel comfortable disclosing this type of information in an organizational survey or do not think that they fit within the existing categories of barriers to collaboration.

**Discussion**

The study’s results demonstrate researchers’ strong preference for collaborative research and desire to increase their level of collaboration. However, this paper found that administrative regulations and institutional structures often serve as barriers to collaboration in university settings. This finding was consistently observed in both the quantitative and qualitative results. This highlights the need for additional studies to examine the role that organization culture plays in shaping collaborative culture in university settings. Interpersonal issues also presented significant barriers to collaboration, which is consistent with industry research. Additionally, interviews and conversations with faculty members revealed that race and gender played a role in shaping the research and collaboration experiences of the female faculty and faculty of color I interviewed. Since these topics were not raised in the survey portion of the study, it is difficult to determine the prevalence of this perception. Future research should keep this in mind when developing a study on this topic and try to integrate a multi-method approach if possible.

Interdisciplinary research collaborations presented additional challenges in every barrier category. Interview and survey respondents suggested that universities devote more time and resources to addressing the challenges of interdisciplinary collaborations and providing more recognition when these collaborations result in publications and grants. Many respondents thought that recognition should occur at both the department
and college level. Many also believed that it should ideally include either equal or additional credit in T&P processes and personal recognition from the chair and/or dean.

I also found that barriers and scientific collaboration networks vary significantly by college using an ANOVA of research barriers and social network analysis of grant funding from 2010 to 2015. This analysis also found that health science center colleges experienced higher research barriers than other colleges even though their self-reported level of collaboration was not statistically significantly higher. However, respondents said in interviews that these barriers were reduced when researchers collaborated with other researchers within these colleges.

**Conclusions and Suggestions**

As I have highlighted throughout the paper, there are many areas that require improvement. Reducing barriers to research and scientific collaboration requires a real commitment on the part of university administration to value and prioritize collaboration. As a researcher discussed in an interview, universities need to ask themselves, “What do you value as an institution?” If the answer is collaboration, the institution needs to prioritize collaborative research at every level and stage of the research process. This researcher further stated that,

> The university says we want it [collaboration] but they really don’t have a metric in place to evaluate it…The way we hire (the people we hire) 100% dictates how well they collaborate…We’ve got to have those lead performers, but if you have all lead performers it’s really difficult a lot of times to have a lot of collaboration.

> From hiring to tenure decisions, scientific collaboration requires administrators and researchers to be united in the shared goal of creating a research culture that prioritizes, evaluates, and incentivizes scientific collaboration. Minimizing barriers to
research and scientific collaboration will require providing additional administrative, financial, and interpersonal resources to support collaborative research.
Table 2-1. Survey respondents’ opinions on collaboration

<table>
<thead>
<tr>
<th>Question</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you feel you have sufficient opportunities to collaborate with other researchers across the university?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>478</td>
<td>58.22%</td>
</tr>
<tr>
<td>No</td>
<td>202</td>
<td>24.60%</td>
</tr>
<tr>
<td>Unsure</td>
<td>141</td>
<td>17.17%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>821</td>
<td>100%</td>
</tr>
<tr>
<td>Are you interested in building new research collaborations?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>627</td>
<td>77.41%</td>
</tr>
<tr>
<td>No</td>
<td>60</td>
<td>7.41%</td>
</tr>
<tr>
<td>Unsure</td>
<td>123</td>
<td>15.19%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>810</td>
<td>100%</td>
</tr>
<tr>
<td>Would you be interested in using a &quot;matchmaking&quot; service to identify potential collaborations?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>403</td>
<td>53.81%</td>
</tr>
<tr>
<td>No</td>
<td>107</td>
<td>14.29%</td>
</tr>
<tr>
<td>Unsure</td>
<td>239</td>
<td>31.91%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>749</td>
<td>100%</td>
</tr>
</tbody>
</table>
Table 2-2. Current level of collaboration by college

<table>
<thead>
<tr>
<th>College</th>
<th>Mean</th>
<th>I would conduct most of my research by myself</th>
<th>I would work with a few researchers from my department</th>
<th>I would work with a few researchers from different departments across the university</th>
<th>I would work with a large number of researchers from across the university</th>
<th>I would work with a few researchers from other institutions</th>
<th>I would work with a large number of researchers from this and other institutions or organizations</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>3.77</td>
<td>13 9.03%</td>
<td>25 17.36%</td>
<td>41 28.47%</td>
<td>6 4.17%</td>
<td>21 14.58%</td>
<td>38 26.39%</td>
<td>144   100%</td>
</tr>
<tr>
<td>DN</td>
<td>3.44</td>
<td>1 3.70%</td>
<td>4 14.81%</td>
<td>14 51.85%</td>
<td>1 3.70%</td>
<td>4 14.81%</td>
<td>3 11.11%</td>
<td>27    100%</td>
</tr>
<tr>
<td>ED</td>
<td>4.05</td>
<td>0 0.00%</td>
<td>4 19.05%</td>
<td>4 19.05%</td>
<td>2 9.52%</td>
<td>9 42.86%</td>
<td>2 9.52%</td>
<td>21    100%</td>
</tr>
<tr>
<td>EG</td>
<td>3.92</td>
<td>3 4.55%</td>
<td>7 10.61%</td>
<td>23 34.85%</td>
<td>5 7.58%</td>
<td>15 22.73%</td>
<td>13 19.70%</td>
<td>66    100%</td>
</tr>
<tr>
<td>CLAS</td>
<td>4.38</td>
<td>7 11.48%</td>
<td>5 8.20%</td>
<td>10 16.39%</td>
<td>1 1.64%</td>
<td>12 19.67%</td>
<td>26 42.62%</td>
<td>61    100%</td>
</tr>
<tr>
<td>MD</td>
<td>3.85</td>
<td>11 4.47%</td>
<td>38 15.45%</td>
<td>90 36.59%</td>
<td>13 5.28%</td>
<td>27 10.98%</td>
<td>67 27.24%</td>
<td>246   100%</td>
</tr>
<tr>
<td>PH</td>
<td>4.38</td>
<td>1 2.50%</td>
<td>3 7.50%</td>
<td>13 32.50%</td>
<td>2 5.00%</td>
<td>5 12.50%</td>
<td>16 40.00%</td>
<td>40    100%</td>
</tr>
<tr>
<td>PHHP</td>
<td>4.20</td>
<td>0 0.00%</td>
<td>0 0.00%</td>
<td>16 53.33%</td>
<td>1 3.33%</td>
<td>4 13.33%</td>
<td>9 30.00%</td>
<td>30    100%</td>
</tr>
<tr>
<td>VM</td>
<td>3.55</td>
<td>4 10.53%</td>
<td>4 10.53%</td>
<td>17 44.74%</td>
<td>1 2.63%</td>
<td>4 10.53%</td>
<td>8 21.05%</td>
<td>38    100%</td>
</tr>
<tr>
<td>Total</td>
<td>3.91</td>
<td>40 5.94%</td>
<td>90 13.37%</td>
<td>228 33.88%</td>
<td>32 4.75%</td>
<td>101 15.01%</td>
<td>182 27.04%</td>
<td>673   100%</td>
</tr>
</tbody>
</table>
### Table 2.3. Ideal level of collaboration by college

<table>
<thead>
<tr>
<th>College</th>
<th>Mean</th>
<th>I would conduct most of my research by myself</th>
<th>I would work with a few researchers from my department</th>
<th>I would work with a few researchers from different departments across the university</th>
<th>I would work with a large number of researchers from across the university</th>
<th>I would work with a few researchers from other institutions</th>
<th>I would work with a large number of researchers from this and other institutions or organizations</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>4.53</td>
<td>2 (1.40%)</td>
<td>9 (6.29%)</td>
<td>39 (27.27%)</td>
<td>9 (6.29%)</td>
<td>29 (20.28%)</td>
<td>55 (38.46%)</td>
<td>143 (100%)</td>
</tr>
<tr>
<td>DN</td>
<td>4.37</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>12 (44.44%)</td>
<td>2 (7.41%)</td>
<td>4 (14.81%)</td>
<td>9 (33.33%)</td>
<td>27 (100%)</td>
</tr>
<tr>
<td>ED</td>
<td>4.7</td>
<td>0 (0.00%)</td>
<td>1 (5.00%)</td>
<td>4 (20.00%)</td>
<td>3 (15.00%)</td>
<td>4 (20.00%)</td>
<td>8 (40.00%)</td>
<td>20 (100%)</td>
</tr>
<tr>
<td>EG</td>
<td>4.53</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>23 (34.85%)</td>
<td>9 (13.64%)</td>
<td>10 (15.15%)</td>
<td>24 (36.36%)</td>
<td>66 (100%)</td>
</tr>
<tr>
<td>CLAS</td>
<td>4.75</td>
<td>4 (6.67%)</td>
<td>4 (6.67%)</td>
<td>9 (15.00%)</td>
<td>1 (1.67%)</td>
<td>10 (16.67%)</td>
<td>32 (53.33%)</td>
<td>60 (100%)</td>
</tr>
<tr>
<td>MD</td>
<td>4.81</td>
<td>1 (0.40%)</td>
<td>5 (2.02%)</td>
<td>65 (26.32%)</td>
<td>27 (10.93%)</td>
<td>19 (7.69%)</td>
<td>130 (52.63%)</td>
<td>247 (100%)</td>
</tr>
<tr>
<td>PH</td>
<td>5.05</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>10 (25.64%)</td>
<td>2 (5.13%)</td>
<td>3 (7.69%)</td>
<td>24 (61.54%)</td>
<td>39 (100%)</td>
</tr>
<tr>
<td>PHHP</td>
<td>4.72</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>10 (34.48%)</td>
<td>3 (10.34%)</td>
<td>1 (3.45%)</td>
<td>15 (51.72%)</td>
<td>29 (100%)</td>
</tr>
<tr>
<td>VM</td>
<td>4.71</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>15 (39.47%)</td>
<td>0 (0.00%)</td>
<td>4 (10.53%)</td>
<td>19 (50.00%)</td>
<td>38 (100%)</td>
</tr>
<tr>
<td>Total</td>
<td>4.7</td>
<td>7 (1.05%)</td>
<td>19 (2.84%)</td>
<td>187 (27.95%)</td>
<td>56 (8.37%)</td>
<td>84 (12.56%)</td>
<td>316 (47.23%)</td>
<td>669 (100%)</td>
</tr>
</tbody>
</table>
Table 2-4. Survey respondents’ perceptions of barriers to collaboration

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Strongly disagree</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>I have difficulty in identifying likely collaborators</td>
<td>2.56</td>
<td>151 (18.78%)</td>
<td>281 (34.95%)</td>
<td>170 (21.14%)</td>
<td>174 (21.64%)</td>
<td>28 (3.48%)</td>
<td>804 (100%)</td>
</tr>
<tr>
<td>It is a challenge to find experts outside of my discipline</td>
<td>2.68</td>
<td>119 (14.80%)</td>
<td>289 (35.95%)</td>
<td>157 (19.53%)</td>
<td>205 (25.50%)</td>
<td>34 (4.23%)</td>
<td>804 (100%)</td>
</tr>
<tr>
<td>Collaboration is discouraged in my department</td>
<td>1.73</td>
<td>421 (52.43%)</td>
<td>236 (29.39%)</td>
<td>104 (12.95%)</td>
<td>25 (3.11%)</td>
<td>17 (2.12%)</td>
<td>803 (100%)</td>
</tr>
<tr>
<td>I do not feel that collaboration would be productive</td>
<td>1.57</td>
<td>484 (60.12%)</td>
<td>219 (27.20%)</td>
<td>73 (9.07%)</td>
<td>20 (2.48%)</td>
<td>9 (1.12%)</td>
<td>805 (100%)</td>
</tr>
<tr>
<td>The UF business model poses financial barriers to collaboration</td>
<td>3.25</td>
<td>62 (7.70%)</td>
<td>119 (14.78%)</td>
<td>286 (35.53%)</td>
<td>234 (29.07%)</td>
<td>104 (12.92%)</td>
<td>805 (100%)</td>
</tr>
</tbody>
</table>
Table 2-5. Mean of survey respondents’ perceptions of barriers to collaboration by college

<table>
<thead>
<tr>
<th>College</th>
<th>Mean</th>
<th>I have difficulty in identifying likely collaborators</th>
<th>It is a challenge to find expects outside of my discipline</th>
<th>Collaboration is discouraged in my department</th>
<th>I do not feel that collaboration would be productive</th>
<th>The UF business model poses financial barriers to collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>2.316</td>
<td>2.45</td>
<td>2.57</td>
<td>1.67</td>
<td>1.67</td>
<td>3.22</td>
</tr>
<tr>
<td>DN</td>
<td>2.312</td>
<td>2.62</td>
<td>2.65</td>
<td>1.85</td>
<td>1.65</td>
<td>2.79</td>
</tr>
<tr>
<td>ED</td>
<td>2.484</td>
<td>2.63</td>
<td>3.05</td>
<td>1.74</td>
<td>1.26</td>
<td>3.74</td>
</tr>
<tr>
<td>EG</td>
<td>2.472</td>
<td>2.83</td>
<td>2.95</td>
<td>1.86</td>
<td>1.50</td>
<td>3.22</td>
</tr>
<tr>
<td>CLAS</td>
<td>2.348</td>
<td>2.22</td>
<td>2.63</td>
<td>1.87</td>
<td>1.72</td>
<td>3.30</td>
</tr>
<tr>
<td>MD</td>
<td>2.326</td>
<td>2.57</td>
<td>2.68</td>
<td>1.65</td>
<td>1.52</td>
<td>3.21</td>
</tr>
<tr>
<td>PH</td>
<td>2.186</td>
<td>2.43</td>
<td>2.59</td>
<td>1.41</td>
<td>1.50</td>
<td>3.00</td>
</tr>
<tr>
<td>PHHP</td>
<td>2.194</td>
<td>2.14</td>
<td>2.29</td>
<td>1.68</td>
<td>1.36</td>
<td>3.50</td>
</tr>
<tr>
<td>VM</td>
<td>2.342</td>
<td>2.45</td>
<td>2.63</td>
<td>1.71</td>
<td>1.53</td>
<td>3.39</td>
</tr>
<tr>
<td>Table 2-6. Survey respondents’ perceptions of barriers to research</td>
<td>Mean</td>
<td>Not a barrier</td>
<td>Slight barrier</td>
<td>Moderate barrier</td>
<td>Serious barrier</td>
<td>Extreme barrier</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------</td>
<td>----------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Human subjects (IRB) submission and approval</td>
<td>2.59</td>
<td>282 34.64%</td>
<td>160 19.66%</td>
<td>205 25.18%</td>
<td>107 13.14%</td>
<td>60 7.37%</td>
</tr>
<tr>
<td>Contracting processes</td>
<td>2.55</td>
<td>246 30.52%</td>
<td>192 23.82%</td>
<td>230 28.54%</td>
<td>92 11.41%</td>
<td>46 5.71%</td>
</tr>
<tr>
<td>Recruitment of research participants</td>
<td>2.22</td>
<td>341 42.36%</td>
<td>163 20.25%</td>
<td>203 25.22%</td>
<td>75 9.32%</td>
<td>23 2.86%</td>
</tr>
<tr>
<td>Research Administration and Compliance (RAC)</td>
<td>2.58</td>
<td>238 29.24%</td>
<td>204 25.06%</td>
<td>223 27.40%</td>
<td>109 13.39%</td>
<td>40 4.91%</td>
</tr>
<tr>
<td>Availability of research coordinator support</td>
<td>2.20</td>
<td>340 41.36%</td>
<td>167 20.32%</td>
<td>169 20.56%</td>
<td>100 12.17%</td>
<td>46 5.60%</td>
</tr>
<tr>
<td>Space to conduct research</td>
<td>2.00</td>
<td>376 45.58%</td>
<td>201 24.36%</td>
<td>151 18.30%</td>
<td>68 8.24%</td>
<td>29 3.52%</td>
</tr>
<tr>
<td>Availability of biostatistical support services</td>
<td>2.03</td>
<td>384 47.00%</td>
<td>175 21.42%</td>
<td>145 17.75%</td>
<td>79 9.67%</td>
<td>34 4.16%</td>
</tr>
<tr>
<td>Preparing project budgets for grant applications</td>
<td>2.15</td>
<td>280 34.27%</td>
<td>242 29.62%</td>
<td>211 25.83%</td>
<td>63 7.71%</td>
<td>21 2.57%</td>
</tr>
<tr>
<td>Availability of biomedical informatics services</td>
<td>1.82</td>
<td>445 55.69%</td>
<td>146 18.27%</td>
<td>135 16.90%</td>
<td>51 6.38%</td>
<td>22 2.75%</td>
</tr>
<tr>
<td>Identifying relevant experts</td>
<td>1.90</td>
<td>379 46.56%</td>
<td>226 27.76%</td>
<td>144 17.69%</td>
<td>44 5.41%</td>
<td>21 2.58%</td>
</tr>
</tbody>
</table>
Table 2-7. Mean of survey respondents’ perceptions of barriers to research by college

<table>
<thead>
<tr>
<th>College</th>
<th>AG</th>
<th>DN</th>
<th>ED</th>
<th>EG</th>
<th>CLAS</th>
<th>MD</th>
<th>PH</th>
<th>PHHP</th>
<th>VM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.85</td>
<td>2.35</td>
<td>1.94</td>
<td>1.82</td>
<td>1.73</td>
<td>2.33</td>
<td>2.21</td>
<td>2.36</td>
<td>2.32</td>
</tr>
<tr>
<td>Human subjects (IRB) submission and approval</td>
<td>1.70</td>
<td>2.81</td>
<td>1.65</td>
<td>1.89</td>
<td>1.82</td>
<td>2.90</td>
<td>2.46</td>
<td>3.60</td>
<td>2.24</td>
</tr>
<tr>
<td>Contracting processes</td>
<td>2.22</td>
<td>2.21</td>
<td>2.16</td>
<td>2.23</td>
<td>1.95</td>
<td>2.63</td>
<td>2.43</td>
<td>2.37</td>
<td>2.30</td>
</tr>
<tr>
<td>Recruitment of research participants</td>
<td>1.66</td>
<td>2.76</td>
<td>2.50</td>
<td>1.58</td>
<td>1.47</td>
<td>2.39</td>
<td>2.18</td>
<td>2.93</td>
<td>2.24</td>
</tr>
<tr>
<td>Research Administration and Compliance (RAC)</td>
<td>2.07</td>
<td>2.62</td>
<td>2.10</td>
<td>2.14</td>
<td>1.98</td>
<td>2.64</td>
<td>2.58</td>
<td>2.70</td>
<td>2.59</td>
</tr>
<tr>
<td>Availability of research coordinator support</td>
<td>1.93</td>
<td>2.41</td>
<td>2.60</td>
<td>1.75</td>
<td>1.88</td>
<td>2.34</td>
<td>2.13</td>
<td>2.47</td>
<td>2.32</td>
</tr>
<tr>
<td>Space to conduct research</td>
<td>1.99</td>
<td>1.82</td>
<td>2.05</td>
<td>1.95</td>
<td>1.52</td>
<td>2.01</td>
<td>2.05</td>
<td>2.33</td>
<td>2.25</td>
</tr>
<tr>
<td>Availability of biostatistical support services</td>
<td>1.94</td>
<td>2.30</td>
<td>1.53</td>
<td>1.50</td>
<td>1.42</td>
<td>2.24</td>
<td>2.03</td>
<td>2.03</td>
<td>2.54</td>
</tr>
<tr>
<td>Preparing project budgets for grant applications</td>
<td>2.28</td>
<td>1.93</td>
<td>2.05</td>
<td>1.66</td>
<td>2.38</td>
<td>2.01</td>
<td>2.23</td>
<td>1.77</td>
<td>2.63</td>
</tr>
<tr>
<td>Availability of biomedical informatics services</td>
<td>1.22</td>
<td>2.22</td>
<td>1.15</td>
<td>1.43</td>
<td>1.34</td>
<td>2.18</td>
<td>2.00</td>
<td>1.77</td>
<td>2.00</td>
</tr>
<tr>
<td>Identifying relevant experts</td>
<td>1.52</td>
<td>2.41</td>
<td>1.60</td>
<td>2.06</td>
<td>1.56</td>
<td>1.98</td>
<td>2.00</td>
<td>1.60</td>
<td>2.11</td>
</tr>
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</table>
Table 2-8. Means and standard deviations of survey respondents’ perceptions of research barriers score by college

<table>
<thead>
<tr>
<th>College</th>
<th>n (With barriers’ score)</th>
<th>n (Survey respondents)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>135</td>
<td>177</td>
<td>18.4</td>
<td>5.2</td>
</tr>
<tr>
<td>DN</td>
<td>22</td>
<td>30</td>
<td>23.45</td>
<td>9.2</td>
</tr>
<tr>
<td>ED</td>
<td>19</td>
<td>24</td>
<td>19.32</td>
<td>6.5</td>
</tr>
<tr>
<td>EG</td>
<td>57</td>
<td>69</td>
<td>17.93</td>
<td>6.3</td>
</tr>
<tr>
<td>CLAS</td>
<td>57</td>
<td>68</td>
<td>17.12</td>
<td>5.6</td>
</tr>
<tr>
<td>MD</td>
<td>234</td>
<td>266</td>
<td>23.41</td>
<td>7</td>
</tr>
<tr>
<td>PH</td>
<td>39</td>
<td>40</td>
<td>22.03</td>
<td>6.2</td>
</tr>
<tr>
<td>PHHP</td>
<td>30</td>
<td>32</td>
<td>23.57</td>
<td>6.8</td>
</tr>
<tr>
<td>VM</td>
<td>32</td>
<td>39</td>
<td>23.34</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>625</strong></td>
<td><strong>745</strong></td>
<td><strong>21.05</strong></td>
<td><strong>6.9</strong></td>
</tr>
</tbody>
</table>
Figure 2-1. Barriers to collaboration by category

Figure 2-2. Visualization of barriers to collaboration by code
CHAPTER 3
RECOGNIZING TEAM SCIENCE IN THE TENURE AND PROMOTION PROCESS:
DEVELOPING A COMMON TOOL FOR EVALUATING FACULTY ACHIEVEMENT

Overview

The tenure and promotion (T&P) process is an important ritual for evaluating the work of academics at universities and colleges. (Tierney, 1983; Tierney & Rhoads, 1993; Youn & Price, 2009) Tenure was initially designed to provide faculty members with stability and the academic freedom to pursue new lines of research that may be controversial to the university or their disciplinary field. (McPherson & Schapiro, 1999) It also serves as an important career marker that allows researchers to pursue new opportunities and lines of research. However, some critics have noted that it can also lead to a stagnation in faculty members’ research outputs.

The recent rise of interdisciplinary team science and decrease in federal university and grant funding have led to changes in academic identity and the practice of contemporary science. (Baldwin, Lunceford, & Vanderlinden, 2005; Barnett & Napoli, 2008; Fiore, 2008; Börner et al., 2010) However, many universities’ faculty evaluation and reward systems have not been updated to reflect these changes.

I address this issue in this chapter using data from text and network analysis of college level annual evaluation and T&P criteria, interviews with faculty who have gone through the tenure process and served on tenure evaluation committees, and a survey of researchers at a large public university in the United States. I also draw from my personal experience as a graduate student participating in multiple interdisciplinary research teams. This chapter’s findings show that current annual evaluation and T&P criteria vary greatly across academic units and colleges (within a university) and do not sufficiently recognize team science. They also highlight the fact that faculty members
want to be rewarded for their collaborative research efforts, which signals a shift away from the current focus on individual research productivity.

This paper begins with a brief discussion of the current state of academic tenure and an overview of the T&P process. Then, I will review the literature on the topic of faculty evaluation through tenure and other rewards systems and outline the research questions that guided this study. Next, I will outline the study’s methodology and explain why I adopted this mixed method approach. The following section will outline the major results of the study and their implications for team science. I will conclude this paper with a discussion of the study’s results and recommendations for better incorporating team science into the T&P process.

**Academic Tenure**

The current state of academic tenure illustrates a dramatic shift from security to growing uncertainty due to the rise in part and full time non-tenure track positions, as well as an increase in governmental oversight at the state level through post-tenure review and other measures. (McPherson & Schapiro, 1999; O'Meara, 2004) According to the National Center for Education Statistics (NCES, 2016), in 2014, 49% of higher education institutions had tenure systems and 48% of faculty members at these institutions were tenured. This percentage has decreased by 6% since 2000. This represents the steady decline in tenure track positions that has occurred. During this period, the number of part-time faculty rose by 104%, whereas the number of full-time faculty rose by only 45%. This rapid increase in the hiring of part-time faculty, which now accounts for 49% of all faculty members, illustrates the increasing casualization and decreasing security of academic labor particularly in for-profit institutions. Male faculty were also 14% more likely to be tenured compared to female faculty. This
relationship between gender and tenure has been well documented in the literature. 
(e.g. Clarke et al., 2013; Johnsrud & Des Jarlais, 1994; Perna, 2001; Perna, 2005; Trower & Bleak, 2004)

The T&P process is the primary evaluation method of academic work in many university settings. This is particularly true in public institutions which grant doctoral degrees. (NCES, 2016) A strong correlation exists between the type of institution and the presence of a tenure system. A large gap in tenure exists between public and private non-profit doctoral granting universities and private for-profit colleges’ faculty evaluation systems. Only 1% of private for-profit institutions (e.g. University of Phoenix) have a tenure system, whereas, nearly 100% of public doctoral granting universities offered a tenure system. (NCES, 2016) This extreme divergence reflects very different histories, cultural traditions, and organizational cultures.

While some elements of this process may vary across universities, at the university where I conducted this study, the process begins when a faculty member is hired for a tenure track position. Many departments provide mentors for junior faculty members. However, the quality and frequency of this mentorship varies greatly both within and across departments.

Department chairs or division chiefs conduct annual evaluations to assess the faculty member’s accomplishments typically in the areas of research, teaching, and service. Some departments in the agricultural or health sciences also evaluate faculty achievements in the areas of extension or patient care. Departments’ annual evaluations do not directly contribute to the T&P process. Yet, this process provides annual feedback to support or redirect junior faculty members’ efforts and often sets the
tone for their T&P packet submission and evaluation. Three years into a faculty member’s appointment, the department chair or division chief conducts a preliminary review of a faculty member’s achievements to evaluate whether they are on the right track to submit their T&P packet in two to four years. Based on this feedback, faculty members either continue on their current path or restructure their efforts to publish more, secure additional grant funding, or complete other tasks suggested by their chair.

After a six or seven-year tenure probationary period in their position, faculty members initiate the formal T&P process by compiling and submitting their tenure packet. Many colleges hold annual workshops led by administrators to provide faculty members with an overview of the T&P process and guidance on how to put together their packets. The packet includes information on a faculty member’s research, teaching, and service efforts, as well as letters from external reviewers that are solicited by the department chair or division chief. Half of these reviewers are selected by the faculty member and the other half is selected by the chair.

A designated committee of full and associate (for assistant to associate tenure cases) professors evaluates the faculty member’s packet and decides whether or not to award tenure in tenure accruing positions or a promotion in other positions. Faculty members are evaluated based on the committee members’ interpretations of the guidelines set by their college and in some colleges by their department. In promotion decisions, distinction must be demonstrated in at least one area. In order to receive tenure, the faculty member must use quantitative and qualitative data to demonstrate to the committee their distinction in at least two of the three categories (typically research and teaching) at the national level. Previous studies have found that the T&P process
primarily rewards faculty members for their research accomplishments with a heavy emphasis on their peer-reviewed publications and grant funding. (Clark, 1997; Fairweather, 1993) Committees often have difficulty determining an individual team member’s effort on a multi-investigator grant or multi-author publication. This leads to variation in the assessment of research distinction for faculty members who often work in teams.

The committee reviews the T&P packet materials and provides a written assessment for other department members to read. Then, all eligible tenured department members review these materials, meet to discuss the nomination, and vote on whether or not to award the faculty member with tenure or promotion. After the department votes, the chair writes a letter that provides their evaluation of the faculty member, explains the results of the departmental vote, and offers their recommendation. Then, the nomination proceeds to the college level. At the college level, a committee of tenured professors evaluates these materials based on college and/or department level T&P criteria. Each committee member writes an assessment of the packet and the dean reviews these assessments in order to determine whether or not to endorse the faculty member’s nomination. At the university level, another committee reviews the packet and provides their reviews to the President. Ultimately, the President has the final say on whether or not to recommend that the Board of Trustees approve the nomination. If the President recommends the nomination for tenure or promotion, the Board of Trustees votes on this nomination and the process is complete. At any point in this process, the packet can be withdrawn by the applicant.
Faculty members who are awarded tenure apply for promotion to full professor later in their career. This is evaluated in a similar way, but requires proof of additional accomplishments to demonstrate areas where they have achieved international distinction in all three areas. The primary focus of this paper will be on examining the evaluation that occurs when assistant professors apply for T&P.

**Theoretical Background and Research Questions**

Many studies have examined general issues related to tenure and academic evaluation systems. (Chait, 2004; McPherson and Schapiro, 1999; O’Meara, 2010) Previous studies have found that university reward structures, which include salary, recognition, travel funds, and T&P evaluation, focus almost exclusively on faculty members’ individual researchers’ productivity on grants and publications. (Boyer, 1989; Clark, 1997; Fairweather, 1993; Bloch, Graversen, & Pedersen, 2014) O’Meara (2011) provides an excellent overview of the literature on academic reward systems and their variation across disciplines. O’Meara, Terosky, and Neumann (2008) define faculty reward systems as,

The many ways in which an institution regards faculty – including but not limited to how it recruits, sustains, assesses, and advances faculty throughout their careers.

Other studies have identified the lack of clarity on the evaluation process and criteria for junior faculty members as a major issue with many faculty reward systems. (O’Meara, 2010)

Organizational culture also plays a major role in shaping the tenure process and evaluation criteria. (Tierney & Rhoads, 1993) As O’Meara (2010) explains,

Each institution has local traditions or expectations not stated in formal policies but understood in everyday practice, such as whether it is appropriate to go up early for tenure, how much service a faculty member
should have done, and what kinds of relationships with the external community are most valued.

O'Meara (2005) provides a deep examination of faculty reward systems. She also highlights the fact that T&P criteria and evaluation are heavily influenced by disciplinary cultures and institutional leadership. These systems largely reflect the collective values and goals of the leadership (at the university, college, and department level) and their narrow and highly subjective view of what constitutes academic productivity. (Clark, 1997) These implicit and explicit signals from leadership often shape researchers' selection of research topics and collaborators. (Bianco, Gras, & Sutz, 2016)

Tenure was initially designed to reward faculty members' joint efforts in research, teaching, and service across all academic units. However, previous studies have shown that in practice faculty evaluations and rewards vary greatly across disciplines and even within the same department based on the individual's gender, race, network, and research topic in concert with the university, college, and department's current resources and priorities. (O'Meara, 2010) Research on the peer review process has demonstrated the role that scientists' networks and status plays in shaping whether or not their grants receive funding and how papers get published and cited. (Clarke et al., 2013; Niehaus & O'Meara, 2014; Rogers, 2000; Zuckerman & Merton, 1971) Many studies on faculty reward systems have also revealed systemic racial and gender biases in terms of salary, mentorship, and T&P evaluation. (Aguirre, 2000; Clarke et al., 2013; Fairweather, 1993; Johnsrud & Des Jarlais, 1994; Moss-Racusin et al., 2012; O'Meara, 2010; Perna, 2001; Perna, 2005; Tierney & Bensimon, 1996; Trower & Bleak, 2004) These studies suggest a need for a reconsideration of these reward and evaluation systems.
Some qualitative studies have analyzed tenure as a rite of passage for young researchers. (Tierney, 1983; Tierney & Rhoads, 1993) These types of studies often provide rich faculty narratives about the shifting cultural norms of science, issues with the current T&P process, and variation in evaluation criteria across a single university. (Müller, 2014; Ambrose, Huston, & Norman, 2005; Austin & Rice, 1998; Tierney & Bensimon, 1996) Others have explored how the socialization process of graduate students and post docs shapes their professional identity formation, research preferences, knowledge sources, and perceptions of academic culture as faculty members. (Clarke et al., 2013; Mendoza, 2007; Müller, 2014; O’Meara & Jaeger, 2006; O’Meara et al., 2014)

In-depth case studies have also been used to explore individual university’s norms and cultures surrounding the research process (Herbert & Tienari, 2013; Mendoza, 2007; Serow, 2000) and faculty departure. (Ambrose, Huston, & Norman, 2005; O’Meara, Lounder, & Campbell, 2014) Few quantitative studies have been conducted on this topic. A notable exception is a study by Lawrence, Celis, and Ott (2014) which found that a faculty member’s level of knowledge and sense of control over the T&P process predicted their perception of its fairness.

Many studies have also called for an expanded definition of scholarship to reward multiple types of scholarship. (Bennett & Khanna, 2010; Bunton & Mallon, 2007; Hutchinson, 2011; O’Meara, 2005; O’Meara, 2010; O’Meara & Braskamp, 2005; Roberts & Glod, 2013) Specifically, some scholars have explored new ways for rewarding faculty engagement with the public. (Boyer, 1990; Driscoll & Sandmann, 2001; Fitzgerald et al., 2012; O’Meara, 2010) Others have explored how the lack of
emphasis on teaching in evaluation criteria and reward systems creates a tension between student education and research productivity. (Hackett, 1990; Serow, 2000; Roberts & Glod, 2013; Müller, 2014; O'Meara & Braskamp, 2005) Many scholars have also suggested rewarding collaborations related to patents, commercialization, and industry applications. (Roberts & Glod, 2013; Sanberg et al., 2014; Mendoza, 2007)

Some universities outside the US have adopted different systems for evaluating and rewarding academics' productivity. For example, the evaluation system at Australian public universities uses a universal formula for all disciplines that incorporates statistics on a researcher's level of funding, publishing productivity, teaching, and mentorship of graduate students rather than a peer evaluation process. (Gläser & Laudel, 2007) Whereas, a case study on developing a faculty evaluation system in Finland illustrates that even when tenure is transplanted to new contexts it often replicates the United States model of disciplinary emphasis with few rewards for teaching and interdisciplinary collaborations. (Herbert & Tienari, 2013)

Previous studies have suggested providing clearer guidelines, instituting a formal mentorship process, increasing institutional support (funding and resources), revising department evaluation criteria to provide additional weights for interdisciplinary collaborations in the T&P process and other faculty reward systems. (Benson et al., 2015; Lawrence, Celis, & Ott, 2014) I believe that developing a universal annual evaluation process with room for some adaptation can help to reduce variation in the T&P process, adapt to changes in science, and better recognize team science.

Studies have also proposed alternatives to the current faculty reward systems and provided examples of universities that have adopted new criteria to better recognize
team science in the T&P process. O’Meara (2015) provides an overview of three potential alternatives to the current T&P system to accommodate the recent changes in academia. These include tenure by objectives, post-tenure departmental reviews, and academic freedom guarantees without tenure. Each of these options could help to update these evaluation systems to simultaneously meet the increasing economic demands on universities while providing security for faculty members. The University of Washington provides an example of how developing universal faculty evaluation rubrics can increase the objectivity, reproducibility, and transparency of the faculty evaluation process. (Hoyt, 2014)

Vanderbilt University School of Medicine and Michigan State University College of Human Medicine have specifically incorporated recognition of team science into their T&P criteria. (Bunton & Mallon, 2007) In 2006, the Vanderbilt University School of Medicine wrote in their criteria for appointment to the tenured rank of associate professor,

Vanderbilt recognizes the critical importance of collaboration (“team science”) in research and scholarly activity and that the contributions of middle authors in multiauthored publications are often seminal and of the highest quality. When the research and/or scholarship is pursued in a collaborative fashion and results in multiauthored publications, the specific contributions of the candidate must be clear and significant. The candidate’s role can be described via the Critical Reference Form that must be included in the promotion dossier. In addition, the Chair, the manuscript’s senior author, and external correspondents can make an assessment of the quality and impact of a middle author’s contribution. (Vanderbilt, 2017a)

This specific recognition in the tenure criteria represents a way for colleges to explicitly acknowledge team science and explain how it is evaluated. Their incorporation of a critical reference form that allows the candidate to explain their role on a multi-authored publication also provides a model that other universities could adopt to provide much
needed clarity and context on the nature of the collaboration for the tenure committee. (Vanderbilt, 2017b) The University of Michigan incorporated team science into their T&P criteria by adding the phrase “including research conducted in collaboration with colleagues, students, and postdoctoral associates” to their current T&P guidelines for research. (cited in Bunton & Mallon, 2007) At other universities, deans have made formal announcements about recognizing collaborative and translational research in the T&P process. (Bunton & Mallon, 2007) These examples highlight different ways to start to incorporate team science into the T&P process. However, true incorporation of team science will require a cultural shift at a disciplinary and university level in addition to changing formal evaluation criteria.

Stokols et al. (2008a) highlight the role that institutional policies, support resources, and reward structures play in facilitating team science. However, few papers have examined how team science is evaluated in the T&P process. (Börner et al., 2010; Bunton & Mallon, 2007; Hall et al., 2008) Specifically, this study began based on the insight from Börner et al. (2010) that,

Although many young scientists are drawn to the intellectual rewards of interdisciplinary research as graduate students, they may also be deterred by the professional risks as early-career tenure-track scientists…In order to realize the unprecedented opportunities posed by team science, we need to develop new means to recruit, retain, and empower scientists from many different fields to work together [and] support the tenure and careers of younger scholars working across disciplines. (2, 8)

The literature on team science often references the critical need for a cultural shift towards recognizing and incentivizing interdisciplinary team science in formal and informal faculty reward and evaluation systems, but have not yet provided concrete suggestions for facilitating this change. (Disis & Slattery, 2010; Fiore, 2008; Rhoten & Parker, 2004)
I argue in this paper that updating and streamlining the T&P process to recognize and reward team science is essential to recruiting and retaining young interdisciplinary scientists, solving complex problems and advancing innovative research agendas.

Three research questions guided this study:

- How does the annual evaluation and T&P process currently evaluate collaborative research/team science?
- How does the evaluation of team science vary across colleges?
- What changes could be adopted (at a university, college, or department level) to better recognize team science, reward interdisciplinary collaborations, reduce variation in the evaluation process, and improve the T&P process?

**Methodology**

This paper is part of a larger ethnographic study of scientific collaboration and organizational culture at a large public university in the United States. This study used four methods to analyze the faculty evaluation and T&P process. These methods were:

1) text analysis of annual evaluation and T&P criteria by college (n=16); 2) network analysis of annual evaluation and T&P criteria by college (n=16); 3) qualitative analysis of an open-ended survey question administered to UF faculty soliciting alternative methods for recognizing collaboration in the T&P process (n=441); and 4) thematic analysis of semi-structured interviews with faculty members about the T&P process (n=32). These four methods were chosen because they allow me to explore the relationship between the formal T&P guidelines and actual evaluation practices that faculty members experienced.

The study began by examining the formal annual evaluation and T&P criteria set by each college to identify the official policies towards team science. Network analysis helped me to visualize variation in T&P criteria across colleges. Soliciting and analyzing
open-ended survey responses allowed me to identify common trends across the university. Semi-structured interviews provided an opportunity for in-depth contextual inquiry into the implicit norms that govern the T&P evaluation process and how they differed from the explicit criteria set by colleges and departments.

By triangulating our quantitative and qualitative research findings, I was able to capture and provide thick description of both the formal and informal T&P process. (Creswell & Clark, 2011; Geertz, 1973) This mixed method approach allowed me to provide practical recommendations for revising the formal evaluation criteria and incorporating team science into a university's organizational culture.

Data Collection

I collected the most recent annual evaluation and T&P criteria from each college in September 2015. I also collaborated with the Clinical Translational Science Institute (CTSI) to administer an online survey through Qualtrics in September 2015. This survey asked respondents a series of questions about research collaboration and barriers. The survey was distributed to 2,380 faculty members. 810 faculty members completed the survey and 103 partially completed the survey with a 38.4% response rate. (AAPOR Response Rate 2, 2016) The greatest college-level response came from faculty members in medicine and agricultural and life sciences, which corresponded with the university’s staffing patterns. One optional open-ended survey question solicited faculty members’ recommendations for better recognizing collaboration in the T&P process. This question was answered by 441 faculty members (54.4% of respondents who completed the survey).

I conducted semi-structured interviews with 31 assistant, associate, or full professors and 1 administrator from eight different colleges about their experiences with
scientific collaboration and the T&P process between November 2015 and April 2017. All of these faculty members either had extensive experience with T&P or were currently going through the process. They were selected using social network analysis (SNA) of collaborative publications and grant funding data between the period of 2013 and 2016 (n=25) or recommendations from interviewees (n=7). This approach allowed me to incorporate insights gained from text and network analysis of formal tenure criteria, as well as open-ended survey questions into our interview questions.

Each respondent was asked questions on the same general themes, but the interviews varied in depth, length, and focus based on their answers. Questions included: Is there anything you would change about the current T&P process; how did the T&P committee evaluate your collaborative research projects; and how do you think your department/college could better recognize and reward collaboration in the T&P process? Participants were interviewed for between 30 mins and 1 hour about their experiences going through the T&P process, evaluating T&P packets as committee members, and collaborating with other researchers. All interviews were recorded. I took notes during the interviews and again after listening to the recordings. Repetitive themes and specific suggestions from each interview were identified. Then, the constant comparison method was used to compare the interviews. (Glaser, 1965) Similarities and differences were also identified across colleges.

Data Analysis

I used an inductive grounded theory approach to analyze the qualitative data and identify themes. (Glaser & Strauss, 2009; Ryan & Bernard, 2003) The T&P guidelines and survey responses were read through twice before being sorted into categories. The first read through was used to get a general sense of the responses. During the second
read, repetitive themes were identified. These themes were recorded and entered into MAXQDA (1989), a qualitative data analysis software. Then, the responses were read through a third time and sorted into categories and further divided into subcategories. College’s T&P criteria, respondents’ survey responses, and semi-structured interviews varied in their specificity and length. Many responses highlighted more than one theme and were coded into multiple categories. More specific recommendations, categories, and subcategories were also identified during this coding stage. After all the responses were coded, the categories were compared and related themes were combined. The college unit was also used to compare theme occurrence across all three methods.

Networks of T&P criteria co-occurrence across colleges were analyzed using UCINET and visualized using NetDraw. (Borgatti et al., 2002) To create these networks a college by tenure criteria spreadsheet for each T&P category was created in Microsoft Excel. Each of the categories were mentioned by at least two colleges in their T&P criteria. This data was imported into UCINET and converted from a two-mode (college by T&P criteria) to a one-mode network (T&P criteria by T&P criteria). This process created an adjacency matrix that compared the amount of shared T&P criteria by college. NetDraw was used to visual the overlap between themes.

I examined the betweenness centrality and core-periphery network structure for each tenure category (research, teaching, and service). Examining the betweenness centrality of each category allowed me to examine the brokering role that T&P criteria play within each category. Betweenness centrality calculates the frequency that the T&P criteria are brokered across colleges by counting the number of short paths between these criteria (nodes). (Freeman, 1978) Those with high betweenness centrality serve a
brokering role between common and uncommon criteria. This measure visualizes T&P criteria variance across colleges. This measure was also used to determine the criteria’s size in the network visualization. T&P criteria that played a major brokering role appear larger on the network visualization than those that did not.

I also analyzed the core-periphery structure (Borgatti & Everett, 1999) for each tenure category network using a discrete model. I did this by partitioning the criteria into two groups: a cohesive densely-connected core and a sparse, loosely-connected periphery. The core group represents the tenure criteria with the highest level of cohesion across colleges. Criteria in the core group are connected to the greatest number of other criteria not connected to one another.

**Results**

**Text Analysis of Annual Evaluation and T&P Criteria**

There was a great deal of variation across colleges in terms of their annual activity report forms, T&P criteria, distribution channels, and whether guidelines are set at the college or department level. Some colleges use a paper form for their annual faculty evaluation, whereas others have adopted an online system for tracking faculty achievements. These different data collection and storage systems make it difficult for the university to share information or examine trends across academic units or colleges. The terminology used to refer to this annual evaluation form/report also varied greatly across colleges. This suggests a lack of consensus and communication across colleges about the annual faculty evaluation process.

There was also significant variation across and between colleges as to whether colleges or departments set the T&P criteria. The colleges of agricultural and life sciences, dentistry, journalism and communication, law, medicine, nursing, pharmacy,
public health and health professions, and veterinary medicine set T&P guidelines at the college level. The colleges of arts, health and human performance, liberal arts and sciences, and design, construction, and planning provided departmental level T&P guidelines in addition to college level criteria. Whereas, the colleges of business administration, education, and engineering had mixed level guidelines. This means that some departments within a college set specific guidelines, but others used college level guidelines. This variation results from the vast disciplinary differences within a college. This is especially true in colleges like the liberal arts and sciences where the humanities, social sciences, and natural sciences coexist within the same academic unit, but have vastly different publication and funding norms and preferences. It also highlights the lack of university level consensus on the T&P process.

Each of the sixteen colleges’ annual evaluation and T&P guidelines were separated into the categories of research, teaching, and service (Table 3-1). They also contained twenty distinct administrative fields. Three colleges in the health sciences (medicine, nursing, and veterinary medicine) also had a patient care category. The college of agricultural and life sciences had an additional tenure category for extension, the application of research findings to serve the public. No college had a specific section devoted to collaborative or interdisciplinary research efforts.

**Research**

Nineteen subcategories were identified within the research category of T&P criteria (Table 3-1 and Figure 3-1). The categories of peer-reviewed articles, conference presentations, and external funding had the highest betweenness centrality among research criteria for T&P (Figure 3-2). This suggests that distinction in research is most commonly evaluated using the number of peer-reviewed articles, attainment of external
funding, and presentations at academic conferences. Our analysis of this network’s core-periphery structure identified the core group of research criteria as peer-reviewed articles, external review of publications, reputation in discipline, conference presentations, impact of publication, differentiation between single versus co-authorship, and external funding ($r = 0.85$).

There was less agreement between colleges in the research category than in the teaching and service categories. The large number of subcategories used to evaluate research highlights cultural differences in the research products that are produced and valued by colleges. Only four colleges (agriculture and life sciences, engineering, journalism, and nursing) specifically referenced interdisciplinary or collaborative research in their T&P guidelines. This suggests that most colleges have not formally developed policies for evaluating interdisciplinary or collaborative research.

**Teaching**

Sixteen subcategories were identified within the teaching category of T&P criteria (Table 3-1 and Figure 3-3). The subcategories of student evaluations, department-level peer evaluations, and mentoring/advising students had the highest betweenness centrality among teaching criteria for T&P (Figure 3-4). This finding suggests that distinction in teaching is primarily evaluated by analyzing the candidate’s record of teaching evaluations and mentoring students. The categories of student evaluations, department-level peer evaluations, and mentoring/advising students were the commonly reported teaching criteria. Our analysis of this network’s core-periphery structure identified the core group of teaching criteria as student evaluation, graduate level mentoring/advising, teaching awards, general mentoring/advising, department peer evaluations, and curriculum development ($r = 0.89$).
Two colleges (arts and health and human performance) did not specify any criteria for evaluating teaching in their T&P guidelines. This suggests that these colleges have not formally developed policies for evaluating teaching in the T&P process. This could demonstrate a lack of weight or emphasis on teaching efforts in T&P decisions. However, all colleges established criteria for determining faculty members' teaching efforts in their annual evaluations. Amongst the colleges that listed teaching evaluation criteria, there was complete agreement on using both student evaluations and department-level peer evaluations to evaluate faculty member's teaching performance.

Service

Fifteen subcategories were identified within the service category of T&P criteria (Table 3-1 and Figure 3-5). The subcategories of service to discipline/profession, university, and the public had the highest betweenness centrality among teaching criteria for T&P (Figure 3-6). This finding suggests that the service evaluation typically focuses on a candidate’s record of service to the university, their discipline, and the general public. However, most colleges did not explicitly describe methods for engaging with the public or measuring their work’s impact. The categories of service to the public, university, and discipline/profession were the most commonly reported service criteria. Our analysis of this network’s core-periphery structure identified the core group of service criteria as service to the public, public presentations of research, service to the university, committee participation/leadership, service to discipline/profession, leadership role in professional organization, conference panel participation, and reviewing journal/grant submissions ($r = 0.88$).

Two colleges (public health and health professions and dentistry) also listed patient care under the service category. This differs from other colleges in the health
science category who have a separate T&P category devoted to patient care. There was also a lack of consensus across colleges on what category advising students falls into. Colleges sorted advising students into all three T&P categories.

**Qualitative Analysis of Open-ended Survey Question**

The three most common responses to the survey’s open ended question on revising the T&P process to more appropriately recognize research collaboration and team science were increased recognition for 1) all investigators in a team (n=76), 2) collaboration and/or team science in general (n=75), and 3) all authors on a publication (n=46). This means that many faculty members believe that the T&P process needs to be revised to better recognize investigators who collaborate on grants and publications.

Respondents also proposed explicit changes like: creating a new section in the packet to document research collaboration, clearly assigning weights for collaborative efforts, providing additional guidance for junior faculty members, and giving faculty members an opportunity to provide narrative about team roles. Incorporating these types of specific changes could help the T&P process to reward investigators for their efforts in team based scientific research. A few faculty members’ responses also highlighted the role that organizational and disciplinary culture plays in shaping these processes. This mirrors the findings of O’Meara (2011) and Gardner and Veliz (2014) that faculty reward systems largely reflect the values and goals of the institution’s leaders. Addressing these issues and promoting cultural changes across disciplines or colleges will require far more time and effort than universities simply changing the formal required contents of a university’s T&P packet. Rather, it requires bottom up disciplinary conversations and approaches that embrace and prioritize team science.
Table 3-2 provides an overview of the most common changes proposed by faculty members to better recognize team science and research collaboration in the T&P process. I also compared responses by colleges. However, different sample sizes across colleges made identifying clear patterns difficult. No statistically significant correlations were found between faculty members’ college affiliation and their recommendations.

In addition to this specific question on the T&P process, respondents were also asked to identify major barriers to collaboration. Eleven respondents specifically cited the T&P process as a major barrier to collaboration. One survey respondent wrote,

The [university’s] T&P system encourages senior authorship over collaborative work. Also, increasing administrative burdens on faculty have made them reluctant to reach out to other disciplines.

This response demonstrates the T&P committee’s lack of recognition of multi-authored publications. Another faculty member defined the greatest barrier to collaboration as,

Boundaries that exist between colleges (e.g., [College of Medicine] and [Pharmacy]) making it difficult to optimize certain programs.

This response demonstrates how the differences in T&P evaluation criteria and faculty reward systems across colleges negatively affects interdisciplinary research teams.

These differences in T&P guidelines at both a college and departmental level play a major role in shaping who participates, what research products (e.g. publications and grants) they produce, and how team science occurs across the university. This suggests that university administrators need to collectively address college level boundaries to collaboration. These responses also highlight the need for greater institutional unity and support at all levels (university, college, institute, and department) for interdisciplinary collaboration in the T&P process.
Thematic Analysis of Semi-Structured Interviews with Faculty about the T&P Process

Most faculty members interviewed highlighted a strong disconnect between the individualistic nature of the T&P process and the collaborative nature of contemporary research. These interviews also highlighted the cultural differences between colleges, which is reflected in their T&P criteria. Most respondents felt that the current T&P system needed to be improved to better recognize team science. They also said that the T&P timeline can present challenges for collaboration as collaborative projects often take more time than individual projects. However, they agreed that they preferred working in teams because the impact of collaborative work is often far greater than individual work.

Many faculty members suggested increasing and standardizing mentorship for junior faculty members about collaboration. These respondents described their own experiences with mentorship both as a mentor and a mentee. One faculty member said that he specifically instructs junior faculty to think critically about the types of collaborations they get involved in and carve out smaller portions of the collaborative project early on in the project. This allows them to publish on their individual research focus to develop their T&P packet and develop a strong individual record while collaborating with other researchers on important projects. Another faculty member described how she encourages junior faculty to collectively plan out their team authorship order as soon as they start collaborating to ensure that all team members going up for tenure have enough first authored publications.

The T&P process often appears unclear and mysterious to junior faculty members. (O'Meara 2010) Communication failures were a major theme across all of the
interviews. Faculty members (at different stages in their careers) could not explicitly identify what specific factors makes someone eligible to receive tenure in their department or college. Rather, all respondents discussed the case-by-case nature of tenure and emphasized a combination of factors (number of publications, funding record, research publication’s impact, reputation, personal factors, etc.). However, all respondents agreed that research was the most important factor in the T&P process regardless of college. Reputation in their field, as determined by external letters, in addition to in their department also played a major role in these decisions.

Researchers and clinicians in the health sciences also discussed the challenges of evaluating clinical faculty in the T&P process. One faculty member described how developing unique evaluation criteria the multi-mission track was essential to supporting clinicians and prioritizing patient care. He suggested that other colleges could learn from this process to better evaluate faculty members at every stage of the research process. These evaluations could be used to measure different stakeholders (e.g. collaborators, colleagues, community organizations, patients) perceptions of the faculty members’ contribution and quantify their impact. This example highlights the important T&P criteria development lessons that can be shared between colleges to improve the evaluation process. However, since this is a fairly new track some clinicians explained that there is still some stigma associated with any non-research focused tenure track.

Faculty members agreed that clear hierarchy and expectations are often not set and communicated to junior faculty members by colleges or departments. Faculty members also said that these unclear expectations and ambiguity about how T&P criteria are interpreted often leads to anxiety among junior faculty members. One
associate professor who had also served on T&P committees recounted his own experiences with T&P by describing the process as an “active conversation” rather than a strict following of T&P criteria. He used this phrase to describe the major disconnect between what the formal guidelines state and his tacit knowledge of the T&P process. This illustrates a stark disconnect between the formal guidelines, what deans say in college level faculty meetings, and individual committee member’s interpretation of criteria in T&P evaluations. Other respondents also reported discrepancies between written criteria, oral recommendations, professors’ perceptions of the process, and actual T&P decisions. This mismatch between expectations and reality creates a culture of fear surrounding the T&P process. This disconnect also often leads to conflict over processes within colleges and departments. Clearly defined guidelines and expectations could help to reduce this tension.

Discussion, Conclusion, and Recommendations

Team science will continue to play an important role in the evolution of science and development of innovations. Contemporary research often requires team based science to complete complex interdisciplinary projects and receive competitive grant funding. Many faculty members, especially younger investigators, also enjoy working in teams and want to be recognized and rewarded for their research collaborations. However, the T&P process has traditionally been focused primarily on individual research achievements. This disconnect between university expectations, T&P guidelines, and the contemporary research process causes team science to be evaluated inconsistently and often undervalued across departments and colleges.

This paper provided a case study that explored how one US university evaluates team science in their annual review and T&P process through a mixed method
approach. This study examined trends in faculty evaluation and provided recommendations for more appropriately recognizing collaboration in higher education. The findings from this in-depth contextual inquiry reflect larger trends in science and higher education. As a result, I believe that our recommendations can be applied to improve the T&P process and better recognize team science at other tenure granting colleges and universities.

Our study had three key findings. First, it found that the current annual evaluation and T&P guidelines at the college level focus predominantly on individual research achievements (e.g. single or first author publications and primary investigator status on grants). This result is consistent with the findings of Clark (1997) and Fairweather (1993). As a result, faculty members who collaborate on publications and grants are often penalized for working in teams.

The study’s findings reveal that this structural focus on individual versus collaborative research often disincentives and discourages faculty members from engaging in team science. Interviews with faculty members also suggests that many scientists continue to collaborate despite these disincentives due to their passion for innovative research and the increasing availability of research grants that emphasize and reward team science. These findings expand upon previous studies’ findings that team science often generates higher impact research findings that are often marginalized in the evaluation of contemporary research. (Stokols et al., 2008a; Börner et al., 2010; Bunton and Mallon, 2007) Our findings also suggest a need for future studies to conduct cross-university comparisons on the evaluation of team science in the T&P process.
Second, it found that the evaluation of team science in the T&P process varies significantly across colleges within a single university. Many colleges also had additional variation in their evaluation criteria defined at the department level. This makes it difficult to track or compare tenure within a university. Our network analysis of T&P criteria visualized the college level variance in research, teaching, and service criteria. This variation was especially pronounced in the research category. Only three of the sixteen colleges specifically mentioned team science or collaboration in their T&P guidelines. This illustrates a lack of emphasis in team science.

Our qualitative results also show that committee members’ interpretations of the guidelines vary greatly based on their own research experiences, especially when evaluating collaborative research products (e.g. co-authored publications and co-investigator status on grants). This variation also presents challenges for T&P, as faculty members who collaborate on interdisciplinary projects are often evaluated differently than their collaborators based on the same publications and grants. This is consistent with Rhoten and Parker (2004) findings that a university or discipline’s lack of emphasis on team science often forces graduate students and junior faculty members to balance their desire to conduct collaborative interdisciplinary research with their goal to receive tenure. Universities need to develop a universal evaluation tool that allows for comparison across colleges, but also provides departments and colleges with autonomy to add specific criteria in order to reduce these issues.

Third, our analysis of annual evaluation forms, T&P criteria, survey data, and faculty narratives from semi-structured interviews illustrated a clear need to improve the
T&P process through increasing the recognition of team science, rewarding interdisciplinary collaborations, and reducing variation in the evaluation criteria.

The following are ten recommendations I identified for better recognizing team science in the T&P process:

1. Clarify and broaden existing T&P criteria to better address the role that collaboration plays in contemporary science and address the challenging federal funding climate.

2. Create a numbered section in the T&P packet that allows faculty members who collaborate to describe their role in their collaborations, be evaluated by their collaborators, and use data to assess the impact of the collaboration.

3. Improve and increase communication about the T&P process at all levels (university, college, and department) to increase transparency, get feedback, and reduce process conflicts. An excellent way to increase transparency would be to provide all faculty members with access to an overview of the process and the online packet. This would allow faculty members to create a habit of regularly filling out their achievements and receiving feedback on their progress from their mentors. The packet should also be updated to allow faculty to input their publications and grants through Web of Science, PubMed, their biosketch from NIH and NSF, or other online tools.

4. Set clear expectations for junior faculty members (when they first enter the university), specifying how their college evaluates collaboration and the research outputs (co-authored publications, co-investigator status on grants, etc.) that the team collectively produces.

5. Share lessons learned between colleges. Colleges have different research norms and structures. As a result, individual colleges put a lot of effort into developing their own criteria. However, a great deal can be learned by increasing communication between colleges and T&P committees about the process of evaluating faculty members.

6. Continue holding college level meetings that explain the T&P process and make sure that all colleges adopt and schedule these meetings on a regular basis. Add panels of associate and full professors who have previously served on college’s T&P committee to provide general suggestions to assistant professors on how to best highlight collaborations in the existing packet and answer questions. Answers to common questions should be posted on the college T&P website.

7. Plan to host additional open conversations between faculty members at different stages of their career about the T&P process (for example a town hall meeting), in particular at the college level. This dialogue could help to generate new ideas.
for recognizing collaboration at the college level. In addition, hearing from associate and full professors about their experiences with the T&P process could reduce anxiety among junior faculty members about the process.

8. Provide formal and regular mentoring (at least once a semester) for junior faculty members to receive feedback on their packets, help them choose better collaborative projects/collaborators, negotiate for their individual interests within their research group, and produce research outputs that will be recognized by their department/college.

9. Clearly outline the steps in the T&P process (at the university, college, and department level) so that the experience is unambiguous for all stakeholders.

10. Provide clearer and more objective evaluation criteria at the department and college level that can be followed by all stakeholders in the T&P process. For example, this department expects that faculty members will produce 3 first-author articles or 5 non-first author publications and 1 awarded grant as a PI or 2 awarded grants as a co-PI per year. This type of clarity reduces ambiguity for applicants and committees.

Recognition of team science requires changes in the T&P evaluation criteria as well as a cultural shift in administrators and faculty members’ attitudes towards scientific collaboration. This shift will require broadening the academic scholarship to incorporate research products that are created in teams. It will also require a deeper consideration of what qualities make someone a good scholar. Developing clear definitions of scholarship and collaboration can help researchers and administrators to improve the hiring process, standardize their evaluation criteria, and improve faculty retention.
Table 3-1. Categories and subcategories identified by text analysis of annual evaluation and T&P criteria.

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>Peer-reviewed articles</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>External funding</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Conference presentations</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Reputation in discipline</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Impact of publication</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Differentiation in credit between single and co-authorship</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>External review of publications</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Books</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Awards/honors</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Patents</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Creative work (e.g. films)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Quality of journal/press</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Publications (did not specify which type)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Differentiation in credit between primary investigators (PI) and co-investigators</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Interdisciplinary or collaborative research efforts</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Graduate student training</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Innovation</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Software development</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Book reviews</td>
<td>2</td>
</tr>
<tr>
<td>Teaching</td>
<td>Student evaluations</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Department-level peer evaluations</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Mentoring/advising students</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Curriculum development</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Teaching awards</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Creating instructional materials</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Evidence of learning outcomes/effectiveness</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Publishing educational research</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Classroom observation data</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Clinical training</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Self-evaluation of teaching</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Courses taught</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Peer evaluation committee feedback</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Invited professorship at other academic institutions</td>
<td>2</td>
</tr>
<tr>
<td>Service</td>
<td>Service to the public</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Service to the university</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Service to the discipline/profession</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 3-1. Continued

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Committee participation/leadership</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Public presentations of research</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Leadership role in professional organizations</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Conference panel participation</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Reviewing journal/grant submissions</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Consultations</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Mentoring junior faculty</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Publications for nonprofessionals</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Membership on committees and boards</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Extension/outreach</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Clinical service</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Advising students</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
Table 3-2. The most common (6+) faculty recommendations for revising the T&P process to more appropriately recognize research collaboration and team science.

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>n</th>
<th>Example response</th>
</tr>
</thead>
<tbody>
<tr>
<td>More recognition for all investigators in a team</td>
<td>76</td>
<td>&quot;Recognition for engaging in collaboration as opposed to focus on first authorship or principal investigator.&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;Not completely understanding the process, I would suggest that [the] T&amp;P committee should recognize collaborative research particularly amongst basic science (PhD) and practicing physicians (MDs). To only recognize solo accomplishments diminishes the strength of the University as a whole.&quot;</td>
</tr>
<tr>
<td>More recognition for collaboration/team science</td>
<td>75</td>
<td>&quot;A decreased focus on first/senior authorship and increased focus on high impact team research productivity.&quot;</td>
</tr>
<tr>
<td>Better recognition for all authors</td>
<td>46</td>
<td>&quot;People should be incentivized to participate in team science, not just PI's. At present, PI status is the coin of the realm and nothing else really matters on the tenure track. If &quot;PI&quot; status is important, then make all Co-I's PI of their own subcontract. Doing so, however, makes it difficult to really code and understand the nature of their collaborative effort. Perhaps social network analysis could be used to develop metrics identifying investigators’ ‘centrality’ in an emerging network and such metrics could supplement existing ones when making T&amp;P decisions.&quot;</td>
</tr>
<tr>
<td>Support and reward team science/collaboration</td>
<td>26</td>
<td>&quot;Making multi-department and multi-college research count more, not only for researchers but for department chairs and Deans so that they have incentives to recognize that. Now, the administrative leaders do not have direct incentives for participation outside their units and therefore tend to discount them in evaluations.&quot;</td>
</tr>
<tr>
<td>More recognition for interdisciplinary efforts</td>
<td>26</td>
<td>&quot;Scientists should be given weightage during Tenure and Promotion in recognition of the translational work and successfully bringing products into market, especially when it brings positive revenue stream into UF as royalty. Weightages should also be given to recognize research collaboration with other universities that helps take the science forward. Some of the premier institutions like MIT have already taken this route.&quot;</td>
</tr>
<tr>
<td>Clearly assign weights for collaborative efforts</td>
<td>20</td>
<td>&quot;The definition of true contribution to team research must be addressed so that young faculty members can gain credit for the research contribution for tenure/promotion packet even if one is not the PI of the grant.&quot;</td>
</tr>
<tr>
<td>Specifically address collaboration in the T&amp;P packet</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Recommendation</td>
<td>n</td>
<td>Example response</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-----</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Less emphasis on individual's external funding</td>
<td>16</td>
<td>&quot;The definition of true contribution to team research must be addressed so that young faculty members can gain credit for the research contribution for tenure/promotion packet even if one is not the PI of the grant.&quot;</td>
</tr>
<tr>
<td>Better address differences in clinical settings</td>
<td>14</td>
<td>&quot;If I am teaming up as a faculty member with another department in UF or outside UF, as a co-investigator, don't hold that against me. Recognize Co-investigators. Recognize grant applications and recognize that first and last authorship on manuscripts are not the only way that researchers contribute. I have been second author on a manuscript to give the postdoc a chance to make a name for his or herself and have collaborated with my coPI and have been second author and he was last author, even though I thought of much of the project, designed a good portion of it, and without me, the results would not exist. The College of Medicine does not recognize this situation. In my review, I was told that I would have to have 5 first/last author papers, some could be reviews, of my own. I cannot collaborate with anyone if this is the case. And, with this pressure, I cannot think of taking any inexperienced clinical faculty who have never worked in a lab because this is who the COM is hiring. Teaching them would slow us down. My whole salary depends on grants, so the UF Tenure and Promotion System cannot be so formulaic.&quot;</td>
</tr>
<tr>
<td>Create a numbered section to list/document research collaboration</td>
<td>14</td>
<td>&quot;Add a numbered category for collaboration in the Tenure-Promotion-Permanent Status packet; combine the recently established two panels for the Academic Personnel Board to recognize collaboration between research and non-research faculty.&quot;</td>
</tr>
<tr>
<td>More recognition for funding sources beyond federal/R01</td>
<td>14</td>
<td>&quot;I wish that the NIH R01 was not almost the currency of promotion. The university could do more to help young investigators get funding. They need training in how to identify funding sources and support for producing applications.&quot;</td>
</tr>
<tr>
<td>Provide more guidelines and mentoring for junior faculty members</td>
<td>12</td>
<td>&quot;The goal of establishing independence with the funding focus on team science is hard to reconcile for early investigators. Mentoring from professors at other colleges can help, however, you also need to stay focused in your own discipline.&quot;</td>
</tr>
<tr>
<td>Recommendation</td>
<td>n</td>
<td>Example response</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>----</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>More recognition for collaborations outside the university</td>
<td>11</td>
<td>&quot;Outside collaborations and positions on multi-site projects; at the moment it feels like you are penalized if you collaborate with other institutions because they have infrastructure and resources that we don't. Faculty and administration here don't want to admit that.&quot;</td>
</tr>
<tr>
<td>Remove penalization for collaboration</td>
<td>11</td>
<td>&quot;Researchers should not be penalized for collaborating on research (which may yield many important contributions to science but not always a first or last authored paper).&quot;</td>
</tr>
<tr>
<td>Less emphasis on individual accomplishments, more focus on team performance</td>
<td>10</td>
<td>&quot;The field of research is more about a team approach and less on a single individual. The tenure and promotion process seems very focused on the individual and less on being a strong member of a team.&quot;</td>
</tr>
<tr>
<td>More recognition for support faculty’s contributions to collaborations/team science</td>
<td>10</td>
<td>There is no real place for people who have a support mentality. There is one person that I know who is doing that, but he is not also functioning as an independent scientist. This will be an issue for him when he submits his tenure packet.&quot;</td>
</tr>
<tr>
<td>More recognition for research</td>
<td>9</td>
<td>&quot;Research efforts not just published efforts should be recognized teaching is sorely underrepresented and is one of our main goals&quot;</td>
</tr>
<tr>
<td>A cultural change is needed at the university/college level</td>
<td>8</td>
<td>&quot;The challenge may not be rules and procedures so much as departmental culture and tradition, where colleagues don't value collaborative research as much as independent (or &quot;fundamental&quot;) research.&quot;</td>
</tr>
<tr>
<td>Better recognition for clinicians who do translational research</td>
<td>7</td>
<td>&quot;Clinicians who paticipate in translational should be acknowledged as much as those who do basic research. Impact factor does not reflect this type of research. These individuals are likely not to be first or last authors.&quot;</td>
</tr>
<tr>
<td>Improve tenure committees</td>
<td>7</td>
<td>&quot;P&amp;T Committees are as good as the members who serve. Right now, there are little or no incentives for the best people available to serve.&quot;</td>
</tr>
<tr>
<td>More recognition for innovation</td>
<td>7</td>
<td>&quot;Explicitly value innovative work.&quot;</td>
</tr>
<tr>
<td>Give opportunity to provide narrative about collaboration/team roles</td>
<td>7</td>
<td>&quot;Opportunity to provide narrative about collaborative relationships - including how the partnership developed and has continued.&quot;</td>
</tr>
<tr>
<td>Recommendation</td>
<td>n</td>
<td>Example response</td>
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</tr>
<tr>
<td>Better define levels of participation in collaboration/team science</td>
<td>6</td>
<td>&quot;Define levels of participation in collaboration and team science.&quot;</td>
</tr>
<tr>
<td>Value both individual and team research</td>
<td>6</td>
<td>&quot;The system is fine. The change must be at the department and college levels where leaders need to emphasize the collaboration is an accepted norm. Collaboration should be viewed no differently than non collaborative research. One type is not better than another.&quot;</td>
</tr>
<tr>
<td>Emphasize quality over quantity</td>
<td>6</td>
<td>&quot;Have more weight to quality of the science and impact of the science compared to number of publications for the T&amp;P packet.&quot;</td>
</tr>
<tr>
<td>More support for clinical research efforts</td>
<td>6</td>
<td>&quot;Clinical research is often funded by Industry, but Tenure review emphasizes NIH funding. This can be a problem for young investigators if their time is consumed with important clinical research that does not build NIH funding record.&quot;</td>
</tr>
</tbody>
</table>
Figure 3-1. This network visualizes research T&P criteria co-occurrence across colleges for criteria identified by at least 2 colleges (nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Figure 3-2. This network visualizes research T&P criteria co-occurrence across colleges for criteria identified by at least 6 colleges (the nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Figure 3-3. This network visualizes teaching T&P criteria co-occurrence across colleges for criteria identified by at least 2 colleges (nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Figure 3-4. This network visualizes teaching T&P criteria co-occurrence across colleges for criteria identified by at least 6 colleges (nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Figure 3-5. This network visualizes service T&P criteria co-occurrence across colleges for criteria identified by at least 2 colleges (nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Figure 3-6. This network visualizes service T&P criteria co-occurrence across colleges for criteria identified by at least 5 colleges (nodes are sized by betweenness centrality, line thickness is based on the strength of the tie).
Scientific collaboration produces new discoveries, perspectives, and fields of knowledge. However, it is difficult to track the emergence of new fields at an organizational level or evaluate teams using an experimental research design. I address this issue in this paper by outlining a mixed method approach for identifying emerging research communities within a university’s scientific collaboration network. These communities represent real groups of between ten and a hundred researchers identified within the university’s whole network of approximately 5,000 researchers using the Louvain method for community detection. (Blondel et al., 2008)

Our combined use of quantitative and qualitative methods provides our study with a more nuanced understanding of the structure and cultural context of these emerging research fields. This paper provides an overview of an 8-step method that combines the principles of social network analysis, ethnography, and design thinking to identify emerging scientific fields and alter these group by creating new teams (by adding edges/links between previously unconnected nodes/scientists) within these existing communities. This study is significant because it proposes a new method for identifying emerging research fields and outlines how to use an experimental design to evaluate the outcomes of a network intervention.

The main questions that guided this study were:

- How can we identify which fields are emerging at a particular university?
- What is the network composition of these emerging fields?
• What is the level of collaboration and communication between researchers in an emerging field?

• How does disciplinary and departmental affiliation shape these collaborations and their communication dynamics?

• What types of collaboration and contextual details are missing from scientific networks that operationalize collaboration as co-authorship on a publication or co-investigator status on a grant? How can we broaden the lens of collaboration?

A mixed method approach allowed my collaborators and I to answer these and other important questions. It also improved our knowledge and models of these communities by helping us combine insights from big data and thick data. (Wang, 2013)

The insights gained from our ethnographic field data about the context and narratives behind big data could also be applied to correct and refine the models presented by quantitative studies. Applying an ethnographic lens allowed my collaborators and I to connect scientific collaboration networks with larger narratives about team science and translational research. I believe that using this network ethnography approach can help organizations in academia, industry, and government better track emerging research fields in their organization, support existing teams, provide funding to encourage new groups to collaborate on these topics, and translate their findings to the public.

This study builds on Valente (2012), Vacca et al. (2015), and other network scientists’ research on the role of network interventions in science, health, management, and other fields. These studies have outlined methods for identifying influential individuals within a community, segmenting communities, inducing increased interaction between already connected community members, or altering the whole network to create or remove individuals or connections within an existing community. Our study adopts an alteration approach to increase edges (connections) between group members who had not collaborated before.
Previous studies have also highlighted the need for network ethnography to better understand the complexities of social networks and design interventions. (Valente et al., 2015; Berthod et al., 2017) Thus, this study uses network ethnography to identify emerging scientific fields and design a network intervention to encourage new collaborations in these research communities. I believe the ethnographic dimensions of this project can highlight the important role that iterative design, qualitative data collection methods, and contextual analysis can play in developing better visualizations of networks and understanding context when using large data sources. Our study data included collaboration information for approximately 5,000 researchers, 189,000 collaborative connections between scientists, and 150 research communities between a five-year period. Collecting ethnographic data allowed us to improve our models to better fit the realities of collaboration culture at a particular university and examine organizational trends.

**Literature Review**

Scientific collaboration networks are a crucial channel for the diffusion of knowledge and innovation across disciplines and organizations. Collaboration between scientists has been steadily growing each year. (Dhand et al., 2016; Wuchty et al., 2007; Leahey, 2016) As a result, the field of team science has developed new metrics and methods for measuring team functioning in academic, government, and industry contexts using rigorous scientific methods. (Börner et al., 2010, Stokols et al., 2008b; Fiore, 2008; Falk-Krzesinski et al., 2010; Falk-Krzesinski et al., 2011; Rozovsky, 2015) These studies have found that research collaborations vary greatly both within and across organizations. This variation occurs primarily based on the number of
collaborators, the amount of team members/organizations involved, the group’s disciplinary orientation, and the team’s end goal. (Stokols et al., 2008a)

On one end of the collaboration spectrum, pairs or teams of researchers from the same department and university work together to address a problem that advances the discipline (unidisciplinary). Many scientific collaborations are unidisciplinary due to the organizational structures, training process, and reward systems of many institutions. Two major advantages of single discipline collaborations are the ability to build consensus on what is at the edge of the discipline and work more quickly to produce results due to a shared disciplinary training and language. (Sonnenwald, 2007; Jacobs, 2014) As a result, unidisciplinary collaborations are often prioritized by departments in the tenure and promotion (T&P) process. However, this disciplinary focus causes silos of knowledge to emerge and fragments scientific research. This insulated process limits knowledge diffusion, innovation transfer, and general awareness of others work on similar topics across disciplines. It also has caused disciplines to develop very different standards for evaluating the impact of research and the productivity of researchers.

Despite departmental pressures, many scholars choose to collaborate across disciplines. Cross-disciplinary collaborations can be divided into three categories: multidisciplinary, interdisciplinary, and transdisciplinary. (Stokols et al., 2008a) There has been a growing interest in supporting these types collaborations based on their potential to bridge disciplinary research silos. (Jacobs, 2014) In a multidisciplinary collaboration, teams include researchers from multiple disciplines who propose a solution to a shared problem by dividing up the project based on their individual expertise to sequentially collect and analyze the data. Whereas in an interdisciplinary...
team, investigators work jointly to collect and analyze their data in a more interactive manner. Transdisciplinary collaborations occur when team members from different disciplines and/or multiple organizations collaborate on a project that transcends the individual or combination of their disciplines to develop an entirely new model or research field that addresses a substantive problem.

This study uses social network analysis (SNA) and community detection algorithms to identify cross-disciplinary emerging research fields within a university’s scientific collaboration network that could benefit from additional support. SNA provides a method for visualizing the social connections (edges) between individuals or other entities such as organizations (nodes). It is also an interdisciplinary field that illustrates the role that social relationships play in shaping individual and group behaviors. (Wasserman and Faust, 1994) As described in the overview section, it has been used to design interventions that use information about the network’s structure and individual members’ attributes to promote behavioral changes. (Valente, 2012; Valente et al., 2015; Vacca et al., 2015) SNA has also been used to measure and describe the structural patterns of scientific collaboration networks. (Newman, 2004)

Scientific collaboration network structure is driven by a variety of organizational, disciplinary, geographic, linguistic, and cultural factors. Spatial proximity, homophily, transitivity, past collaboration experiences, shared funding sources, disciplinary training, and department and/or college affiliation play a major role in shaping the structure of scientific collaboration networks. Previous studies have found that spatial proximity is a strong predictor for research collaboration, with those closest to one another most likely to collaborate. (Katz, 1994; Newman, 2001; Olson & Olson, 2003) Analysis of
homophily (the idea that birds of a feather flock together) in collaboration networks has found that researchers are more likely to work with other researchers who are similar to them in discipline, age, gender, and other background characteristics. (Powell et al., 2005) Research on the transitivity (the concept that friends of my friend are also my friends) of scientific collaboration networks found that the clustering coefficient was greater than by random chance and occurs due to scientists often introducing their collaborators to their other collaborators. (Wasserman & Faust, 1994; Newman, 2001) Studies have also found that disciplinary affiliation is a significant predictor of grant and publication network structure. (Dhand et al., 2016)

Scientific collaboration networks are often very large. The networks in our study range in size from between 3,000 and 5,000 nodes (individual researchers) and between 10,000 and 20,000 edges (collaborative links between researchers). Other studies have used a variety of different quantitative methods to examine specific research fields or groups. (Chen, 2003; Chen, 2004; Braam & Van Raan, 1991a; Braam & Van Raan, 1991b; Massy, 2014) Community detection algorithms allow researchers to identify smaller meaningful units within a larger network. (Newman & Girvan, 2004; Blondelet al., 2008) This helps to compare and contrast communities within the network and identify trends.

The community detection literature has primarily focused on quantitative approaches for identifying and examining communities. Many of these approaches have been adapted from methods developed in computer science, sociology, and statistics. (Newman, 2004; Porter et al., 2009) Previous studies in this field have highlighted the difficulty of testing and evaluating algorithms’ effectiveness at community detection in
real-world networks. (Gregory, 2008; Fortunato, 2010) Newman (2008) also acknowledged this issue in his critique that,

> The development of methods for finding communities within networks is a thriving sub-area of the field, with an enormous number of different techniques under development. Methods for understanding what the communities mean after you find them are, by contrast, still quite primitive, and much more needs to be done if we are to gain real knowledge from the output of our computer programs…Moreover, it’s hard to know whether we are even measuring the right things in many cases.

Applying a network ethnography approach and interviewing a sample of community members can help to address these measurement issues. It can also add important details to the network analysis about the cultural context of the community.

There is a long history of anthropologists combining ethnographic and network methods to examine personal and small community networks. (Radcliffe-Brown, 1940; Mitchell, 1974; Wasserman & Faust, 1994) Ethnography provides a scientific method for analyzing cultures. This ethnographic study of a university focuses on how organizational dynamics and disciplinary norms shape scientific collaboration culture. This paper is part of a small but emerging body of literature applying ethnographic approaches to examine networks and other models created by big data sources. (Velden & Lagoze, 2013; Wang, 2013; Nafus, 2014, Berthod et al., 2017)

In order to design a network intervention, the planners must possess a strong understanding of both the underlying network structures of a community and how its cultural context shapes group behavior. Network ethnography combines SNA and ethnographic methods to explore communities more deeply. (Velden & Lagoze, 2013; Berthod et al., 2017) Combining qualitative and quantitative approaches enables scientists to cultivate a deeper understanding of both network structures and cultural processes. This dual analysis adds depth to both sides of the analysis. It helps to
develop more realistic models of community behavior, address measurement issues, and analyze decision-making processes at both an individual and group level.

Our study applies a design thinking framework to the community detection process. Design thinking is a method that prioritizes iteration and constant revision. (Buchanan, 1992; Brown, 2009) This approach is primarily used by designers especially in agile product development in technology companies. It also draws on the vast literature on translational science. (Woolf, 2008; Hörig et al., 2005; Sussman et al., 2006; Stokols et al., 2008a) This field has two main focuses. First, the translation of scientific knowledge to facilitate the adoption of new clinical practices and improve public health outcomes. Second, translating knowledge within teams or transferring knowledge between teams, institutes, or other organizations. The translation process plays a vital role in the development of novel therapies, replication of scientific studies, and dissemination of findings to the public. This literature provided the study with a framework for translating this network intervention to other contexts.

**Methods and Results**

Our study adopted a multi-stage mixed method iterative approach for identifying emerging scientific fields, investigating their collaboration dynamics, and proposing new collaborations between community members. I created an 8-step iterative process that combined social network analysis, community detection, ethnographic interviews, behavioral observation, web profile analysis, and surveys to achieve these goals (Figure 4-1). The following sections will outline this study’s research methods and process.

**Retrieve and Disambiguate Collaboration Data**

Our first step was to acquire scientific collaboration data for all investigators at the university. I operationalize scientific collaborators as co-investigators on at least one
funded grant or co-authors on at least one academic publication. Therefore, I used grant and publication data to create scientific collaboration networks. My collaborators and I chose this approach because we had access to university level data on these topics and believe that they represent the most common products of formal research collaborations in academia. Many studies have used publication data to explore scientific collaboration networks. However, grant data is less frequently used due to more limited access. Other studies have examined different types of scientific collaboration by using data on clinical trial recruitment, patents filed, clinical care of patients, spatial proximity, co-citation in publications, or less formal indicators such as communication via email. My collaborators are also experimenting with including data on co-membership in graduate student and university service committees in future models.

We retrieved grant funding data from the university’s office of research. This data provided grant transactions that occurred between 2011-2015. Since these data were not initially designed for network analysis, we encountered two challenges. First, since the data represented credits and debits related to all types of funding, we had to be careful not to use the number of lines as an indicator of the level of collaboration. Second, we recognized that in some large grants (e.g. institute funding or training grants) a single contract includes many subprojects or trainees. In some cases, the primary investigator listed on the grant might be the director of institute who does not know or collaborate with all the other investigators listed on the grant. Thus, levels of collaboration on a grant varied and not all lines represented an actual or equal collaboration.
We used publication data extracted from the Web of Science from the same period. The data was disambiguated using an algorithm written for a semantic web application that linked publication names with university IDs. (Börner et al., 2012) However, previous studies have highlighted the challenges of disambiguating publication and co-citation data. Despite these limitations, we believe that this is the best way to create a scientific collaboration network for a single university.

Identify Emerging Research Communities

Our second step was to identify emerging research communities within the university’s scientific collaboration network from this period (Figure 4-2). We conceptually define an emerging research community as a group of researchers collaborating on a related scientific topic identified using the Louvain method of community detection. (Blondel et al., 2008) The first round of analysis identified 147 communities with 688 researchers. The mean number of individuals in a community was 4.68 (with a maximum of 51 and a minimum of 2). Most of the community members identified were from the health (279) and agricultural sciences (186). There was also a significant distinction by gender with a majority of male community members (75%). This percentage was slightly higher than the university’s staffing patterns where males made up 61% of all full-time faculty members.

These communities sometimes mapped onto traditional disciplinary boundaries, which are typically reflected in departments across universities. These types of collaborations allow researchers from different universities to discuss trends and advance their field. Departments also play an important role in compartmentalizing science. These disciplinary units are reflected in federal programs, funding opportunities, hiring practices, money allocation, graduate training, and the division of
university resources. Yet, our primary goal for this analysis was to identify cross-disciplinary communities that present unique combinations of knowledge (Figure 4-3).

We operationalize cross-disciplinary communities as groups with collaborations between researchers from at least two different disciplines which are often operationalized as departments. We believe that tracking these combinations of knowledge can help us to identify the emergence of new scientific fields that often transcend disciplinary boundaries. These emergent research communities also highlight the unique research focuses of a particular university and allow organizations to track the evolution of a specific field at their institution.

There are several different methods for identifying communities within networks. These methods include cliques, cluster analysis, factions, Girvan-Newman, and Louvain. We chose to use the Louvain method because it maximizes modularity. (Blondel et al., 2008) This algorithm allowed us to identify very specific communities within our large scientific network and easily see the distinction between communities. (Fortunato, 2010) It also allowed us to identify persistent (longitudinal) rather than temporal (single-year) communities.

We applied the Louvain method to identify emerging research communities in two different ways: sum and co-membership. The sum method identifies communities where investigators collaborated at some point between a certain period. A tie between community members in this network represents a collaboration on either a funded grant or publication for at least \( n \) years during a period of \( x \) years. The strength of the tie is calculated by summing the total number of collaborations on grants and publications during a period of \( x \) years. For example, Figure 4-4 represents an emerging research
community that contains individuals who have been in the community at any time in at least two of the past five years (not necessarily consecutively). This method allows us to examine the total amount of collaborations over a certain period of time.

The co-membership method identifies communities where investigators collaborated consecutively for a certain period of time. In the co-membership networks, a tie between two researchers indicates that they have been members of the same research community for two or more consecutive years. Specifically, a tie between community members in this network represents a collaboration on either a funded grant or publication for at least \( n \) consecutive years during a period of \( x \) years. The strength of the tie is calculated by summing the total number of consecutive years where investigators collaborated on at least one funded grant and/or publication during a period of \( x \) years. For example, Figure 4-5 represents the same community of investigators as Figure 4-4 who have been part of the same community for two or more consecutive years in the past five years.

The co-membership method has a higher threshold than the sum method. Thus, Figure 4-4 visualizes a larger community that spans across a wider range of the university’s scientific collaboration network than Figure 4-5. This co-membership method also allows us to examine the social multiplier effect. We initially defined the time period as of co-membership as five years. However, we later relaxed these criteria to two and three years based on user feedback.

This analysis revealed two distinct types of communities: cores and bridges. Core communities are research groups that are concentrated within the same section of the university’s scientific collaboration network with dense connections typically
between a small (<20) group of investigators (Figure 4-6). Bridging communities represent groups that span across different sections of the university’s scientific collaboration network with sparser connections typically between a large (>20) group of investigators (Figure 4-7).

We also examined the network structure and composition of each community. In a previous collaborative paper (Leone Sciabolazza, Vacca, Kennelly Okraku, McCarty, in review), we provided a detailed overview of the quantitative elements of this project. This quantitative data and analysis played a major role in framing the scope of this project. However, in this paper we will primarily focus on the qualitative dimensions of the project and explain how these methods were able to inform our quantitative methods and improve our community detection algorithms.

**Analyze Web Profiles to Identify Keywords**

I performed a profile analysis of each researcher or clinician identified in an emerging community to determine their research topics. This began by looking at each researcher or clinician’s university website and performing a Google search to identify their scientific expertise. I read through the names of the publications, grants, and collaborators they mentioned on their faculty web page or other online profiles. Then, I identified common keywords for each researcher. I compared these keywords to other researchers identified as part of their community to identify shared topics within research groups. I classified their research field by combining the most commonly shared topics across the community. This process was completed by hand using Microsoft Excel. However, natural language processing and machine learning could be used to expedite this process.
One limitation of this approach was that their profiles varied greatly in their scope, tone, the level of detail, and the types of information they provided. Also, their profiles were catered to different audiences. In the clinical sciences, profiles were geared towards a doctor or patient audience. In the agricultural sciences, web pages were targeted towards farmers or community stakeholders. In most other circumstances, the profiles were written for consumption by other highly specialized academics. This made comparing keywords across community members difficult.

Some faculty member's web profiles used a lot of disciplinary jargon that was difficult for a non-specialist to read. This was especially common among engineers and basic scientists. Other profiles in the applied sciences spoke about their research in a way that was more accessible to non-academic or non-specialist audiences. This was most common among faculty in the agricultural sciences and medicine. We hypothesize that this occurs because these faculty members often work with non-academic stakeholders as part of their extension and clinical work.

**Interview Scientists and Clinicians**

We solicited feedback from 23 researchers on our network visualizations. This process had three steps. First, we conducted semi-structured interviews with three researchers to learn about their collaboration experiences and ask for feedback on the visualizations. Second, we received additional feedback from six researchers on our revised visualizations via email. Third, we conducted sixteen interviews with researchers to learn about the specific research context of these emerging scientific fields, compare the visualizations, and evaluate the usefulness of this type of tool.
Results from first round of interviews

Our goal for this first round of ethnographic interviews was to evaluate the measurement of our community detection instrument and determine if we should adjust our time frame, inclusion criteria, or exclusion criteria. We selected three researchers from two of the communities (from different departments and colleges) that were working on similar research topics (hypertension) to compare and contrast their visualizations. We then interviewed them for approximately one hour about their research collaborations to get feedback on our network visualizations (Figure 4-8).

The first round of interviews revealed five common themes: measurement issues due to criteria limitations, missing data, respondents’ poor perceptions of the visualizations, the role of mentorship in these networks, and researchers’ motivations for transdisciplinary collaboration. All of the respondents made it clear that these visualizations were too narrow. One scientist responded to the visualization by explaining,

The search criteria are pretty strict […] I get what you are getting at, it’s just you are gonna miss some things because [you know] it can still be a consistent collaboration but some of the people may change over time […] It’s a way to reduce the complexity of this but I just worry that you lose a lot.

They also reported that many of their critical collaborators and more recent projects were missing from these visualizations. This feedback indicated a need to adjust the time frame to better capture their current collaborations and breadth of their research.

The comments from all three interviews suggested that though we were trying to capture emerging communities we were actually identifying stable communities in this first iteration. By identifying only communities where members had collaborated in all five of the past five years, we were capturing small core groups that had a strong history
of collaboration. These communities often represented strong relationships between mentors and their mentees. Though these are important relationships to examine, they were not the target of our analysis.

We also found through the interviews that the networks looked simpler and more homogeneous than they actually were in terms of their department/college identification and the strength of the collaboration. The respondents said that though the collaborations highlighted in this group were true, they did not highlight their most innovative or interdisciplinary work on emerging topics. This is a measurement issue that was addressed by adjusting the criteria from five years to a two to three-year period. This shift allowed us to capture much larger, more dynamic communities, working on more recent scientific issues in emerging research fields.

Interviewees also noted that many of their critical collaborations from this period were missing though they believed that they fit the inclusion criteria. It seemed like on a large scale the network data was great at identifying trends, but its accuracy from year to year can be limited. The issues of some missing data points are problematic when you have set strict community criteria. Thus, it is essential to loosen the criteria to improve the accuracy of the models. If a collaborator needs to be in the community all five years, small issues can result in big problems like a lack of appearance within the network. However, if we relax the criteria to two or three years these collaborations will still appear though the strength of the tie between researchers may be underreported.

These initial interviewees also found the network visualizations interesting but perceived them negatively. They were frustrated that these visualizations did not highlight what respondent’s self-identified as their most emergent research
collaboration/topic. They also believed that they minimized the interdisciplinary work they were often most proud of. These responses highlight the importance of getting feedback on models created through big data sources. Negative perceptions of visualizations can signal a deeper problem with the tool you are building. It is important to create visualizations that fit people’s mental models of the phenomenon you are trying to map or they will simply dismiss your results as irrelevant.

The interviews highlighted the critical role that mentorship plays in developing stable research communities. Mentors play a major role in socializing mentees and setting collaboration norms. Mentees introduce mentors to new ideas, challenge their assumptions, and introduce them to other faculty members (typically through co-membership on graduate committees). The mentor-mentee relationship forms a strong bond that does not respond to funding mechanisms the same way that other collaborations do. Mentors and mentees also play a critical role in brokering new collaborations by introducing them to new collaborators outside their network. They also provide a sounding board for questioning assumptions and developing new insights.

Interviewees explain that their primary motivations for collaborations were intellectual curiosity and passion for the project. They also shared the belief that interdisciplinary collaborations can be more difficult but they are also more rewarding long term. They highlighted different expectations, administrative barriers, disciplinary norms, and academic language as the primary challenges when engaging in interdisciplinary team science.

After this first round of interviews, we shared this feedback within our team and redefined our criteria. Based on our user feedback from these initial interviews, we
revised our models and adjusted the time frame from five years to 2-3 years. We chose to create both two and three-year visualizations because we believed based on the interview feedback that sharing both types of communities with interviewees would allow us to examine different types of collaborative projects.

**Results from additional feedback via email**

Next, we solicited additional feedback from six researchers on these revised visualizations via email. Two of these researchers participated in the first round of interviews, one was unable to meet for an interview due to scheduling issues, and three had been previously interviewed about their collaboration experiences for another research project we conducted. Our goal for this feedback was to test the new visualizations to determine whether the changes to the time frame helped to identify emergent research communities that reflected researchers' perceptions. Respondents found the revised visualization much more helpful. The feedback from this stage verified that the changes we made to the time period allowed us to identify emerging research fields that fit their mental models and were more positively perceived by respondents.

**Results from second round of interviews**

We conducted additional contextual inquiry into emerging research fields through interviewing sixteen scientists and clinicians. We used these interviews to further evaluate the revised visualizations, get feedback on their strengths and weaknesses, and collect narratives on team science and the translational process. Our goal for this stage of the process was to cultivate a better understanding of these communities in order to design a network intervention to propose new research pairs.

These interviews highlighted the challenges of capturing emerging research fields. Emergent fields are difficult to capture due to the fast pace of science and slow
speed of the peer-review process. The networks highlighted the general trends in the community but were not able to capture the subtle nuances of group dynamics and informal collaboration relationships that transcend publications and grants. Interviewees suggested integrating other collaboration products like grant applications, patents, and abstracts from conference presentations to identify more recent research collaborations and emerging topics.

The consecutive co-membership networks were identified as the most accurate by interviewees. The two-year consecutive co-membership networks were identified by the most interviewees as the best representation of their emerging research field. However, the three-year consecutive co-membership network was seen as the most meaningful by many respondents, especially those with larger collaboration networks.

Communities need to be not too big and not too small to be received positively by interviewees. Communities of ten to forty researchers were typically most meaningful to participants. When communities were smaller than ten people, respondents often said it was too small and highlighted only their core collaborators. Communities of more than forty researchers were helpful for situating researchers’ context within the larger university’s network, but they often did not know of all of the community members. This was especially true in communities that had more than one hundred members. This finding is consistent with Dunbar’s number. (Dunbar, 1992)

Respondents said that they enjoyed seeing where their work fit into the larger scientific research landscape at their university. However, they were often overwhelmed by looking at the larger visualizations and did not derive a lot of meaning from these types of networks beyond being excited to share them with others. Most respondents
identified their middle-sized community as the most accurate representation of their collaboration network and the emerging research field in which they were identified. They explained that this community best balanced the breadth and depth of their research in a meaningful way.

Scientists’ perceptions of themselves and their research also shapes the way they interpret these visualizations. Those with a high level of status within the university and collaborators viewed these visualizations as proof of their accomplishments. Whereas, those with a lower level of status within the university and fewer collaborators saw these visualizations as tools that demonstrated their self-worth, the level of their connections, and the value of their research. One associate professor even asked to use these visualizations as resources for her tenure packet. Other faculty members expressed interests in using the visualizations for other purposes. These included fostering new collaborations at a department level or starting new collaborations within their research group. The act of sharing and starting a conversation about these visualizations with faculty members served as a form of intervention to raise community members’ awareness of these emerging research fields and their collaboration patterns. Though these efforts were not part of our initial goals for the project, they demonstrate the potential network effects that sharing these visualizations can have on research communities.

Researchers define their research community in different ways. This definition varies based on their individual conception of collaboration and the disciplinary context of their field. These different conceptions of communities vary greatly by research context. Interviewees provided different narratives about their collaboration in response
to each community they were shown. This means that there is no clear best way to identify and visualize a research community. It also means that different communities reflect the team dynamics and focuses of many of the same researchers and clinicians during a distinct time period. As one researcher explained,

“All of them actually represent probably components of my research…Each of the little connection charts encompass kind of different components of the collaborations I’ve done. Ranging from I think the first one tended to be more cell biological and biochemical and I think the last one was more focused on kind of the translational.”

This description highlights the potential utility of sharing these network visualizations as a tool for starting conversations about the processual nature of translational and team science.

Most researchers responded positively to the network visualizations. They seemed excited to view the visualizations, provide feedback, and highlight connections between themselves and other researchers throughout the university. They also appreciated seeing the overlap between their different fields. Examining these connections between themselves and other researchers and clinicians seems to give many interviewees a sense of purpose. Most respondents were able to draw connections between their research and others they knew or had heard of before but had not collaborated with. It also allowed them to highlighted the impact of their work and its impacts beyond their discipline or academia.

Though the overall comments were very positive, researchers also pointed out several limitations of using these visualizations to examine emerging research fields. Most researchers were able to identify one or two of their key collaborators who were missing from the visualization. Often, these were collaborations that had not yet resulted in an awarded grant or publication, but that had resulted in a grant proposal or
conference presentation. A few times the person they identified was involved but they were missing because either they had been grouped into another community or there was a disambiguation error with the data.

Another limitation was the presence of investigators who had either left the university or died in the past three years. Interviewees did not really mind seeing the names of students who had graduated, post-docs who had received positions at other universities, or faculty members who had recently retired. Rather, they often used this as an opportunity to share stories about their past collaborations or their current position. However, interviewees were often upset to see the name of researchers who had passed away recently. Many interviewees were also sad or frustrated to see the names of researchers who recently left for other positions. They explained that though the networks were technically correct, the presence of investigators in their community who were no longer at the university seemed wrong. We tried to remove investigators who were no longer at the university. However, this process was more difficult than we initially anticipated due issues with pay period records.

Collaborations within these fields were described by interviewees as a way to both improve the quality of their research and ride out the storms of funding in an increasingly competitive market. Many interviewees described the turn taking process of authorship/investigator status that often occurs when publishing articles and writing grants in long term collaborations. They also highlighted the role that career level plays in collaboration dynamics in terms of status, power, funding, and priorities. Some respondents said that it was often easier to work with those at the same level so their goals were aligned; whereas, others said it was helpful to work with people at different
levels to help them cope with funding lulls within the group. Interviewees’ research narratives illustrated the role their mentors played in shaping their collaboration style and choices when choosing collaborators. Mentees often mirror the collaboration patterns demonstrated by their mentor, whether consciously or unconsciously.

**Identify Pairs for Network Intervention**

In the final stage of this project, my collaborators and I identified pairs of researchers in the same emerging research community who had not previously collaborated. In order to be eligible for our network intervention, communities had to contain at least one member from the health sciences. We identified both a treatment and control group that had similar network structures and shared similar group characteristics (i.e. level of interdisciplinary). We selected pairs from the periphery of the communities who had not previously collaborated on a publication or awarded grant.

I then conducted another round of web profile analysis to evaluate whether or not the pairs were viable. This analysis revealed that many of the pairs we initially identified were not eligible to participate because one or more members of the pair had left the university. We were surprised by this finding. This issue was particularly challenging because if one members of a pair in either a treatment or control group had left the university we had to remove the whole group. It also highlighted the issue that many key investigators in emerging scientific fields have left the university in the past three years.

This issue also came up during my interviews with researchers and clinicians. In some cases, the investigators who left were graduate students who had graduated or post-docs who had moved to another university. However, the more troubling finding was that many of these researchers were assistant and associate professors. We
believe that their periphery location within their research group could be one of contributing factors why they left the university.

We tried to ameliorate this issue by updating the data to include only researchers who had been paid by the university during the last pay period. Then, I conducted additional web analysis of the pairs. This analysis revealed that this update removed many of the researchers who had left the university. However, some researchers who were no longer at the university still remained in the data. As a result, I continued to analyze faculty members’ web profiles and manually remove researchers who had left the university. We also ran into an issue where some of the people identified were in non-research staff roles. We also manually removed these individuals from our list of potential pairs. Through this analysis, we identified 15 pairs.

**Results from first round of pairs identified**

After we identified fifteen viable pairs of thirty investigators, we sent them an email in December 2016 informing them about a new pilot program we had developed with the university’s Clinical Translational Science Institute and inviting them to participate in our study. This email also outlined the study’s incentives. Each member of the pairs who participated would be awarded $1,500 in professional development funds. This funding would be contingent upon the pairs attending a meeting to provide an overview of our network intervention and jointly submitting a letter of intent that described a new collaborative project for potential pilot funding from the institute. Based on the quality of their letter of intent, three pairs were asked to submit a full grant proposal. These proposals will be peer-reviewed and the institute will select one or two of the pairs to receive a pilot award of up to $25,000 to complete the project.
At the end of the email, we asked them to complete a short survey to determine whether or not they were eligible to participate in the study. Participants were determined to be ineligible if they had collaborated on an awarded grant or publication in the past three years. We included these questions to make sure that our networks contained accurate publication and grant records for this period.

In this round, twelve respondents (40%) agreed to participate, but only six (20%) were part of pairs where both investigators consented to participate. This process revealed that some of the selected investigators had also recently left the university but still had active web profiles. One pair was determined ineligible due to a past collaboration on a publication that were missing from our data. One pair agreed to participate, but then one respondent withdrew their consent. In four of the pairs, one of the investigators was interested in participating but we were unable to identify a collaborator for them in their community. Many of the investigators that we were unable to match requested that we provide them with alternative collaborators because either they were either unable or not interested in collaborating with the person we identified.

**Results from second round of pairs identified**

As a result of these issues, we reached out to eleven additional pairs in January and February 2017. Some of these pairs included investigators from the previous round who were unable or unwilling to collaborate with the researcher we initially identified. In this round, we were able to identify two new viable pairs that consented to participate. In one case, we were able to identify an alternative collaborator for one of the members of a previously ineligible pair. The other pair was a completely new pair.

In this round, we faced similar challenges in identifying viable pairs. Nine of the twenty-two investigators identified consented to participate (41%). However, only four of
these investigators were part of a pair where both researchers consented and were eligible to participate (18%). For one pair, we identified an alternative collaborator for someone was unwilling to work with the initial investigator we identified. However, though both members of the pair agreed to participate, they were determined to be ineligible due to previous collaboration on an awarded grant. We also had three investigators who consented to participate but we were unable to match them with a new collaborator in their research community. It was difficult to find pairs where both investigators were interested in participating. One investigator (typically a junior investigator) was often more invested in participating than the other.

After contacting twenty-six pairs composed of forty-eight investigators, we were able to identify five pairs of ten investigators who consented to participate in our network intervention. All five pairs successfully submitted their letter of intent in March 2017 and were provided with an incentive to submit their letter of intent (for a pilot award) together. These letters were reviewed by the institute and three pairs were asked to submit a full pilot proposal in May 2017. One or two of these pairs will be selected through peer-review to receive a pilot award of up to $25,000.

Discussion

Identifying emerging research communities helps to visualize trends in team science and evaluate their network effects. This study found that mixed method approach can help to design better network interventions and improve our understanding of scientific teams. It also allowed us to gain new perspectives on teams and the communities in which they coexist. As expected, we observed an overlap between the communities we detected and traditional department, colleges, and academic units. However, our interviews with community members revealed that
interdisciplinary collaborations were central to their research aims. Researchers took pride in their interdisciplinary work in these fields even when it was actively discouraged by their peers or dis-incentivized by their departments.

Soliciting feedback from respondents through interviews was a critical part of improving our models to better fit the realities of team science. During the first round, all three interviewees agreed that the models we showed them were too simplistic, focused too much on their long-term collaborations, and were not emphasizing their current research agendas. They were also disappointed that the networks did not capture the diversity of their achievements, especially when these were interdisciplinary collaborations. We were able to incorporate their feedback into the models by shortening the length of time individuals needed to be in the same community. After reducing the time period from five to between two and three years, interviewees responded positively to the networks and reported that they saw them as meaningful representations of their emerging research field.

Sharing these visualizations with researchers transformed the way they looked at their research community and place within the larger university. Respondents enjoyed seeing their position in the community and explaining the story of why that connection existed and how the collaboration started. Respondents were also excited to interact with the models and provide feedback on who was missing and share their explanations of why they might be missing. It was rather intuitive for them to make connections between their work and the work of others in the group even if they have not worked with them directly. In many cases, people were excited to see that a colleague they knew but had not formally collaborated with was also a part of their community.
Typically, there were only one or two people who they did not know in their research community, especially the one they believed most accurately reflects their collaboration. This suggests that these research communities are more than just abstract representations of science but represent real communities of scientific inquiry and connection. They highlight both actual collaborations on grants and publications as well as thought communities that researchers use to disseminate and share their ideas with their colleagues working on related but distinct topics. By modeling five different ways that respondents could conceptualize their research communities, we were able to examine different types of communities. For some the most meaningful group was the community of their closest collaborators on a specific topic. Yet, they also drew meaning from the fact that they were connected to other researchers through a training or larger grant that focused on broader issues.

Starting these types of programs can present challenges but we believe that it can also lead to new ways of fostering innovation and knowledge production. We experienced several recruitment challenges when contacting pairs about participating in the network intervention. Since the pair’s participation is contingent upon their partners’ desire to participate, it can be difficult to identify viable pairs. Some investigators were eager to participate but we could not identify an eligible collaborator in their community who was interested in our study. One way to address some of the issues we experienced in our study would be to ask a researcher who knows both members of the pair to introduce them and suggest that they collaborate. A request from an existing collaborator could be more impactful than an email from someone they do not know.
Conclusion

Identifying emerging research communities provides a useful method of visualizing team science its network effects. Organizations with limited capital or ability to support network interventions on a larger scale could facilitate the distribution of these types of visualizations to raise faculty members’ awareness and the status of these emerging research communities. This could help these fields demonstrate their importance within the organization and recruit new members. It can also help to empower members of these communities.

Sharing network visualizations with faculty members can also be a great way of eliciting conversations about research and collaborations between faculty members and administrators. It could also be helped to include these types of visualizations in annual faculty reports or other performance review processes. This could allow researchers and clinicians to write up a short narrative describing their role in this network. This could be a useful first step in better integrating and recognizing team science in the T&P process.

Using network metrics to select pairs and introduce investigators to one another provides a new method for testing and evaluating the effects of a pilot program. This method has the potential to increase a pilot program’s impact on an emerging research field or a university’s scientific collaboration network. However, it is also important to highlight some of the potential limitations and ethical challenges of applying these approaches to alter networks and their implications for other studies.

Designing a network intervention that alters community dynamics and structures requires researchers to make a series of decisions that have implications for the people and communities identified, as well as those who are not selected. Community detection
and other algorithmic decisions are often marketed as objective criteria. However, as Gregory (2008) writes,

There is no standard definition of community and no consensus about how a network should be divided into communities.

Also, as this paper demonstrates, these methods require individuals to make subjective choices about what and how to measure. These individual choices are also shaped by the priorities and organizational culture of the institutions they are embedded within.

Algorithms are powerful and not neutral. There is a great deal of power that comes from creating these algorithms and making decisions based on their results. (Lustig et al., 2016) Engaging with the community members you are attempting to map and soliciting their feedback can help to reduce this power imbalance and create more realistic and thicker models of big data sources. Yet, it is important to acknowledge their limitations and realize that regardless of the methods the creators used to design these algorithms, they still wield a great deal of power. Their creators’ subjective decisions can have very real impacts on the communities they map and those that they ignore.

In the case of this study, these communities were used to identify pairs of researchers that would be offered exclusive access to apply for pilot award/seed grant funding. This amount significant and can make am impact in a researchers’ career. Thus, providing access to some faculty members over others requires critical decision making and hard choices. Controlling this process provides a great deal of power to algorithm creators. (Lazer, 2015) We believe that our network intervention can help to reduce some of the biases of traditional funding mechanisms that have been reported in previous studies. (Helmer et al., 2017; Marsh et al., 2008; Lee et al., 2008) However, it also introduces its own bias and challenges. These issues would be compounded if the
stake of the intervention were higher. Therefore, it is important to keep these ethical challenges in mind when using community detection algorithms to design interventions.
Figure 4-1. An overview of the eight-step process we used to identify emerging research communities and plan the network intervention.
Figure 4-2. The university’s scientific collaboration network in 2013. Nodes are colored to distinguished between collaborations on a publication, grant, or both.
Figure 4-3. A comparison of traditional disciplines (a) and emergent research communities (b) for 2015. Nodes are colored by department and shaded by community.
Figure 4-4. An example of a community using Louvain sum method. The image on the left highlights the community’s location within the university’s scientific collaboration network. The image on the right represents a community that contains individuals who have been in the community at any time in two of the past five years (not necessarily consecutively). Nodes are colored by academic unit.
Figure 4-5. An example of a community using Louvain co-membership method. The image on the left highlights the community's location within the university's scientific collaboration network. The image on the right contains investigators who have been part of the same community for two or more consecutive years in the past five years. Nodes are colored by academic unit.
Figure 4-6. An example of core community.

Figure 4-7. An example of bridging community.
Figure 4-8. Comparison of two communities working in emerging research fields on the topic of hypertension.
CHAPTER 5
EVALUATING RESEARCH IMPACTS ON THE PUBLIC

Overview

Scientific research and discoveries play a major role in shaping our daily lives. The results of scientific research can be seen in the tremendous advances in medicine, technology, marketing, management, and many other fields over the past decade. Previous studies have reported that the public generally has positive attitudes towards science, despite low scientific literacy rates. This highlights a disconnect between scientists and the public that stems from a lack of engagement with one another. In this article, I use survey and interview data to compare and contrast how the public and university faculty members define and evaluate research impacts. This article explores how these values and perceptions are shaped by the priorities of the media and university leadership. It also proposes new metrics for evaluating research impacts beyond academia in the tenure and promotion (T&P) process and provides suggestions for integrating public engagement into the organizational culture of a university.

Science plays a critical role in the United States and global economy. The National Science Foundation’s Science and Engineering Indicators (2016) reported that nearly $1.7 trillion was spent worldwide for research and development (R&D) in 2013. In the US, R&D accounted for $456 billion in revenue. (NSF, 2016) According a report from the Federation of American Scientists (2014), 6.2 million scientists and engineers work in the US (4.8% of the total US workforce in 2012). These scientists are responsible for a great deal of research knowledge and innovation. However, many of their findings are published exclusively in academic journals. These types of journals are largely inaccessible to the public due to the cost and technical nature of peer-
reviewed articles. A large gap also exists between the original peer-reviewed journal articles that scientists publish and the news coverage that journalists provide. (Weigold, 2001) This gap leads to public confusion on the nature, level of certainty, and implications of scientific discoveries.

Many scientists have identified the lack of research dissemination and public engagement as critical issues for science. However, the training and evaluation metrics at most universities prioritize publishing in peer-reviewed academic journals over other dissemination methods. (O’Meara, 2010; Clark, 1997; Fairweather, 1993) This incentivizes faculty members to spend the majority of their time writing peer-reviewed publications and grants. As a result, there has been a push over the past twenty years to recognize different types of scholarship and incorporate public engagement into faculty reward systems including T&P criteria. (Boyer, 1990; Driscoll & Sandmann, 2001; O’Meara, 2010; Fitzgerald et al., 2012)

This paper argues that scientists have an important role to play in making their work and findings more accessible to the public. My primary aims for this study were to gain a better understanding of the public’s perceptions of science and develop new metrics for evaluating research impacts beyond academia. This paper begins with a brief overview of the literature on this topic. Next, I will outline the study’s materials and methods. Then, I will provide the results from our survey of members of the public and interviews with faculty members and discuss the implications of these findings. Finally, I will conclude the paper by providing suggestions for improving communication and engagement strategies between scientists and the public.
Literature Review

The literature on science communication and public engagement reveals a large disconnect between public knowledge of and attitudes towards science. Previous studies on public attitudes on science have been conducted on a national level by the federal governments in the United States and United Kingdom. (NSF, 2016; Castell et al., 2014; Royal Society, 1985) Most surveys of the public have found general support for science. (Miller, 2004; Bernard, 2012) Yet, the public’s scientific literacy remains low.

This disconnect reflects the many issues with the dissemination of science and potential opportunities for improvement. (Fischhoff & Scheufele, 2014) It suggests a need to increase both the public’s scientific literacy and scientists’ interaction with the public. (Einsiedel & Thorne, 1999; Logan, 2001; Weigold, 2001) It highlights the need for an ongoing interaction and dialogue between scientists, journalists, policy makers, and the public. (Yankelovich, 1991) These types of engagement require trust, warmth, respect, and clarity of both research findings and individual’s values to increase the credibility of the information. (Dietz, 2013; Fiske & Dupree, 2014)

The literature on science communication also highlights the complexities of disseminating discoveries from scientists to the public. (Weigold, 2001) Partnerships between natural and social scientists can help to increase the effectiveness of science communication. (Wong-Parodi & Strauss, 2014) Iteratively testing science messaging using the same rigor we apply to other scientific methods can also help to improve the dissemination process and relevancy of science communication. (Fischhoff & Scheufele, 2014)

Public engagement is critical because it simultaneously increases the relevance of science for the public and improves the rigor of the research. Traditional explorations
of scientists’ engagement with the public emphasize the one directional flow of information from scientists to the public. These types of science communication include scientists disseminating their findings to the public through talks and publications and the public consulting with scientists to request or improve their studies. More recent studies have explored the distinction between scientists’ unidirectional communication or consultation with the public and multidirectional participation in creating and improving science. (Rowe & Frewer, 2005) Public participation can be defined as

The practice of involving members of the public into the agenda setting, decision-making, and policy-forming activities of organizational institutions responsible for policy development. (Rowe & Frewer, 2005)

This type of engagement allows for a mutual exchange of knowledge, input, and resources between scientists and the public. (Glass, 1979)

Prior to the advent of the internet, most people learned about scientific discoveries from traditional news organizations via print media and television. (Weigold, 2001) Over the past two decades, there has been a massive shift away from print media towards online and cable news sources. In the past ten years, social media sites like Facebook and Twitter have played a major role in the dissemination of information. Scientists have been slow to adopt and use these platforms to disseminate their research. Yet, many have used social media to recruit participants for their research.

There has also been increased pressure from the state and federal government in the United States to increase research impacts on the public. This has been translated into an increased focus on broader impacts and public engagement by funding agencies. The National Science Foundation (NSF) introduced a broader impact section to identify the project’s anticipated effects on the public. The Patient-Centered Outcomes Research Institute (PCORI) was also formed as part of the 2010 Patient
Protection and Affordable Care Act (ACA) to increase patient’s access to healthcare research and improve their health outcomes. (Frank et al., 2014; Selby & Lipstein, 2014, Forsythe et al., 2015) In an effort to achieve these goals, Eugene Washington PCORI Engagement Awards were established to provide funding specifically for healthcare research on best practices for community engagement, stakeholder capacity building, dissemination of research findings, and implementation of patient-centered solutions. This shift in funding priorities suggests a need for universities to incorporate public impacts into their criteria for evaluating faculty members. However, this change will require universities, funding agencies, and researchers to conduct follow-up studies to measure the actual impacts of the project.

Many models have been proposed in other studies to outline rationales for public engagement. The most commonly cited models are the deficiency, rational choice, context, and efficiency models. (Ziman, 1992; Weigold, 2001; Rowe & Frewer, 2005) The deficiency model argues that higher levels of knowledge about science will improve public trust and attitudes towards science, which will lead to increased funding for science. However, this model has been largely undermined by the few rewards and high costs for scientists to communicate their findings or engage with the public. Many critics also suggested that the relationship between public knowledge and federal funding is more complex than this model suggests. The rational choice model focuses on providing the basic scientific knowledge that is necessary for informed citizenship. This model portrays basic scientific education as an essential part of life. Whereas, the context model attempts to make science relevant to members of the public by learning about their individual interests and asking them what scientific information we would like
to know. This model prioritizes public input and values. The efficiency model explores how scientists and public resources could be optimized through determining the engagement style based on the specific context. This model builds on the context model but emphasizes the allocation of resources. These models provide a general overview of how scientists have categorized public engagement in the past. Current models generally include aspects from multiple models.

Scientists typically do not know how to communicate with the public and have not received training in this area. (Weigold, 2001) As a result, they often have a difficult time translating their findings into something that can be easily processed and utilized by researchers working in another discipline or a lay audience. The emphasis of translational science is to provide services and resources that facilitate and speed up this process. Translational science represents the cyclical process of researchers and clinicians collaboratively developing new healthcare approaches and improving patients and communities’ access to these treatments and services. (Woolf, 2008) It is simultaneously focused on healthcare innovation and equity. This translational feedback loop is meant to encourage public engagement. However, as previous studies have demonstrated public engagement is more difficult and time consuming than it appears.

**Materials and Methods**

This study’s data were collected through a survey of the public (n=504) and semi-structured interviews with nine scientists and one administrator (n=10). In July 2016, we conducted a telephone survey asking a random, representative sample of 504 people in Florida ten questions about their knowledge and opinions on scientific research and discoveries. This phone survey was part of the Bureau of Economic and Business Research’s monthly Florida Consumer Sentiment Index (CSI). The University of Florida
Survey Center has conducted this monthly survey since 1985 to measure Florida consumers' perceptions of the economy and track changes in consumers’ attitudes.

Survey respondents were sampled using a cell phone Random Digit Dialing (RDD) sample from Marketing Systems Group. This provided a representative sample of respondents consistent with the demographic patterns in Florida. Each number was called a minimum of five times. Respondents were surveyed if they consented to participate in the study and met the inclusion criteria of living in a private residence in Florida and being 18 or older. The survey interviews were conducted in both English and Spanish. These interviews lasted approximately twelve minutes.

We conducted semi-structured interviews with nine faculty members and one administrator from eight departments and four colleges at a large university in the United States. Interviews were used to identify alternative research products, faculty’s motivations for collaborating with non-academic stakeholders, reasons for producing non-traditional outputs, incentives to encourage engagement with non-academic stakeholders, and metrics for evaluating research impacts beyond academia.

Faculty members were asked questions about their experiences engaging with the public, identifying alternative channels for disseminating their work, translating their findings to non-academic audiences, and evaluating alternative research outputs. These interviewees were selected by asking scientists to recommend researchers that they believed were doing impactful research or had previous experience evaluating research impacts in the T&P process. One faculty member suggested that I talk with a college-level administrator in human resources. In this interview, we discussed how the T&P
process in that college evaluated public engagement and alternative research outputs. These interviews lasted approximately one hour.

**Data Analysis**

We analyzed the quantitative responses to the closed-ended survey questions in SPSS. Descriptive statistics were performed to examine demographic data (Table 5-1), in addition to respondents' level of information about science, interaction with scientists, and perceptions of research (Table 5-2). Chi-square tests of independence were used to test whether there was a relationship between respondents’ education level and their knowledge about science, interaction with scientists, and perceptions of research.

We analyzed the qualitative responses to the open-ended survey questions and themes from the semi-structured interviews in Microsoft Excel. Qualitative data analysis was performed on two questions to examine how respondents were personally impacted by scientific research (Figure 5-3) and how they thought universities should evaluate the impact of scientists’ research and discoveries (Figure 5-5).

We used an inductive grounded theory approach to code the data from the open-ended survey questions and interviews. (Glaser and Strauss, 2009; Ryan and Bernard, 2003) Repetitive themes and exemplar quotes were identified through reading through survey responses and listening to interview recordings. We sorted these responses into categories and subcategories based on these themes. Some responses highlighted more than one theme and were coded into multiple categories. Therefore, the total code percentage could be greater than 100%.
Survey Results

Level of Public Knowledge

The survey began by asking respondents how informed they felt about scientific research and discoveries. Respondents self-identified as either very well informed, fairly well informed, or not very well informed. Table 5-2 shows that most respondents (56%) reported feeling fairly well informed about scientific research and discoveries. Figure 5-1 examines the relationship between respondents’ education level and how informed they felt about scientific research and discoveries.

A chi-square test of independence was performed to examine the relationship between education level and level of knowledge about science. We found a statistically significant relationship between these variables ($X^2 (4, N = 500) = 22.10, p < .001$). Another chi-square test of independence was performed to examine the relationship between gender and perceived level of knowledge about science. We also found a statistically significant relationship between these variables ($X^2 (2, N = 502) = 15.54, p < .001$). Respondents with higher levels of education and male respondents reported being more informed about scientific topics.

This first finding is consistent with previous studies that have reported a strong positive association between respondents’ level of education and their knowledge about science. (Miller, 2001) This finding was expected due to the traditional role that universities have played in introducing students to scientific research and discoveries. However, they suggest that additional efforts are needed to share research findings with the public outside of university settings. The second finding is consistent with the literature on women and science. This suggests that additional efforts are needed to
make science education more relevant to women and encourage women to study science, technology, engineering, and mathematics (STEM).

**Level of Public Engagement**

Respondents were also asked two questions about their perceptions of how scientists communicate with the public about their research and discoveries. These questions probed for respondents’ opinions about scientists’ current levels of research dissemination and engagement. For each question, respondents were read a descriptive statement and ranked that statement using a Likert scale (from strongly agree to strongly disagree). (Likert, 1932) The results are summarized in Table 5-2.

Most respondents agreed that scientists should spend more time talking about their scientific research and discoveries with the public. They also agreed that scientists should be rewarded for doing so. Two chi-square tests of independence were performed to examine the relationship between their level of education and 1) attitudes towards scientists’ current levels of engagement with the public and 2) whether or not scientists should be rewarded for publically discussing their findings. We did not find a statistically significant relationship between level of education and either of these variables. This means there was general agreement across education levels that scientists should increase their levels of engagement with the public and that universities should reward these types of activities.

These findings illustrate the public’s strong desire for higher levels of interaction between scientists and the public and their belief that scientists should be rewarded for public engagement. This finding is consistent with previous studies that have reported a need for additional public engagement mechanisms to target different audiences across educational levels. (Rowe & Frewer, 2001)
Knowledge Sources

Respondents also answered questions about the sources where they usually heard about new scientific discoveries. Respondents were read a list of potential knowledge sources and selected all that applied. They also had the option to provide additional sources. These other sources included: discussions with other people, social media, journals or periodicals, and educational resources. Sixty-two respondents referenced other sources. However, only twenty-two of these responses actually warranted the creation of another category. Responses that referenced a previously identified category were recoded within the existing categories. These results are summarized in Table 5-2.

Members of the public reported that they typically heard about new scientific discoveries through websites, movies or TV, and newspapers or magazines. Less than ten percent of respondents said they heard about these findings directly from scientists and roughly one in four reported reading about them in scientific journals. This finding illustrates that the public has limited access to scientists’ traditional channels for disseminating their research findings. However, these numbers were higher than I anticipated. This could be due to over reporting by respondents.

Figure 5-2 examines the relationship between respondents’ education level and their sources of scientific knowledge. A chi-square test of independence was performed to examine the relationship between education level and sources of scientific knowledge. We found statistically significant differences by education level in whether or not respondents heard about scientific discoveries directly from scientists ($X^2 (2, N = 502) = 10.15, p = .006$), websites ($X^2 (2, N = 502) = 18.45, p < .001$), movies or TV ($X^2 (2, N = 502) = 13.43, p = .001$), newspaper or magazines ($X^2 (2, N = 502) = 17.64, p$
books ($X^2$ (2, N = 502) = 13.48, p = .001), scientific journals ($X^2$ (2, N = 502) = 36.96, p < .001), and people at work ($X^2$ (2, N = 502) = 11.74, p = .003). Higher levels of education were positively associated with seeking information from scientific journals, people at work, books, newspapers or magazine, websites, and directly from scientists. Lower levels of education were positively associated with seeking information from movies or TV. There was not a statistically significant difference by education in whether or not respondents learned about scientific discoveries from family and friends or radio. These findings suggest that education level plays a significant role in shaping where members of the public obtain information about science.

Another chi-square test of independence was performed to examine the relationship between gender and sources of scientific knowledge. We found a statistically significant relationship between gender and seeking information from websites ($X^2$ (1, N = 504) = 6.75, p = .009). Men reported seeking information from websites at a significantly higher rate than women. We did not find a statistically significant relationship between gender and the other sources.

These findings highlight how differences in education and gender shape what channels people use to learn about scientific discoveries. Scientists and universities can use this information when selecting which channels to use to disseminate their research findings to the public. Being aware of these differences can also help scientists tailor their messages to different audiences in order to reach a broader cross-section of the population. More emphasis should be placed on disseminating findings through movies or TV, as these channels were reported as significant sources of information by respondents with lower levels of education.
**Personal Impact of Scientific Research**

Respondents were also asked if they believed that they had been personally impacted by scientific research. If they responded yes, this question was followed by an open-ended question asking how they have been personally impacted. No prompts were provided to respondents for this question. Three hundred and seventy-two respondents (74%) provided an answer to this open-ended question. Their responses were recorded verbatim and subsequently classified into twenty-seven different categories. The results are summarized in Figure 5-3.

Most respondents reported that they have been personally impacted by scientific research (Table 5-2). A chi-square test of independence was performed to examine the relationship between education level and whether or not respondents reported being personally impacted by scientific research. We found a statistically significant relationship between these variables ($X^2 (2, N = 498) = 24.63, p < .001$). This finding further highlights how educational level shapes public attitudes towards science. Figure 5-4 examines the relationship between respondents’ education level and if they believed that they had been personally impacted by scientific research.

Most respondents outlined the positive impact that scientific research has had on their lives, as well as the lives of their friends and family. Only two percent of respondents reported that they had been negatively impacted by scientific research. The most commonly reported positive impacts were advances in medicine, health, and technology. Many respondents referenced the effect that research has on most aspects of their daily lives. One respondent said that,

> Everything that we do is because of science: TVs, vacuum cleaners, phones, and cars. Everything we have is helped by science.
This response highlights the public’s knowledge that science is integral to their daily lives. Respondents also discussed the value that a general knowledge of science plays in education and the advancement of society. Some respondents even referenced their participation in the survey as an example of scientific research.

**Evaluation of Scientists’ Research and Discoveries**

Respondents were then asked how they thought universities should evaluate the impact of scientists’ research and discoveries. The interviewer did not provide any prompts to respondents for answering this question. Respondents’ answers were recorded verbatim and subsequently classified into forty-four categories. The results are summarized in Figure 5-5.

Previous studies have asked the public to share their perceptions of science. (Miller, 2001) However, these surveys have not asked the public their opinions on how scientists and their work should be evaluated. My primary goal for asking respondents this question was to solicit public input on creating alternative metrics for evaluating research impacts. I anticipated that this question would be difficult for many respondents to answer because they are unfamiliar with faculty evaluation systems. However, I wanted to learn about public’s perception of the current academic evaluation process and receive suggestions for improving this system. As anticipated, a quarter of respondents chose not to answer this question.

Five common themes arose from the respondents’ answers. These themes include: measuring its effects on the public, validating research findings, increasing engagement with the public, conducting follow-up surveys, and prioritizing teaching efforts. Twenty-seven respondents did not provide specific approaches for examining research impacts but believed that it should be evaluated higher than currently. Only
two respondents expressed negative opinions of scientific research. This supports the findings of previous studies that the public generally has positive attitudes towards science.

Survey respondents suggested that universities could measure research studies’ effects on the public through collecting and analyzing longitudinal survey and observational data. One respondent explained that research impacts should be evaluated,

By the number of people that can be helped by it or by the significance of the research to people's health and welfare and the betterment of the world.

Another respondent said that,

It depends on the effect that their discovery or research has and the importance of what they're researching to the general population.

These responses emphasize the need to directly measure and evaluate research impacts on the public. They also suggest that scientists need to make their work relevant to the public. Current research evaluation metrics do not sufficiently measure these types of broader impacts or reward research that is significant to the public.

Respondents also suggested that researchers should be evaluated based on their level of communication, dissemination, and engagement with the public. One respondent suggested that this could be achieved,

By holding forums and allowing scientists to come and talk to student bodies, [they can] create an environment where students are comfortable talking to scientists no matter their [educational] level.

Another respondent suggested, “They should utilize social media such as Facebook and Snapchat.” Increasing engagement with the public through utilizing different channels for communication can increase public knowledge and perceptions of science.
Talking with students is a traditional knowledge dissemination tool that should be used more frequently. Adopting new platforms for sharing knowledge through social media can also increase the relevancy of science.

Respondents believed that these efforts could also help to increase the quality and transparency of research. As a respondent explained,

One of the biggest problems is lack of sharing, if [there was] better communication between scientists, [they] would stop reinventing the wheel.

Another said, “Instead of hiding it let everybody know.” These responses suggest that the public feels that scientists are overly secretive and nervous to share their findings. These sentiments can contribute to lack of trust in science. Therefore, it is important for scientists to be open about their work and increase their engagement with the public.

Universities could provide faculty members with access to consultation from communication specialists to help them update their web profiles. This could help them translate their findings and impacts to a broader audience. Research evaluation metrics could be updated to provide equal credit for public and conference presentations of research findings to encourage faculty members to share their results with the public. However, this would require additional assistance to translate their findings into a presentation that is accessible and relevant to a broad audience with varying education levels. Disciplinary jargon or complex terminology should also be removed.

I was surprised by respondents’ knowledge of the faculty review process. Ten respondents specifically referred to elements of the peer-review process for grants or publications. One respondent said that,

Scientific research is a big thing right now. They evaluate it by the number of grants they attract [and] by the research they are doing.
These types of responses illustrate the diversity of public knowledge and the increasing public conversation about science. As discussed in previous sections of the paper, level of education can play a role in shaping the public’s understanding and perceptions of science. It can also shape individuals’ knowledge of universities’ evaluation systems. Information about these processes can also be obtained through movies and TV.

Respondents also emphasized the value of research that translated into products or services. One respondent said that universities should reward scientists for creating Things that translate into tangible products or implementations leveraged into industry (commercial, healthcare, etc.)

Another respondent explained that,

They need to keep on inventing things and learning things as much as they possibly can. Innovation. That’s the future, science is the future.

These responses emphasize the important role that alternative research outputs play in the public’s understanding of science. Members of the public see value in producing patents for medical or other commercial devices that will directly improve their lives. Many colleges and universities have technology licensing offices that help scientists patent these types of research outputs. They have also incorporated patents into their T&P criteria. Universities could further emphasize the products and services in the evaluation process by providing additional weight for discoveries that have been translated into products, services, or interventions for public consumption.

**Interview Results**

My interviews with faculty members identified some best practices for public engagement and common issues with the current T&P process. Researchers reported that public impacts are often an afterthought in research design. They agreed that public engagement goes beyond simply disseminating research findings. Rather, it requires
planning and a concerted effort to incorporate stakeholders throughout the research process and solicit their feedback.

They suggested that research projects begin by identifying their end point. This increases the likelihood that the findings or intervention will make it to people who need or want it. Prioritizing setting objectives before starting the project also helps researchers to plan and measure their study’s impacts. SMART objectives provide a helpful format for introducing researchers to the concept of research evaluation. (Diehl & Galindo-Gonzalez, 2012) Setting these objectives requires researchers to define specific, measureable, achievable, relevant, and time-bound goals for the project. By setting up these goals, researchers are able to evaluate their project at various stages to determine if it is working and check in with stakeholders.

**Misalignment of Goals and Evaluation Metrics**

Faculty members noted in their interviews that there is often a misalignment between a university’s stated mission and their metrics for evaluating faculty’s achievements. The university’s mission emphasizes its commitment to integrating research, teaching, and service into educating students and improving lives. However, in practice, the T&P process overwhelmingly weights research productivity over teaching and service. There was a consensus among interviewees that the T&P process primarily rewards faculty members for securing federal grant funding and publishing in peer-reviewed journals. This finding is consistent with previous studies. (Clark, 1997; Fairweather, 1993) However, it is inconsistent with some of my interviewee’s definition of research as a mission-centered practice with public impacts.

Faculty noted that this incentive structure does not reward and, in many cases, it discourages faculty members from engaging with the public. Many researchers respond
to this recognition structure and focus solely on their own research. This makes it difficult for universities to promote impactful research. However, some researchers, like the interviewees in my study, chose to focus on conducting research with significant public impacts and collaborating with stakeholders outside of academia though there is no formal reward for these practices.

Interviewees also provided personal narratives about how they were actively discouraged from engaging with the public or applying for grant funding from the Gates Foundation or other non-profits. They said that this was because they provided the university with lower facilities and administrative (F&A) Rates also known as indirect costs (IDC) than federal funding sources like National Institutes of Health (NIH) and National Science Foundation (NSF). Issues with budget sharing between academic units can also create tensions when introducing alternative funding models.

They also noted a distinction in credit based on if a proposal was problem-driven or investigator-driven. For example, many non-profits’ calls for proposals or contracts with organizations are centered around a specific problem they have identified. Researchers then submit proposals outlining how they would address this problem of public concern. These proposals often address this broad topic and need to speak directly to public dissemination and implementation strategies. These proposals are evaluated based on their potential to increase uptake of the solution in the target population and easily adaptable to other contexts.

Whereas, many sources of federal funding like the NIH RO1 allow investigators to submit a proposal where they identify the problem in their field that they would like to address in their research. These proposals often address a very narrow topic and do
not need to speak directly to public dissemination and implementation strategies. These proposals are typically evaluated based on their potential to promote excellent cutting edge scientific research.

This difference in evaluation and focus reflects the funding agencies’ different goals and types of research investments. They also represent distinct worldviews on what is “good research.” The current evaluation metrics prioritize the former. However, faculty members believed that a fair and just evaluation process would recognize both.

This evaluation system prioritizes novel investigator initiated questions over problems of public concern or industry demand. Faculty members said that the investigator-driven approach was more highly valued and seen as more rigorous in many departments and colleges. However, this focus presents problems for developing solutions to issues of public concern, as it is highly dependent upon scientists identifying a common problem and choosing to disseminate their findings. It also does not force or incentivize scientists to think about who will use this information and how these stakeholders could be integrated into the research process. Yet, these questions were identified by faculty members as a crucial first step in developing a project with societal impacts.

**Issues with Impact Metrics**

The impacts measured in citation metrics are not the same as public impacts. Most universities’ research evaluation metrics are unable to measure impacts beyond academia. Many of the faculty members also discussed the problems with using impact factors to evaluate research impacts. Previous studies have also highlighted the many limitations of evaluating research by using journal’s impact factors. (Seglen, 1997) Impact factors represent the rate of other scholars citing the work rather than public
usage of the information. Citation indexes do not measure public impact. As one faculty member stated, “You can have a big impact from a paper that is not cited much.” Sometimes the impact is not seen in the peer review process. This often occurs when a topic holds great public interest. Papers with a high public impact can play a role in shaping public policy or improving people’s lives. However, many universities do not have established metrics for measuring these types of public impacts. It is also difficult to establish causation when evaluation societal impacts. Faculty members also found the emphasis on financial metrics problematic. These types of metrics prioritize expensive research that brings in more indirect costs, but costs are not always correlated with quality in research. For example, a large grant could be used to purchase equipment.

Faculty in the agricultural and clinical sciences reported that their colleges had evaluation criteria that measured impacts related to extension and patient care. These fields have traditionally engaged with the public due to the many practical applications of their work. The colleges ask faculty members to quantify their impacts in T&P process. For example, one faculty member said that he reported in his T&P packet how many times his work was cited in a newspaper or other media outlets and how often he was interviewed by these sources about his work. He said that other great strategies for measuring research’s impacts include using pre-and post-surveys to quantify behavioral changes. Another faculty member explained that colleges in the health sciences measure the impacts of clinicians by examining their patient outcomes, number of referrals, clinical outreach, community outreach, teaching and mentorship of medical students, patent applications, and optimization of clinical processes.
These types of changes in T&P criteria require a cultural shift in administrator and faculty members’ values and priorities. Communication across colleges can also help to facilitate the change process. Other colleges could integrate aspects from extension or patient care metrics to prioritize public engagement and research impacts. This requires thinking critically about how the university, college, and department wants to evolve over time. Allowing faculty members to evaluate the chair can also increase departmental accountability over the evaluation process.

**Potential for Translation**

Translating findings to the public presents many challenges for researchers. Faculty members explained that translation requires optimization and consideration of the scope and nature of potential interventions prior to starting the process. Faculty members agreed that it is difficult to change how scientists conduct their research and what motivates them. However, it is possible to request or require them to translate their findings. Monitoring and measuring translation in the T&P process through allowing faculty members to provide a narrative about how they have translated their findings and engaged with the public could help to generate conversations about research impacts beyond academia in the T&P process.

Faculty members also explained that they must think about the goals of their work before selecting collaborators as it often requires particular types of collaborators to conceptualize the practical applications of their work and be willing to continually revise their work until it meets the needs of the stakeholders. Certain collaborators work better for different projects. For example, one researcher described a time when he had to reduce one month of mathematical computation into a one-minute medical procedure. In this situation, he realized that he needed to identify new collaborators to
assist him with the translational component of the project because his existing collaborators prioritized the complexity of the computation over the practical value of this reduction.

**Disciplinary and Motivational Differences**

Disciplinary norms and training shape researchers’ feelings about public engagement. Researchers pointed out that each discipline operates within its own time scale and level of applications. Norms differ greatly between the health sciences and agricultural sciences. The health sciences emphasize novel approaches, whereas the agricultural sciences emphasize applied and adaptable studies and the uptake of developed approaches. The university also has a strategic vision of institution with a bottom up approach where departments and colleges decide what counts and what does not. This makes it difficult to get all departments to embrace public engagement. However, interviewees agreed that the university as a whole should incorporate research impacts beyond academia into their T&P process.

Training plays a major role in shaping researchers’ attitudes towards public engagement. Norms regarding the types of research and impacts that are valued by universities are formed during graduate training. Academia trains students to be academics who publish in peer-reviewed journals, speak at disciplinary conferences, and apply for federal funding. It does not train them how to be practitioners who have a social impact, disseminate their findings through popular communication channels like TV or social media, and engage with the public. Faculty members suggested that exposure to these types of research and communication strategies needs to occur at a graduate level. They suggested that teaching graduate students how to think though their research problem and its impact on society can be a way to start this conversation.
Efforts to increase faculty engagement with the public also need to consider researchers’ motivations. Previous studies have found that faculty members are motivated by either financial incentives and awards, the intrinsic satisfaction of solving a puzzle, a sense of purpose, or a combination of these motivations. (Lam, 2011) Interventions that encourage public engagement should keep this in mind and develop different ways to engage researchers from each group. Since there are currently limited financial incentives or awards associated with public engagement, the faculty members I interviewed said that they were primarily motivated by the puzzle and a general sense of purpose. Faculty members explained in interviews that a research problem needs to be both intellectually interesting and meet their research objective.

**Conclusions and Suggestions**

Scientists have an important role to play in shaping public policy and sharing their work with the public. Universities have a responsibility to promote and recognize research impacts outside of academia. This requires a shift in focus in both faculty evaluation and graduate training. This study examined the public’s perceptions of science and solicited suggestions from the public and university faculty members on creating alternative metrics for evaluating research impacts beyond academia.

This study has three main findings about scientists’ relationship to the public. First, it found that the public generally has positive views of science and would like to learn more about research discoveries from scientists. Second, it found that levels of interaction and knowledge dissemination between scientists and the public are quite low. However, the public has a desire for increased public engagement. Third, it found that educational level shapes the public’s knowledge about and views of scientific research and discoveries. This finding is consistent with previous studies which have
found that science education increases the likelihood of effective communication between scientists and the public. (Fischhoff & Scheufele, 2013) These findings suggest that universities need to encourage and incentivize scientists to engage with and share their findings with the public. Doing so will require providing scientists or graduate students with science communication training to help them translate their findings for the general public and utilize different distribution channels (e.g. websites, movies or TV, newspapers or magazines, and social media) for sharing their research results.

This study also has three main findings regarding creating alternative metrics for evaluating research impacts beyond academia. First, it found that scientists and the public have a common interest in measuring research impacts and prioritizing public engagement. A survey of the public revealed that they believe that research should be evaluated by measuring its effects on the public, validating research findings, increasing engagement with the public, conducting follow-up surveys, and prioritizing teaching efforts. Interviews with faculty who engage with the public highlighted similar themes.

Second, research impacts beyond academia should be weighted equally with impacts inside of academia. Faculty interviews revealed that funding sources which prioritized public impacts and publications written for non-academic audiences were often stigmatized in the T&P process or relegated to the service category. Removing this stigma by treating all funding and publications equally can help to increase the fairness of the evaluation process and allow faculty members to pursue different types of research impacts.

Third, public engagement, communication, and evaluation techniques should be emphasized in graduate training programs and conversations between mentors and
mentees. Previous studies have argued for increased communication training for scientists. However, this recommendation has not come to fruition due to limited time, interest, and resources. Mentors can play an important role in bridging the gap between training and practice. Therefore, efforts to increase science communication and public engagement should be targeted at improving graduate training and mentor-mentee relationships. Science communication training should focus on teaching researchers how to frame their findings in relevant ways, highlight shared values, and emphasize big ideas versus specific details.

There are five steps that universities could take to reduce these issues in the T&P process. First, universities could create a section of the T&P packet that specifically addresses research impacts. Second, universities could ask external reviewers to comment on the applicability of faculty members’ work. Third, the university could implement a program to talk with department chairs about the importance of faculty members sharing their research with the public and translating their findings. Fourth, departments and colleges could recognize different publication outlets such as popular science or grey literature (non-conventional sources, technical reports, conference proceedings). Fifth, social media sharing metrics could be integrated into the research evaluation process to determine the publication’s reach.

Universities could also implement rewards that highlight faculty members who are engaged in research with high social impacts to increase their visibility. They could publicize this type of work by posting it on the university’s main website or the cover of a university publication. They could also set aside money for a temporary president professorship focused on social impact work. This would provide these junior faculty
members with greater access to university leadership (e.g. the provost and president). It also would signal a symbolic change and demonstrate that the university is interested in prioritizing the social impacts of research. These types of changes would suggest to faculty members a shift in university leadership’s values and priorities. They would also show a commitment to increasing public engagement and science communication.
Table 5-1. Survey respondents' demographics

<table>
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<tr>
<th>Demographic Category</th>
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<td>79</td>
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<tr>
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</tr>
<tr>
<td><strong>Total</strong></td>
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<td>100</td>
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<tr>
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<tr>
<td>Multi-racial or mixed race</td>
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<tr>
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<td>Some college or Associate's degree</td>
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<td>Bachelor's degree or higher</td>
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<td>37.7</td>
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<td>0.4</td>
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<td>100</td>
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<td>%</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>How well informed do you feel about scientific research and discoveries?</td>
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<td></td>
</tr>
<tr>
<td>Very well informed</td>
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<tr>
<td>Fairly well informed</td>
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<td>0.2</td>
</tr>
<tr>
<td>Refused</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>504</td>
<td>100</td>
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</tbody>
</table>

I would like scientists to spend more time talking about their scientific research and discoveries with the general public.

<table>
<thead>
<tr>
<th>I would like scientists to spend more time talking about their scientific research and discoveries with the general public.</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>135</td>
<td>26.8</td>
</tr>
<tr>
<td>Agree</td>
<td>251</td>
<td>49.8</td>
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<tr>
<td>Refused</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>504</td>
<td>100</td>
</tr>
</tbody>
</table>

Scientists should be rewarded for discussing their scientific research and discoveries with the general public.

<table>
<thead>
<tr>
<th>Scientists should be rewarded for discussing their scientific research and discoveries with the general public.</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
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<td>20.8</td>
</tr>
<tr>
<td>Agree</td>
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<td>41.5</td>
</tr>
<tr>
<td>Neither agree nor disagree</td>
<td>96</td>
<td>19.0</td>
</tr>
<tr>
<td>Disagree</td>
<td>70</td>
<td>13.9</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>17</td>
<td>3.4</td>
</tr>
<tr>
<td>Don’t Know</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>Refused</td>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>504</td>
<td>100</td>
</tr>
</tbody>
</table>

From which sources do you normally hear about new scientific discoveries? (Respondents were allowed to select all responses that applied, so total percentage does not equal 100%)

<table>
<thead>
<tr>
<th>From which sources do you normally hear about new scientific discoveries? (Respondents were allowed to select all responses that applied, so total percentage does not equal 100%)</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly from scientists</td>
<td>40</td>
<td>7.9</td>
</tr>
<tr>
<td>Scientific journals</td>
<td>113</td>
<td>22.4</td>
</tr>
<tr>
<td>Friends and family</td>
<td>125</td>
<td>24.8</td>
</tr>
<tr>
<td>People at work</td>
<td>94</td>
<td>18.7</td>
</tr>
<tr>
<td>Movies or TV</td>
<td>242</td>
<td>48.0</td>
</tr>
<tr>
<td>Books</td>
<td>125</td>
<td>24.8</td>
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</table>
Table 5-2. Continued

<table>
<thead>
<tr>
<th>Media Type</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newspapers or magazines (in print or online)</td>
<td>230</td>
<td>45.6</td>
</tr>
<tr>
<td>Radio</td>
<td>122</td>
<td>24.2</td>
</tr>
<tr>
<td>Websites</td>
<td>305</td>
<td>60.5</td>
</tr>
<tr>
<td>Other</td>
<td>22</td>
<td>4.4</td>
</tr>
<tr>
<td>Don’t Know</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Refused</td>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1422</td>
<td>282.1</td>
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</table>

Do you think that you have been personally impacted by scientific research?

<table>
<thead>
<tr>
<th>Response</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>370</td>
<td>73.4</td>
</tr>
<tr>
<td>No</td>
<td>130</td>
<td>25.8</td>
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<tr>
<td>Don't Know</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Refused</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>504</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 5-1. How well informed do you feel about scientific research and discoveries? - by educational level.
Figure 5-2. From which sources do you normally hear about new scientific discoveries? - by educational level.
Figure 5-3. Do you think that you have been personally impacted by scientific research? – Most common open-ended responses.
Figure 5-4. Do you think that you have been personally impacted by scientific research? - by education level.
Figure 5-5. Do you think that you have been personally impacted by scientific research? – Most common open-ended responses.
CHAPTER 6
CONCLUSION

Overview

Teams play a major role in research and development (R&D) in universities, governments, and companies. Yet, while companies and governments have been steadily increasing their investments in teams, many universities’ evaluation and reward systems have continued to prioritize individual research efforts over team science. This is a critical mistake because teams are essential to solving complex scientific problems. This also makes it difficult for universities to hire and retain innovative researchers. This dissertation argues that universities need to adapt to the changing landscape of research by supporting and recognizing team science.

Universities can improve researchers’ experiences collaborating and translating their findings to broader audiences by reducing administrative barriers to collaboration and revising the tenure and promotion (T&P) process to reward team science and public engagement. Supporting and rewarding teams requires significant organizational commitment and changes at a university, college, and department level. This requires a cultural shift across the university to emphasize team science in the faculty recruitment, hiring, retention, evaluation, and reward processes. Public universities also have a duty to reward faculty members for engaging with the public and support the translation of their research findings into improvements in products, services, and policy. Institutes like the Clinical Translational Science Institute (CTSI) can play an important role in facilitating this process of prioritizing team science and public engagement.

This dissertation presented four studies that examined the role of team science in a university setting. Each chapter of this dissertation highlights the important role that
organizational culture plays in shaping the practice of team science. This dissertation’s mixed method approach was essential for capturing both the depth and the breadth of a university’s collaboration culture. Combining quantitative and qualitative data sources allowed me to combine a broad knowledge of scientific collaboration network patterns across the university with a deep contextual understanding of individual researchers’ experiences with team science. This combination allowed me to provide a more nuanced portrayal of contemporary team science. It also helped me to propose solutions to these issues that were grounded in both general university trends and specific researchers’ experiences.

These studies found that encouraging team science begins by prioritizing a candidate’s potential for collaboration in the hiring process. Teams are made up of people with different personalities, leadership styles, interests, and backgrounds. Successful teams are typically composed of team members with complementary collaboration styles. Whereas, unsuccessful teams often have too many leaders, a lack of clearly defined roles, or high levels of interpersonal conflict. Thus, hiring committees should consider the type of role that a candidate could play in existing and future teams, in addition to examining their research qualifications.

This study also revealed that departments and mentors have a great deal of influence over the way that science is practiced. Departments can encourage collaboration by starting conversations about team science and revising their tenure criteria to recognize this type of research. This bottom up approach requires strong leadership from department chairs and division chiefs, as well as buy-in from the department’s faculty members. Mentors also play an important role in setting research
and collaboration norms for their trainees. Universities could utilize these mentorship networks to disseminate information or encourage scientific collaboration by using a network intervention to target influential mentors. Similar approaches could also be adopted to increase faculty retention in emerging research fields.

As this dissertation demonstrates, it is possible to generate solutions to help universities encourage and recognize team science. My findings from these studies were shared with the CTSI, university administrators, and the tenure taskforce throughout the research process. My team and I sought to implement our findings at a university scale. Initially, I anticipated that the university would quickly make changes based on my findings. However, I learned through this process that organizational change is often difficult and time consuming. This process taught me that developing solutions to a problem represents only the beginning stage of the implementation process. Many challenges arise when implementing findings at an organizational scale.

The following sections of this chapter outline some best practices from the literature on change management for implementing organizational changes and gaining buy-in from key stakeholders. These sections also explore the unique challenges of implementing new processes at universities and provide suggestions for better supporting organizational change in these contexts. This discussion will include examples of why organizations resist change, how to address these concerns, and suggestions for gaining buy-in across the organization.

**Resistance to Change**

Resistance to change has been well documented in the literature on conflict management and organizational culture in businesses. As a result, there have been many suggestions on how to minimize resistance to change in business and community
settings. (Waddell and Sohal, 1998; Susskind et al., 1999; Means et al., 2002) However, little has been written on how to effectively implement interventions and deal with resistance to these changes in a university context. (Rohrbach et al., 2006; Glasgow et al., 2007) This creates challenges for universities when they attempt to introduce organizational level changes.

This is particularly challenging for interdisciplinary institutes like the CTSI. One of the CTSI’s missions is to develop new approaches to reduce barriers to collaboration and innovation. A great deal of time and effort has been put into designing the best interventions to translate insights from research into practice. However, when they attempt to implement these interventions on a university level, they often experience resistance to change from stakeholders. Thus, further research is needed to explore how organizational culture shapes collaboration culture and resistance to change. This section addresses these issues by highlighting relevant practices from other contexts that could be adopted for this aim and providing suggestions for next steps at UF and other institutions with Clinical Translational Science Awards.

Resistance to change is natural. Organizations often resist change because they are composed of people who have a vested stake in the process. People resist change for a variety of reasons. One or a mixture of rational, non-rational, political, and management factors typically play a major role in an individual’s resistance to change. (Waddell and Sohal, 1998) Three common reasons for resistance and conflict are due to the perception of risk involved, amount of effort required, and a desire to remain comfortable. (Stagl, 2015; Kiseloski, n.d.) These reasons highlight a fear of the negative consequences that can sometimes follow organizational change. Reasons for resisting
change vary based on the cultural context and scale of the intervention, but fear is often at the root of this resistance. Waddell and Sohal (1998) write that,

People do not resist change *per se*, rather they resist the uncertainties and potential outcome that change can cause. (547)

Uncertainty about an issue can play a major role in shaping individual and organizational decision making. As a result, it is important to learn why specific stakeholders are resisting this particular change. Understanding why can help you to address the issue of uncertainty by asking what they fear will happen if the change occurs and listening closely to their responses. Change requires empathy. Understanding stakeholders’ resistance and allowing them to feel as though their opinions have been heard can be helpful in developing better solutions that stakeholders can mutually agree on and be invested in.

Stakeholders who resist change often focus on the benefits of not changing, whereas people who design interventions focus on the benefits of changing. Stakeholders will often focus on the benefits of their own approach. They make sense of the issue by framing it in terms of their own interpretation, needs, and values. (Susskind et al., 1999: 212)

**Minimizing Resistance to Change**

Empathetic listening can help to minimize resistance to change and build consensus. Individual stakeholders are usually not able to see all of the underlying conditions that have framed other stakeholders’ point of view. This mismatch in approaches, frames, and interests needs to be addressed on an individual basis by a neutral facilitator using adaptive conflict management strategies. Without this dialogue...
or use of other methods to cultivating stakeholders’ buy-in to the change process, these individuals will often reject the change and the intervention will fail.

When dealing with an emotionally charged topic, it can be helpful to bring in a neutral facilitator. This facilitator could be someone from another department who is unfamiliar with the issue or in extreme circumstances someone you hire from outside the organization exclusively for this purpose. A neutral facilitator can engage stakeholders in dialogue to get to the root of the conflict and determine if it is related to substantive, relationship, or process issues. (Susskind et al., 1999: 199-240) Facilitators can play an important role in breaking down barriers between stakeholders and helping the team find a way to move forward.

**Defining and Managing Conflict**

The term conflict is often used sparingly when dealing with resistance to change, as it evokes strong reactions. People generally see conflict as a negative thing. Yet, acknowledging resistance to change as a type of conflict and addressing it can also be a starting point for managing it and generating a solution. Means et al. (2002) defines a conflict as,

> A relationship among two or more opposing parties, whether marked by violence or not, based on actual or perceived differences in needs, interests and goals. Conflicts are a normal part of human interaction, and many conflicts can be managed productively. (13)

This definition highlights the normalcy of conflict and the role that perceptions can play in shaping conflicts.

Acknowledging conflict related to a proposed change is the first step in minimizing resistance to change. Next, the relevant stakeholders need to be identified. In the case of revising the T&P criteria, this would require identifying representative
faculty members, department chairs, division chiefs, deans, provosts, and the university’s president. A facilitator or neutral party can meet with the stakeholders or their representative if the group is large and discuss their perceptions, needs, interests, and goals. Once the facilitator has talked to all of the relevant stakeholders, they should set a meeting to discuss the change. Small groups (4–6 people) are better for these types of discussions, so the facilitator may need to have multiple meetings to include all of the relevant stakeholders.

The facilitator can use these meetings to generate a dialogue between stakeholders. Fisher and Ury (1983) provide rules of principled negotiation that can be used as a starting point for focusing the discussion. These rules highlight the importance of separating people from the issues at hand, focusing on stakeholders’ interests rather than positions, collectively identifying additional and better options, and setting criteria to come to a mutually agreed upon solution. (ibid) The primary goals of these meetings should be to gain an understanding of the resistance to change and generate alternative solutions for mutual gain.

These types of meetings with stakeholders can be an excellent way of addressing resistance to change, but are not always appropriate or possible. Other options for addressing resistance to change can be individual meetings with a person who resists the change to learn why they oppose it and what could be done to get them on board. It is also important to remember that having the best designed solution on paper is not enough. If you do not have buy-in from the necessary stakeholders, your proposed change will not be successful. Therefore, interventions or other types of organizational changes need to be designed with the end-users in mind. By getting
feedback from a diverse group of stakeholders throughout the design stage, planners can create better interventions that have higher adoption rates and lower failure rates. These stakeholders can also introduce important theoretical and practical considerations that may be missed by the designers.

Regardless of which approach is selected to minimize resistance to change there are five important things to keep in mind. (Stagl, 2015; Kiseloski, n.d.; Waddell & Sohal, 1998)

- **Do not take resistance to change personally.** Making resistance into a personal matter cause personal conflict to complicate the process and make finding a mutually acceptable solution much more difficult.

- **Try to understand resistance.** Asking questions to try to understand the reasons why people are resistant to adopt your approach can help to improve your intervention and gain buy-in for this and future projects.

- **Do not blame others for refusing to change.** People often wrongly attribute someone’s behavior or opinions on an issue to their personality rather than trying to think about other reasons why they may be resisting the change. This can lead to interpersonal conflict rather than focusing on the substantive issues.

- **Do not try to force change.** Your change may be adopted without stakeholders’ buy-in, but it will not be as successful as it should be and can lead to additional organizational conflict down the road.

- **Try to see resistance to change as an opportunity to grow as an organization.** Resistance to change can often help to improve the intervention to better meet the needs of the stakeholders. Facilitated dialogues between stakeholders or other methods of addressing resistance to change can also help to discover new things about the organization and introduce other issues that need to be addressed. After the issue of resistance to change has been initially broached by an organization and a system has been developed to deal with these types of issues, future organizational discussions become easier and decisions are more likely to be adopted by the relevant stakeholders.

**Implementing Organizational Changes in University Settings**

Implementing changes in a university setting presents some unique challenges.

The literature on resistance to organizational change focuses almost exclusively on
business or community contexts. Universities have very different missions, structures, historical contexts, and administrative structures than businesses. Recently there has been a push for the corporatization of universities, which has caused some conflict between faculty and administrators over how universities should be run and its primary mission. (Catropa & Andrews, 2013)

Implementing organizational changes in a university setting requires an awareness of the diversity of stakeholders involved. Organizational cultures and research norms vary greatly between faculty in different colleges and departments. Successful approaches require an appreciation of these differences. The university’s staff also plays a major role in shaping the organization’s structure and culture. Thus, they should also be consulted during the decision-making process and when introducing organizational level changes. Deep contextual inquiry through ethnographic methods, interviews, surveys, and conversations can help to provide valuable information about faculty and staff’s perceptions regarding a specific change.

**Suggestions for Supporting Organizational Change in University Settings**

University administrators and other change agents need to keep in mind the specific cultural, historical, and administrative context of their institution when suggesting or implementing changes. Understanding the organizational culture of the university where the intervention will be adopted helps planners design a more appropriate solution to the problem.

Provosts in particular can play a central role in facilitating organizational change at a university. As an article in the *Chronicle of Higher Education* explains,

The task of shaping change and making it happen across a campus falls to provosts partly because they have institution-wide reach. They can gather information and opinions from all of a university’s colleges and
divisions. The can evaluate possible courses of action relatively free from the parochial concerns of the deans, department chairs, and others who lead academic units. Provosts have the purview to steer resources, setting clear budget priorities. And they can seed change throughout an institution by talking it up, following up with the various deans and department chair, and sharing promising results. (Gardner, 2015)

These complex tasks require the facilitation skills I discussed previously. It is important for change facilitators to learn about all of the relevant stakeholders’ perspectives on the issue at hand and communicate openly about the change process. This can help to alleviate some resistance to change.

A recent *Chronicle of Higher Education* article about cluster hiring highlighted the fact that getting and maintaining faculty buy-in throughout the adoption process is essential to any organizational change. (McMurtrie, 2016) McMurtrie (2016) writes,

> It helps to start slowly from the ground up. Without faculty buy-in, as well as time to review effectiveness, cluster hiring won’t work, or at least won’t work as well as it could. It also helps, they say, to build on existing disciplinary strength and established interdisciplinary work, rather than starting something from scratch.

This advice can also be applied to other types of organizational change at universities. In order for a change to be adopted, faculty must have a voice in the process and time to absorb the changes and express their concerns. Framing also plays a major role in shaping how organizational changes are perceived. (Susskind et al., 1999) Thus, the change should be framed as focus on improving the current strengths of the institutions rather than on highlighting its weaknesses.

Organizational change also typically requires additional infrastructure to provide additional support resources. It is not fair to ask existing stakeholders to assume additional responsibilities and requiring them to do so can cause resentment among personnel. Therefore, when proposing a change the proposal should also clearly lay out
what additional infrastructure is necessary and how this new system will affect the existing staff and faculty.

**Conclusion**

This dissertation explored how organizational and disciplinary norms promote and inhibit team science. The historical and administrative structure of a university plays an important role in shaping its organizational culture and attitudes towards team science. These attitudes are embodied in its tenure criteria, budget structure, facilities and administrative rates, hiring practices, reward systems, and institutional priorities. These components of organizational culture play a major role in shaping collaboration practices at universities. This dissertation argued that universities should support and recognize team science through removing barriers to collaboration, revising the T&P system, tracking emerging research fields, and encouraging translational science.

These types of organizational changes require faculty and administrative buy-in, as well as time to process the changes. Resistance to these types of organizational changes is common. This resistance often stems from individuals, departments, or colleges' fear over ceding control over their cultural domain within the university. Ironically it is often those introducing the changes who are least aware of the roots of resistance and open to changes in the implementation of their ideas. Therefore, it is important for researchers and change agents to try to remain open to new ideas and see resistance as a tool for building better solutions rather than as an impediment. As Waddell and Sohal (1998) explain,

> Resistance can play a critical role in drawing everyone’s attention to aspect of the change that may be inappropriate, not well thought through or perhaps plain wrong.
This quote highlights the importance of listening and maintaining perspective throughout the different stages of the implementation process (exploration, adoption, implementation, and sustainment and monitoring).

Change agents and their organizational leaders need to focus on increasing organizational awareness and accountability throughout the implementation process. (DiDonato & Gill, 2015) Doing small things like letting people know that you think they are doing a great job, you appreciate what they are doing, and you aim to provide them with more resources to achieve their own goals have been shown to have a major impact on reducing resistance to change. (DiDonato & Gill, 2015) Implementing change is all about framing the change in meaningful ways that are appropriate for their particular cultural context. Thus, I have attempted to keep many of these approaches in mind when I share new findings or methods with university administrators.

This dissertation proposed new methods for identifying barriers to team science, evaluating scientific collaboration, building new research teams, and increasing research impacts beyond academia. It also provided concrete steps that universities and other organizations can take to support and facilitate collaboration. However, as discussed in the previous section implementing these findings can present challenges.

These projects and their implementation process started a university dialogue about differences in departmental attitudes towards team science. It also examined how T&P decisions often reflect disciplinary norms and values. These differences made it difficult to incorporate team science and public engagement metrics into the university’s T&P evaluation process. While many researchers recognize that team science is important, it is difficult to standardize the evaluation of scientific collaboration across
departments. Fully integrating team science into the university will require both a revision of the existing T&P system and a cultural shift in research norms.

This dissertation provided a case study of team science at a single university in the US. These findings also have important implications beyond academia. The lessons learned from this study can be used to examine, improve, create, and reward teams in other organizations. Organizational managers can use these findings to frame their teams’ goals in meaningful ways. They can also help them to facilitate team functioning, resolve interpersonal conflicts among team members, evaluate individual and team performance, and reward collaborative innovation.

Future studies could provide cross-university or cross-company comparisons of team dynamics to further explore the role of organizational culture. It is also critical for studies to be conducted on how to best implement these findings in different types of organizations. Gender and race also play a major role in shaping team dynamics and present barriers to collaboration. Additional research could examine women and minorities’ experiences collaborating in teams. Studies could also be completed to examine the relationship between an employee’s position in their organization’s collaboration network and whether or not they have recently left the organization. This study could be translated into developing a predictive model for identifying employees who are at risk for leaving the organization and increasing the engagement of employees on the periphery of their community or department’s network.

There are four main broader impacts associated with this dissertation. First, identifying key barriers to scientific collaboration can help reduce their prevalence. Increasing awareness of barriers at a university, college, and departmental level can
also help administrators make key decisions about how to encourage team science within their unit. Second, knowledge of how the T&P process varies by college is critical for administrators and committees like the tenure taskforce to make recommendations for revising the process to better recognize, reward, and evaluation team science. Suggestions from researchers can also help to shape changes in the T&P and junior faculty mentoring process. Third, identifying scientific fields is critical to understanding a university’s organizational focus and strengths. These findings could also be used to design additional network interventions to bridge researchers or communities working on similar research topics for the advancement of science. Fourth, developing better metrics for recognizing and evaluating research impact beyond academia and incentives for engaging in this type of research will help to encourage researchers to engage with non-academic stakeholders. These efforts are also vital to keeping academic research relevant to the public. Adopting a mixed method research approach helped me increase the impact of this project. This research approach allowed me to provide the university with suggestions for improving the practice of team science on an organizational, team, and researcher level.
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BIOGRAPHICAL SKETCH

Therese Kennelly Okraku is a researcher and social scientist with seven years of experience in mixed method research design, project management, and data analysis. She studies how teams collaborate in order to create new teams and improve group dynamics in existing teams. She has presented her research findings at ten conferences and published results in three peer-reviewed journals. She also has two years of international research experience in West Africa, strong cross-cultural communication skills, and speaks conversational Chinese (Mandarin), Akan (Twi), & Wolof. She received a Ph.D. in anthropology with a certificate in clinical translational science from University of Florida in 2017, a master's degree in anthropology with a certificate in sustainable development from University of Florida in 2015, and a bachelor's degree in history and African studies from Indiana University in 2012. After graduation, she will be researching and designing products for Microsoft.