EXPLORING THE ROLE OF TEAM LEADERS AND THEIR PERCEPTIONS OF BARRIERS TO CONDUCTING INTERDISCIPLINARY RESEARCH

A Dissertation

by

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ABSTRACT

Researchers in the twenty-first century are faced with complex problems that require multi-faceted solutions. To confront these intractable problems—whether they are health, social, or economic crises—there is a need for researchers to work across disciplines and apply multiple perspectives. Interdisciplinary research (IDR) refers to individuals from various disciplines working together, integrating ideas, methods and theories, to address a common problem.

Although IDR may be key to developing solutions to the crises we are facing today, researchers pursuing interdisciplinarity encounter a diverse range of personal, structural, and political challenges. While some impediments are caused by researchers lack of openness to alternate ways of conducting research, others are rooted in the structural aspects of academic institutions including unfavorable promotion and tenure guidelines, which do not credit IDR contributions at par with disciplinary work. In addition to handling some of the common challenges leaders encounter, IDR leaders are required to manage multiple levels, from ensuring team members are motivated at the individual level, bridging communication across disciplines and paradigms at the team level, to operating within varying promotion and tenure guidelines at the institutional level.

Current literature provided limited insights into the role of IDR leaders and the barriers they encounter. To better understand these phenomena, I sought to explore the barriers and role of IDR team leaders—using a social ecological model framework—in this study. Employing a qualitative case study research design, I conducted interviews

with leaders of a X-Grants, an interdisciplinary seed grant initiative at Texas A&M University, and utilized relevant secondary data sources to supplement and triangulate findings from interviews.

Participants indicated encountering barriers at the individual, team, institutional, community, and policy levels. Because of the range and nature of barriers impeding interdisciplinary teams, my findings uncovered that the role of principal investigators (PIs) is multi-faceted and requires them to manage three key components: the team's intellectual direction, interpersonal interactions, and project management.

This study has implications for both theory and practice. By approaching my research questions from a social ecological model and complex dynamics systems perspective, my analysis not only provides a unique lens with which to view IDR teams, but also adds to the emerging conversation in the literature. A social ecological model perspective reveals that there is interaction within and among levels, with influences from the context or setting. A complex dynamic system of interaction explains that factors dynamically influence each other over time

In practice, findings from this study have the potential to inform future steps for strengthening the IDR initiatives in universities and funding agencies. By developing a better understanding of the challenges and role of IDR team leaders, HRD practitioners are likely to develop holistic interventions that address multiple dimensions of a problem rather than tackling an issue merely at the tip of the iceberg.

DEDICATION

To my parents—Saradha and Sankar—for their unconditional love and my husband, Vikram, for his kindness, love, and relentless support.

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It truly does take a village.

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In the Spring of 2020, I worked with Dr. Stanley on a directed study for my dissertation proposal. During that time, neither were my research questions fully formed, nor did I have a clear picture of what methods I would like to employ. It was Dr. Stanley's mentorship and pointed questions that propelled me to think through different aspects of my study.

During the course of my doctoral journey, Dr. Dirani, on more than one occasion, highlighted gaps in my methodology and research design. His questions, comments, and suggestions enabled me to make my study sound and rigorous.

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approach and conduct research. He was very generous in sharing countless articles relating to multilevel and nested systems. My theoretical framework was heavily influenced by our discussions and exchange of ideas.

The Interdisciplinary Research and Evaluation Team (IDRE) has been an integral part of my Ph.D. journey. Our weekly meetings typically involved discussions around logic models, research designs, methodologies, epistemologies, and so much more. I owe a debt of gratitude to the team for letting me learn by doing, even when I was grappling with what goes into a multilevel mixed methods evaluation. Needless to say, the time I spent in the team has enriched and molded me as a researcher.

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Contributors

This work was supervised by a dissertation committee consisting of Professors Michael Beyerlein, Ph.D. [advisor], Khalil M. Dirani, Ph.D., Christine A. Stanley, Ph.D., of the Department of Educational Administration and Human Resource Development and Professor Patricia Goodson, Ph.D. of the Department of Health and Kinesiology.

All other work conducted for the dissertation was completed by the student independently.

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CHAPTER I

INTRODUCTION

From climate change to global health crises, today's social problems are far too complex for a single discipline to tackle alone. To deal with such intractable problems, there is a need for collaborative expertise from different disciplines, often involving, but not limited to, interdisciplinary research (IDR) (Hein, Gopalakrishnan, Livneh, Adams, Marino, & Weiler, 2018; National Academies, 2005). The IDR approach integrates methods, data, tools, and theories from different disciplines for a shared understanding of an issue (Wagner, Roessner, Bobb, Klein, Boyack, Keyton, Rafols, & Börner, 2011).

Although terms multi, inter, and transdisciplinary (TD) research are used interchangeably, they constitute different approaches (Rosenfield, 1992). Researchers engaging in multidisciplinary research "work in parallel or sequentially from disciplinary specific bases to address common problems" (Rosenfield, 1992, p. 1353). In other words, multidisciplinary research "*juxtaposes* disciplinary/professional perspectives" while letting "disciplinary elements retain their original identity."

TD research, on the other hand, "is not research as usual" (p. 1353) and hinges on syntheses that create new departments, new fields, and new career paths. Rosenfield (1992, p. 1353) stated that researchers involved in TD "work jointly using a shared conceptual framework drawing together disciplinary-specific theories, concepts, and approaches to address a common problem." TD approaches, "*transcend* the narrow scope of disciplinary worldviews…" fostering the creation of frameworks that help define and analyze complex problems (Wagner et al., 2011, p. 6).

Academic researchers' interest in IDR has grown tremendously in recent decades (Rosenfield, 1992; Van Noorden, 2015). Funding agencies and universities have created programs and initiatives to promote IDR and teamwork (Choi & Pak, 2007). Although IDR has more funding opportunities today, it poses unique challenges (Laursen, 2018) and is difficult to operationalize (Aagard-Hansen, 2007). IDR might be impeded by methodological and epistemological differences, "lack of knowledge, divergent standards, different approaches, or simply negative attitudes and prejudices" (Aagard-Hansen, 2007, p. 427). Academic reward systems, promotion and tenure policies (Schuitema & Sintov, 2017), differences in departmental cultures, decentralized budgets, and limited resources (Boden & Borrego, 2011) compound the challenges even further. The diverse range of personal, structural, and political barriers and challenges may set apart an IDR team from a more monodisciplinary or traditional team.

IDR leaders face many of the same challenges that leaders of traditional teams encounter. However, what sets IDR leaders apart is that they are required to manage the entire system (Porter, Roessner, Cohen, & Perreault, 2006), ranging from team factors including communication and collaboration across disciplines and paradigms to structural factors that stifle interactions among departments (Fiore, 2008). Along with possessing technical and interpersonal skills, an IDR leader must engage in integrating knowledge (Gray, 2008; Jakobsen, Hel, & McLaughlin, 2004; Mariz-Perez, Teijeiro-Álvarez, & García-Álvarez, 2012; National Academies, 2005; Stedman & Adams-Pope, 2019) from different team members and disciplines. The nature of and barriers impeding

IDR teams might, therefore, require leaders to possess a wide range of skills to effectively lead and to consolidate knowledge from different fields and disciplines.

Background

In the United States, funding agencies are increasingly promoting interdisciplinary research (Bridle, Vrieling, Cardillo, Araya, & Hinojosa, 2013). For example, the National Institutes of Health (NIH) has established the Common Fund's Interdisciplinary Research program and the Clinical Translational Science Awards (National Institutes of Health, n.d.). The National Science Foundation (n.d.) has designed programs such as Smart & Connected Communities, Water Sustainability and Climate, and has funded Engineering Research centers (ERCs) with the goal of encouraging IDR. Even though funding opportunities have grown and more IDR teams are working together, some areas in IDR—including team leadership—are understudied (Adams, Cain, Giraud, & Stedman, 2012).

Current literature varies in the description of the IDR leader role. Some authors note that IDR leaders with clear vision and skills in team-building and communication can engender the integration of multiple disciplines (National Academies, 2005). Besides working with team members on key issues like research plans, goals, timelines, and meeting times, IDR leaders need to integrate knowledge from different disciplines rather than just "stapling together" information (National Academies, 2005, p. 113). Additionally, IDR leaders are required to facilitate conversations about credit and authorship on publications, grants, and conference proceedings (National Academies, 2005), while supporting and empowering the team (Stokols, Misra, Moser, Hall, &

Taylor, 2008). In short, successful IDR leaders are required to be credible, possess the ability to handle different personalities, and mediate diverse viewpoints, goals, and perspectives (Lakhani, Benzies, & Hayden, 2012).

Managing the cognitive, interpersonal, and structural aspects of an IDR team may be a tall order for a single leader. Hence, a recurring theme in IDR team leadership literature is the notion of shared leadership (Fiore, 2008; Lakhani et al., 2012; McCallin, 2003; Pearce & Manz, 2005), in which all team members take responsibility for team processes and outcomes, instead of adopting a strictly vertical leadership approach. Shared leadership is an emergent process, in which team members experience and mutually influence leadership functions (Pearce & Sims, 2000) "as dictated by either environmental demands or the development stage of the team" (Burke, Fiore, & Salas, 2003, p. 105). Due to a lack of consensus regarding the role of an IDR team leader, I am interested in exploring how leaders of IDR teams define their roles.

Statement of the Problem

Leaders of IDR grants—often referred to as principal investigators (PIs)—play a vital role in how IDR teams collaborate to answer their research questions (Adams et al., 2012). Studying PIs of IDR teams is an important topic (Stedman & Adams-Pope, 2019) that has been understudied (Adams et al., 2012). Cerveny and colleagues (2010) state that studies investigating interdisciplinary (ID) team leaders are rare, as opposed to research on leadership in the management literature, which is common, an assertion with which Stedman and Adams-Pope (2019) agree.

Existing literature on IDR team leaders is dominated by conceptual papers and literature reviews (Adams et al., 2012; Bridle et al., 2013; Dodson et al., 2010; Fiore, 2008; McCallin, 2003; Rosen & Callaly, 2005). Among the few empirical studies exploring IDR leadership, most employ quantitative methods (Benoliel & Somech, 2015) and case studies (Creamer, 2005; Lanier et al., 2018; Townsend, Pisapia, & Razzaq, 2015), failing to provide a qualitative description of the PIs' perceptions, beliefs, and experiences. While quantitative methods enable the collection of data from a large sample, it may fail to capture the *experiences* of IDR leaders.

Previous research has established a lack of consensus among scholars on the role of an IDR team leader. Along with taking on the role of a project manager (managing research plans, goals, timelines, and meeting times) (National Academies, 2005), dealing with different personalities, facilitating conversations about authorship, and mediating diverse viewpoints, goals, and perspectives (Lakhani et al., 2012), successful ID leaders must also manage institutional factors (Porter et al., 2006).

The complexity of an IDR leader's role coupled with a range of multilevel challenges could make leading an interdisciplinary team a unique and challenging experience. McCallin (2003) goes as far as saying that leading management teams is poles apart from leading IDR teams because of the differences between traditional forms of leadership and IDR leadership. In traditional forms of leadership, McCallin argues, individual expertise, disciplinary separation, hierarchy, and competition are valued. In contrast, in IDR teams, team members share equal responsibilities and move from leader to follower, based on the situation (McCallin, 2003).

While it might not be poles apart, leading an ID team may warrant that leaders possess additional skills to facilitate the integration of knowledge from different disciplines (Gray, 2008; Jakobsen et al., 2004; National Academies, 2005), manage cognitive factors such as methodologies and paradigms; facilitate interpersonal interactions; and distribute team resources (Fiore, 2008).

Along with the unique facets of the PI role, the dearth of literature focusing on IDR team leaders in university settings is also noteworthy. Researchers have studied interdisciplinary teams in medical, nursing, and research and development settings. Academic institutions have responded to the need for IDR (National Academies, 2005) by funding ID programs and initiatives (see Texas A&M University, Vanderbilt, University of Michigan, UCLA for relevant examples) and by increasing the number of joint training programs and joint appointments (National Academies, 2005). Several policies unique to higher education institutions—such as promotion and tenure procedures and joint appointments—can add additional layers of complexity, affecting the role of a PI and barriers he/she encounters. With universities promoting interdisciplinarity and investing millions of dollars in IDR programs, studying PIs of IDR teams in a higher education setting will not only address the gap in the literature and generate information about leadership roles and barriers they experience, but also enhance our understanding of contextual factors in which PIs and IDR teams are embedded.

Purpose of the Study and Research Questions

The purpose of this dissertation study is two-fold: i) to explore the barriers encountered by leaders of interdisciplinary research (IDR) teams, who I also refer to as principal investigators (PIs); and ii) to understand how PIs perceive their role. The following research questions guide this study:

1. What barriers (if any) do PIs encounter when leading IDR teams?
    a. How do PIs of IDR teams overcome these barriers?
2. How do PIs perceive and describe their role as leaders of IDR teams?

Theoretical Framework

To explore the role of PIs in interdisciplinary research teams, barriers they encounter, and how they overcome these barriers, I will use the social ecological model (SEM) perspective as a framework to guide my dissertation. SEM is widely used in public health research and practice (Golden, McLeroy, Green, Earp, & Lieberman, 2015) to understand and develop interventions concerning health behavior (McLeroy, Bibeau, Steckler, & Glanz, 1988).

SEM involves the application of systems thinking to human development (Bronfenbrenner, 1992). In Bronfenbrenner's (1977) model, behavior is perceived to be both affected by and affecting multiple levels of influence (McLeroy et al., 1988), including people, organizations, and policies (Bronfenbrenner, 1992). SEMs visually depict relationships among individuals, groups, teams, and the environments in which they operate (Golden et al., 2015). According to Bess, Speer, and Perkins (2012), studies

that use an ecological perspective typically assume that contextual factors play a crucial role in the phenomena of study.

Bronfenbrenner (1977) divides the ecological space into four categories: micro-, meso-, exo-, and macro-levels of analyses, which are widely used (Garavan, Wang, Matthews-Smith, Nagarathnam, & Lai, 2019) and cited in the literature. Micro-level refers to interactions between an individual and one's immediate setting, like their family, social, or work groups. A meso-system refers to interrelations among different settings in which an individual is involved, including school and peer groups. In other words, the meso-system is a system of micro-systems (Bronfenbrenner, 1977). An exo-system comprises the larger social system in which an individual operates, such as a university or a government agency, for example. The macro-system comprises cultural values and beliefs that influence micro-, meso-, and exo-systems. Examples of macro-systems include social, educational, and political systems.

Using Bronfenbrenner's (1977) ecological model as a base, McLeroy and colleagues (1988) developed a five-level ecological model, which I adapted to guide my dissertation. According to McLeroy et al. (1988):

- Intrapersonal factors include characteristics such as attitudes, beliefs, values, and behaviors. Instead of intrapersonal factors, I reference this level as individual level factors in my study.
- Interpersonal factors refer to interactions with an individual's immediate social environment, which can include work and research teams. I refer to this level as team level factors in my study.

- Organizational or Institutional factors comprise institutions and other structures that have formal and informal rules for operation.
- Community level factors include demographic and social characteristics that create a sense of shared values and belonging among its members (Allegrante, Hanson, Sleet, & Marks, 2010).
- Public Policy level comprises policies governing local, state, federal laws and systems.

While SEM emerged as a "systems orientation to human development" (Golden et al., 2015, p. 9) and is heavily utilized in public health (Golden et al., 2015), it is also employed in human resource development (HRD) and related fields because of its versatility (see Garavan, McCarthy, & Carbery, 2019; Garavan, Wang, Matthews-Smith, Nagarathnam, & Lai, 2018; Spiegel & Harrison, 2018). Garavan and colleagues (2019) argue that the field of HRD is "nascent in terms of multilevel theorizing and investigations" (p. 305) and call for researchers to undertake multilevel conceptualizations to advance the field.

Organizations as Multi level Systems

Klein and Kozlowski (2000) view organizations as multilevel systems and contend that this axiom is the foundation of organizational systems theory. A multilevel perspective recognizes that micro phenomena are nested or embedded in macro phenomena and that macro contexts emerge from the interaction of micro-level phenomena (Klein & Kozlowski, 2000).

Organizational scholars tend to focus on either micro or macro phenomena, neither of which can account (by themselves) for organizational behavior or phenomena in its entirety (Klein & Kozlowski, 2000). A micro-level perspective neglects the contextual factors that influence individual behavior. A macro perspective, on the other hand, ignores individual perceptions, attitudes, and behaviors that contribute to macro-level phenomena. A multilevel perspective addresses both these issues by capturing dynamic factors affecting a phenomenon at different structural levels (Klein & Kozlowski, 2000).

Multiple levels of analysis can offer insights into the context of a PI's team (micro-system), factors at play in universities in which the team is embedded (exo-system), and beliefs and values that influence the micro- and exo-systems (macrosystem) (Belksy, 1980). The SEM framework not only recognizes that each level has its own influences, but also that they might affect other levels (Dougherty, Fields, & Schumann, 2017). Hanson and colleagues (2005) used the metaphor of an iceberg to describe the multiple levels in an ecological model framework. Metaphorically, the individual who is the tip of the iceberg is just one component of the complex ecological system. Although the individual is the most visible component, there are critical aspects of individual behavior hidden below the surface (Allegrante et al., 2010), which we may uncover using multiple levels of analysis.

In the case of PIs, although they may be the phenomenon of study, the context in which they operate (team, department, college, and university) may influence their roles and leadership in IDR teams. Because most ID initiatives impact a university at multiple

levels—individual, team, institutional, community, and policy—using a social ecological model to study leaders of IDR teams may not only contribute to a better understanding of the multilevel barriers leaders experience, but also how the context and environment in which they are embedded influence their actions and behaviors.

Social Ecological Model: A Theory or Model?

I would like to acknowledge the debate regarding the status of the Social Ecological Model. While Kilanowski (2017, p. 295) maintains that SEM was "first introduced as a conceptual model in the 1970s and was later formalized into a theory in the 90s," there is no consensus in the literature on whether SEM is a theory or model. Some scholars refer to the SEM as Social Ecological Theory (Stokols, 1996; Wandersman et al., 1996; Whittemore, Melkus, & Grey, 2004), while others maintain that it is a model (Cramer & Kapusta, 2017; McLeroy et al., 1988).

For the purposes of this study, this debate (i.e., is SEM a theory or model?) is not germane. What is relevant, however, is that employing a SEM perspective allows me to explore the phenomenon of interest within a context that has multiple dimensions. SEM is a useful analytic tool that equips me with categories, labels, and descriptions of these dimensions to better understand the phenomena of interest. Using a social ecological model perspective will help identify barriers at different levels, decipher the role of the context in which IDR team leaders operate, and if/how the context influences PIs' roles and the barriers they encounter.

Significance of the Study

Because most leadership theories are based on the traditional and monodisciplinary teams (McCallin, 2003), uncovering the role of IDR team PIs and the barriers they encounter can add value to the existing literature. I intend to develop a multilevel model of the barriers impeding IDR team leaders. Such a model might also provide a guide for PIs as to what problems they can expect to face, and for trainers of PIs to improve their leadership capabilities in IDR settings. Since existing research on IDR leadership is dominated by conceptual papers, literature reviews, and quantitative studies, using semi-structured interviews may reveal themes that other methodologies have failed to capture.

In practice, funding agencies and universities have invested in IDR projects, programs, and initiatives (Bridle et al., 2013). For example, Texas A&M University (TAMU) is currently funding T-3 and X-grants, two internal seed grants aimed at promoting IDR (Office of the President, 2019). Similarly, University of Michigan launched MCubed, a program aimed at promoting IDR (University of Michigan, 2020). The findings of this study may help guide similar IDR initiatives undertaken by institutions of higher education. This dissertation will highlight challenges IDR team leaders are facing. Since leaders are essential to an IDR team (Adams et al., 2012), removing hurdles that stand in the way of leadership success can help improve the program's effectiveness. Furthermore, learning about barriers leaders are facing at different levels can help institutions and funding agencies develop support systems and policies to overcome these challenges.

Definition of Terms

In this section, I present definitions of terms used throughout my proposal.

- Barrier: "A problem, rule, or situation that prevents someone from doing something, or that makes something impossible" (Oxford Learner's Dictionary, n.d.).
- Challenge: "A difficult task or problem; something that is hard to do" (Merriam Webster Dictionary, n.d.).
- Interdisciplinary Research (IDR): The IDR approach integrates methods, data, tools, and theories from different disciplines for a common understanding of an issue (Wagner et al., 2011).
- Principal Investigator (PI): An individual responsible for "overall administrative, fiscal, scientific and technical direction and conduct of a sponsored project within the terms and conditions of the award and in accordance with University and System rules and regulations" (Texas A&M University Standard Administrative Procedure, 2016).

Organization of the Study

This dissertation study is organized into five chapters. In Chapter I, I introduced the topic, discussed my theoretical framework, and outlined the research questions guiding this study. In Chapter II, I present a review of the literature regarding barriers to IDR teams and the role and characteristics of IDR team leaders. In Chapter III, I outline the research methods employed in the study, including information about my

paradigmatic identity, positionality, methodological approach, data collection, and analysis procedures. I present the findings of my study in Chapter IV.

Building on the emerging themes in the prior chapter, I interpret and discuss my findings in Chapter V. In addition to the discussion section, I outline how the findings of my study will inform and contribute to theory and practice. The chapter ends with a conclusion, summarizing salient findings and reiterating the implications for theory and practice.

CHAPTER II

REVIEW OF THE LITERATURE

This chapter presents findings from a scoping review of the barriers encountered by IDR teams and the role of IDR team leaders. When discussing the barriers to IDR, I organize the findings into individual, team, institutional, and community levels in line with the social ecological model perspective, which forms the theoretical framework for this study.

Why a Scoping Review?

The purpose of scoping reviews varies from that of systematic reviews. While systematic reviews help researchers address specific questions (Tricco et al., 2016), scoping reviews help identify knowledge gaps (Munn, Peters, & Stern, 2018; Tricco et al., 2016), map out concepts that underpin a research area (Arksey & O'Malley, 2005), and present a broad overview of a topic (Trico et al., 2016). Tricco and colleagues (2016, p. 2) view a systematic review as a "hypothesis-testing exercise" and a scoping review as a "hypothesis-generating exercise." As the name suggests, I am conducting a scoping review because it will help identify the volume of studies available (pertaining to IDR barriers and team leaders) and provide an overview of the area of study (Munn et al., 2018).

Methods

I conducted this literature review using resources such as Google Scholar, Texas A&M University research guides, Cochrane Library Database, Campbell Systematic Reviews, and reports from the National Institutes of Health and Science. I used

Cochrane and Campbell databases in the field of health science, as they are "examples of hybrid fields spawned by interdisciplinary health research" (Stokols et al., 2008, p. 97). I also utilized the report titled *Facilitating Interdisciplinary Research* as a source, as it calls attention to different aspects of interdisciplinarity and suggests ways in which different actors in institutions of higher education can facilitate and strengthen IDR. Using Preferred Reporting Items for Systematic Reviews and Meta-Analysis or PRISMA diagram (Moher, Liberati, Tetzlaff, & Altman, 2009), I depict the process of selecting my articles:

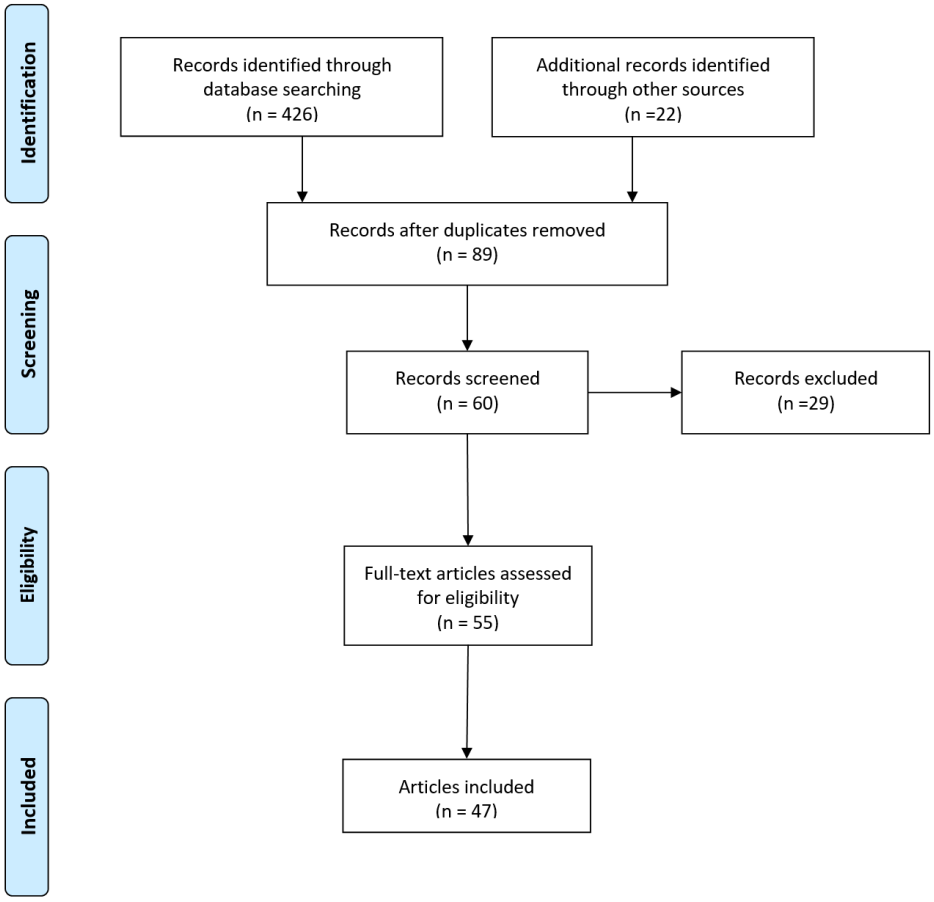

Figure 1. PRISMA Flow Diagram

I conducted my literature review in two stages. In Stage I, I selected certain keywords related to my topic to search databases, applying specific eligibility criteria in the process. I used Boolean phrases such as (barriers or obstacles or challenges or hurdles) AND "(Interdisciplinary research); (interdisciplinary team leaders) AND (interdisciplinary research leadership); and (principal investigators) AND (interdisciplinary teams). Although each of these searches yielded a number of articles, many were not pertinent to my research questions. To narrow down the search to the most germane articles, I developed a set of eligibility criteria.

- All the sources were limited to English because I do not possess the ability to translate articles from other languages to English.
- Literature was limited to topics relating to my research questions. If the articles or books did not discuss barriers or challenges to inter or cross-disciplinary research and failed to discuss leadership in a cross-disciplinary setting, they were excluded.
- The results were not limited to peer-reviewed articles. Since this is a scoping literature review, I wanted to examine articles and reports relating to the topic at hand. Wang (2019), who interviewed Ms. Foster, an expert on literature reviews, posits that articles should not be judged based on where they are published. Additionally, Foster (in Wang, 2019) argues that publication in a peer-reviewed journal does not guarantee that an article has no issues.

- Since I did not want to limit the articles to one methodology, the results focused on conceptual, qualitative, and quantitative studies. As the purpose of this literature review is to explore a wide range of literature for barriers to IDR and IDR team leaders, concentrating solely on one research method could prove counterproductive.

Stage II involved removing duplicates and sifting through articles obtained from the initial search results to ensure that the existing pool of articles was relevant to my literature review. I also adopted a snowball approach, which involved adding new articles using the reference list from existing articles (Wohlin, 2014).

Barriers to Interdisciplinary Research

Although IDR is considered an inspiring human pursuit, a mode for discovery and education (National Academies, 2005), it poses challenges (Laursen, 2018) and can prove difficult to operationalize (Aagard-Hansen, 2007). A "lack of knowledge, divergent standards, different approaches, or simply negative attitudes and prejudices" (Aagard-Hansen, 2007, p. 427) may impede IDR. Furthermore, methodological and epistemological differences within research teams may hamper the process of integrating IDR efforts (Aagard-Hansen, 2007).

Other barriers to IDR include institutional factors such as departmental structure in institutions of higher education, academic reward systems concerning promotion and tenure for faculty (Schuitema & Sintov, 2017), different academic and departmental cultures, decentralized budget strategies, and limited resources to conduct IDR (Boden & Borrego, 2011). I organize my findings into individual, team, institutional, and

community levels, in line with the theoretical framework for this study, i.e., social ecological model.

Individual Level Barriers

"Individual level" refers to characteristics of the individual and includes factors such as personal attitudes, beliefs, behavior, and skills (McLeroy et al., 1988). Individual level barriers to IDR include loyalty to one's own discipline (Aagard-Hansen, 2007; Lynch, 2006; Salazar et al., 2012), insufficient knowledge and skills (Schuitema & Sintov. 2017), domain disparity (Hein et al., 2018, Ju, Jin, & Stewart, 2015; Salazar et al., 2012), negative perceptions of IDR (Hein et al., 2018; Sieldok & Hibbert, 2014), and low levels of engagement and motivation (Ju et al., 2015). Each of these barriers is discussed below. Refer to Table 1 on pages 46 and 47 for a complete list.

Loyalty to One's Own Discipline

To successfully collaborate on an IDR project, individuals must be open to working and engaging with members from other disciplines (Lynch, 2006). However, years of socialization within a particular discipline is likely to enhance a researcher's identification with their own scientific field (Journet, 1993, as cited in Salazar et al., 2012). Additionally, per the tenets of social identity theory, individuals are likely to perceive members of their own group more favorably than members from another group or discipline (Brown, 2000). Using an excerpt from a poem by Rudyard Kipling, Siedlok and Hibbert (2014) argue that the notion of "us" versus "they" prevails in IDR settings: "All good people agree, And all good people say, All nice people, like Us, are We, And everyone else is They" (Kipling, 1926, We and They, Debits and Credits).

Loyalty to one's own discipline and ingroup favoritism can both minimize a researcher's willingness to be open to other forms of research, foster divisive interaction among team members (Salazar et al., 2012), and limit individuals from recognizing the value of alternative approaches (Salazar et al., 2012; Aagard-Hansen, 2007). To engage in IDR, Lau and Pasquini (2008) note, individuals must overcome the deep-seated belief that one's own graduate or doctoral training is the preeminent approach to research (Lau & Pasquini, 2008).

Insufficient Knowledge and Skills

Competencies of individuals and groups have a bearing on the quality of interdisciplinary work (Stein, 2004). Insufficient knowledge, skills, and training in IDR (Carayol & Thi, 2005; Salazar et al., 2012) can not only deter researchers from participating in interdisciplinary projects, but also pose a challenge to existing IDR teams.

In IDR teams, researchers need to first and foremost be well-versed in their own disciplines. Without expertise in a particular subject, Schuitema and Sintov (2017) contend, it is challenging to synthesize and integrate knowledge from other disciplines. In addition to disciplinary expertise, researchers must be exposed to IDR training. Because institutions of higher education are often organized along disciplinary lines or departments, insufficient training in IDR could contribute to researchers' lack of understanding and discrimination against other disciplines (Hein et al., 2018).

Domain Disparity

The reason behind a lack of openness to alternate ways of doing research (Aagard-Hansen, 2007) and ingroup favoritism (Salazar et al., 2012) could be what Ju and colleagues (2015) refer to as "domain disparity." Domain disparity "refers to the differences perceived by individual researchers regarding different subject domains" (p.2). Differences in vocabulary structures (language and jargon), paradigms (beliefs about epistemology, ontology, methodology, and axiology), and mindsets (anthropologist's vs. computer engineer's, for example) contribute to domain disparity in an IDR team (Ju et al., 2015). Insufficient knowledge and skills regarding team members' disciplines and a lack of IDR training could likewise contribute to domain disparity. This topic is further explored in the discussion of team level barriers to IDR.

Negative Perceptions of IDR

Negative perceptions and beliefs including IDR being an intellectual fad and impeding career growth can inhibit researchers and students from participating in interdisciplinary research and projects. Perceptions that IDR lacks rigor and dilutes a researcher's disciplinary expertise may dissuade researchers from participating in IDR projects (Hein et al., 2018).

Negative perceptions coupled with the belief that IDR contributes to challenges in career-advancement opportunities (Hein et al., 2018) can hamper junior faculty and researchers from engaging in IDR. Junior faculty and early career researchers perceive participating in IDR as a risky move for their career progression that leads to difficulty in obtaining tenure (Hein et al., 2018; Rafols et al., 2012; Rijnsoever & Hessels, 2011).

The perception of IDR being a hurdle to early career researchers and faculty could be attributed to a traditional academic reward structure, which values and rewards monodisciplinary outputs. The challenges academic reward system and promotion and tenure processes pose to IDR are explored further when discussing institutional level barriers.

Low Levels of Engagement and Motivation

Low motivation and engagement levels among team members can dampen IDR collaboration (Ju et al., 2015). Unlike individuals who have a high level of motivation to participate in IDR initiatives and programs, researchers with low levels of motivation can be less responsive and active in teams, which can affect team morale (Ju et al., 2015).

Team Level Barriers

At the team level, barriers and challenges to IDR include distance between disciplines (McNeill, 1999), differences in languages and paradigms (Aagard-Hansen, 2007; Ju et al., 2015), power and hierarchy in teams (Choi & Pak, 2007; Pischke, 2017), communication and team functioning (Matthiasson, 1968; Salazar et al., 2012), geographic dispersion among team members (Rekers & Hansen, 2015; Salazar et al., 2012), and team member characteristics (Lynch, 2006; Pischke et al., 2017). I discuss each of these topics in detail below.

Distance between Disciplines

Distance between disciplines and the number of disciplines involved in an IDR team can affect integration of knowledge (Kaplan, Milde, & Cowan, 2016; McNeill,

1999; Rekers & Hansen, 2015; Rijnsoever & Hessels, 2011). If two disciplines are closely related, like anthropology and sociology, minimal restructuring or bridge-building may be necessary (McNeill, 1999). On the other hand, McNeill notes, if two disciplines are far apart, such as linguistics and chemistry, the challenge to bridge the gap between them will likely be more formidable.

Valentin and colleagues (2016), who refer to distance between disciplines as cognitive distance, note that teams with a high cognitive distance may even be faced with "increased costs of communicating and transferring knowledge" (p. 71) as costs associated with communication and knowledge sharing increase with the widening of cognitive distance (Valentin, Norn, & Alkaersig, 2016).

Even if the distance between two disciplines might appear small, they may have a large methodological gap (McNeill, 1999). If an IDR project has members from liberal arts, social sciences, and STEM fields, team integration can prove challenging and sometimes, even frustrating.

Differences in Language and Paradigms

A factor contributing to the distance between disciplines is the diversity of disciplines and languages on an IDR team (Choi & Pak, 2007). What compounds this problem even further is that some of the same terms can have different meanings across disciplines. Words like "sensitivity" and "significance" can mean different things depending on the discipline or field (Choi & Pak, 2007). As a result, even if IDR teams jointly generate artifacts—such as models, codes, and algorithms—members may

interpret the artifacts differently, which could impair communication within the team (Ju et al., 2015).

Paradigmatic differences add an additional layer of complexity and challenge in IDR teams (Aagard-Hansen, 2007; Bracken & Oughton, 2006; Daniels, Dale, Hindmarsh, Fellows, Buckridge, & Cybinski, 2007; Stein, 2004). Differences in paradigms among team members may lead to difficulties in generating a shared language, or when choosing a research method or approach to study the team's research questions (Aagard-Hansen, 2007; Bracken & Oughton, 2006; Daniels et al., 2007; Stein, 2004). Positivists believe there is a "real world out there" and seek to get as close to the truth as possible. Constructivists, in contrast, believe that concepts such as "reality" and "truth" are relative (Lincoln & Guba, 2016).

Power and Hierarchy

Another challenge facing IDR teams comes in the form of power and hierarchy. Historically, disciplines like biomedicine have been regarded as more powerful, owing in large part to status and to funding access (Aagard-Hansen, 2007). Power differences are important to consider since researchers from a "powerful" discipline routinely serve as PIs, while researchers from social sciences are often brought on to solve specific problems relating to the population of study (Aagard-Hansen, 2007; Pischke et al., 2017).

Since not all disciplines have equal power in an IDR setting, some might dominate the discourse and dialogue, as well. This can lead to conflicts and can even end an IDR project or effort (Choi & Pak, 2007). Additionally, power differences can lead to

individuals from high-status fields dismissing contributions from their low-status field colleagues. At the same time, low-status field individuals often feel inclined to give more time to their high-status field teammates (Salazar et al., 2012).

Communication and Team Functioning

Most barriers IDR teams face are in the realm of communication (Matthiasson, 1968). Building a clear channel for communication is challenging due to the distance between disciplines, differences in language and paradigms, power imbalances, and interpersonal issues. A failure to communicate effectively can be divisive and hinder progress towards identifying a common goal (Salazar et al., 2012) and a research plan (Morse et al. 2007; Pischke et al., 2017).

Failing to engage in open communication can also incite what Choi and Pak (2007) refer to as "underground communication," or an increase in rumors and gossip. Underground communication can be detrimental to team trust. Other potential disruptors of team functioning include member conflicts, problems caused by the presence of dominant or isolated members, factions within a team, a lack of clear roles and responsibilities, and poor feedback processes (Choi & Pak, 2007).

Geographic Dispersion

Geographic dispersion of team members can impede effective collaboration compared to teams with moderate or low geographic dispersion (Salazar et al., 2012), a finding with which Rekers and Hansen (2015) and Kiesler and Cummings (2002) agree. Spatial co-location has the potential to increase accidental encounters, stimulate the development of trust among team members, positively impact interpersonal relations and

teams (Kiesler & Cummings, 2002), and reduce costs associated with communication (Rekers & Hanson, 2015).

Geographical and social proximity are valuable in IDR contexts because of the already existing cognitive distance between collaborators. Geographical proximity can be an asset to IDR teams because it allows for creation of social relationships, which is important for effective collaboration considering that researchers in IDR teams come from different backgrounds (Rekers & Hansen, 2015).

Team Member Characteristics

IDR teams and leaders must consider the personalities of researchers for successful interdisciplinary collaborations (Lynch, 2006). The composition of a team and its organization can make or break the research and team process (Choi & Pak, 2007). Finding the right researchers and personnel is as crucial as it is a challenge for an IDR team (Halvorsen et al., 2016). Recruiting the right team members, who have technical and interpersonal skills, can even offset some challenges IDR teams face as individuals with strong interpersonal skills are equipped with the skills to navigate "disparate professional identities, boundaries, and norms" (Halvorsen et al., 2016, p. 3).

Institutional Level Barriers

In a study conducted by the National Academies (2005), some 71% of participants indicated their belief that institutional barriers are major impediments to IDR. Such barriers can include departmental structure and rules (Lynch, 2006; National Academies, 2005), unfavorable reward structures (Rijnsoever and Hessels, 2011; Siedlok & Hibbert, 2014), lack of funding opportunities (Boden & Borrego, 2011;

Lynch, 2006), double-duty (Boden & Borrego, 2011), and lack of support and resources (Boden & Borrego, 2011; Rekers & Hansen, 2015). In the following section, I explore each of these institutional barriers.

Departmental Structure and Rules

Challenges researchers experience when working across academic units and a biased assessment of IDR largely stem from rigid departmental rules and guidelines. Because academic units or departments are often organized along disciplinary lines and vary in terms of allocating credit for interdisciplinarity, departmental structure and rules can hamper IDR. For example, a faculty member in epidemiology is likely to be associated with an institution's public health or medical school and not with biology or economics (Lynch, 2006), which could create barriers for researchers who want to work with colleagues from other disciplines, schools, and colleges.

Second, a faculty member's promotion and tenure opportunities are based on "parochial performance standards that may not apply in other departmentally based disciplines" (Lynch, 2006, p.1122). While departments can vary significantly in allocating credit for multi-author papers when authors span disciplines (National Academies, 2005), some may value single authorship more than a multi-authored publication. Furthermore, publishing in a journal outside one's discipline may not receive any credit towards tenure.

Additionally, in most institutions, faculty only receive credit for teaching and conducting research in their own departments (Boden & Borrego, 2011; National Academies, 2005). As a result, faculty members who engage in IDR and teach outside

their primary department may receive little to no departmental credit (National Academies, 2005). Attempts to foster IDR are bound to be challenging because departments and academic units have different systems and expectations for engaging in and crediting IDR.

Unfavorable Reward Structures

Traditional academic reward systems—overseeing hiring, and tenure and promotion decisions—are a substantial barrier to IDR (National Academies, 2005). Systems within departmental units and colleges are not set up to evaluate IDR contributions and are oftentimes evaluated with a single discipline's norms and rules, thereby making the reward system rigid (Sieldok & Hibbert, 2014).

Siedlok and Hibbert (2014) assert that academic reward systems are inadequate to incentivize faculty to engage in IDR. In a study Rijnsoever and Hessels (2011) undertook at Utrecht University, the authors found no reward system in place for IDR collaboration. Researchers generally perceive IDR to be less rewarding than monodisciplinary research in terms of recognition, career advancement, and publications (Hein et al., 2018; Rijnsoever & Hessels, 2011). Because monodisciplinary pursuits are rewarded and incentivized (Hein et al., 2018; Rijnsoever & Hessels, 2011), early career scientists have a higher number of monodisciplinary research outputs (Carayol & Thi, 2005; Hein et al., 2018; Rijnsoever & Hessels, 2011) and perceive their participation in IDR as a career risk.

Double-Duty

Joint appointments are likely to make boundaries between academic units porous by increasing interactions and collaborations (National Academies, 2005). When a faculty member's duties are distributed and/or shared between two departments, colleges, or programs, he/she has a joint appointment. While joint appointments offer an opportunity to interact with individuals from another department or college, it comes with a heavy administrative work load (Pfirman et al., 2005).

Not only do faculty have to teach, publish, and serve in their primary or home departments, they may be required to fulfill these responsibilities in their secondary departments as well. Faculty with joint appointments might be required to attend and serve on twice as many meetings and committees respectively (Borrego & Newswander, 2008), making the effort time consuming and burdensome. While joint appointments can be appealing, some junior faculty members may want to spend more time in their home departments, which are typically responsible for their tenure and promotion review (Mallon, 2006).

A Lack of Support and Resources

Unlike disciplinary research, which is well supported by structures and systems in universities, interdisciplinary research lacks backing from academic units and university systems (Boden & Borrego, 2011; Rekers & Hansen, 2015). As a result, mechanisms to train or educate faculty and researchers about how to conduct IDR are virtually nonexistent, as are IDR engagement and funding opportunity resources. This

lack of support can lead to insufficient skills and knowledge among researchers who are engaging in or wanting to engage in IDR (Schuitema & Sintov, 2017).

Interdisciplinary research teams require long startup times not only to plan for equipment and staffing, but also to ensure that team members learn each other's language and are able to work in cohesion (National Academies, 2005). As a result, even if provided with additional time to conduct research, IDR team members could have fewer publications, which the tenure and funding clock does not take into account (National Academies, 2005). Rosenfield (1992) notes that teams are more likely to transcend disciplinary barriers and develop an understanding of other disciplines if they are continually supported and funded. Funding organizations must therefore provide sufficient time for IDR teams to conduct and communicate their research, without which ID projects could fail.

Departmental funding is another issue that impedes researchers from engaging in IDR. Departments rely heavily on returned overhead costs for funded research (Boden & Borrego, 2011). Boden and Borrego (2011) contend that financial dependance of institutions on returned overhead to "fund basic operations" leads to many institutional barriers. Some departments may even hesitate to fund cutting-edge research or research on controversial topics (Choi & Pak, 2007) fearing research on a controversial topic may not be profitable or bring in external funding.

Yet another potential barrier to IDR is a lack of shared space. As members in an IDR project often belong to different departments and do not share a common building or office, finding a place to meet can prove problematic (Boden & Borrego, 2011).

Rekers and Hansen (2015) posit that shared space is among the IDR support mechanisms that, when absent, interferes with knowledge creation and integration.

Community Level Barriers

Community level factors include social characteristics that create a sense of shared values and belonging among members (Allegrante et al., 2010). Journal guidelines and peer-review processes are a significant barrier to researchers who engage in IDR.

Journals and Peer-Review Processes

While publishing in high-impact journals can be tough for all academics, this challenge is compounded for those involved in IDR. For one, journals are organized along disciplinary lines (Schuitema & Sintov, 2017) and target specific audiences (Lau & Pasquini, 2008). Moreover, not many journals value IDR publications (Lee, 2006). In fact, those encouraging IDR are rare and are perceived to be of a lower impact (McNeill, García-Godos, & Gjerdåker, 2001; Lau & Pasquini, 2008; Rafols et al., 2012; Schuitema & Sintov, 2017).

Journals that seek IDR publications struggle to evaluate the articles they receive (Lau & Pasquini, 2008). As opposed to monodisciplinary journals, which require reviewers to be knowledgeable about a field, IDR journals require experts from all involved disciplines to understand how these different disciplines are integrated (Schuitema & Sintov, 2017). Finding the right reviewers to evaluate and critique an article can be challenging. If journals do not find reviewers for an IDR article, evaluations tend to rely on “field-based measures” like number of publications, patents,

or funding (Choi & Pak, 2007). Such measurements cannot be fairly applied when evaluating IDR.

Biases against interdisciplinarity are not limited to peer-review processes, but also are evident in journal rankings, which not only suppress IDR publications (Rafols et al., 2012), but also their citation impact, especially for the first three years upon publication (Van Noorden, 2015). Although the short-term costs are high (Schuitema & Sintov, 2017)—because it can deter researchers from engaging in and publishing ID work—there is an increase in the citation impact of ID research in the long-term (Van Noorden, 2015).

Varying Authorship Traditions

Authorship can be contentious due to differences in authorship traditions (Smith & Master, 2017) and what type of publications are valued (Becher & Trowler, 2001) across fields. The role and order of authors varies across disciplines (Schuitema & Sintov, 2017; Wagner et al., 2011). In physics, for instance, it is not uncommon to list contributors—those involved in an experiment—alphabetically, even though individuals did not write sections of the manuscript (Dance, 2012). In contrast, in biological and social sciences, the authors are listed based on the quantity and value of their contributions (Dance, 2012). The first author, typically the corresponding author, initiates the publication, works on writing and gets the manuscript to the finish line (Creamer, 2005). In some other fields such as chemistry, the last author, also the corresponding author, is often the PI who runs a lab (Dance, 2012).

Secondly, disciplines have different preferences regarding which type of publication they value. While some fields such as history value book publications, other fields such as physics may prefer peer-reviewed publications or articles (Becher & Trowler, 2001).

Even though there is an increase in the number of multi-author publications and decrease in single-authored works in fields such as health science (Wuchty, Jones, & Uzzi, 2007) and economics (Kuld & O'Hagan, 2018), some fields still hold single authorship in high regard (Schuitema & Sintov, 2017). Wutchy and colleagues (2007) point out that in arts and humanities, over 90% of publications are still written by single authors, with a growing trend of working in teams. In the field of economics, Kuld and O' Hagan (2018) found an exponential increase in the number of multi-authored publications as well. In 1996, over 50% of articles were written by single authors. By 2014, this percentage dropped to 25%.

When those engaging in IDR are evaluated on parameters regarded by a single discipline, Schuitema and Sintov (2017) note that these evaluation systems are not set up to evaluate interdisciplinary contributions fairly. Perhaps, as a result of how journals are organized, along disciplinary lines, the number of ID publications is lower than monodisciplinary outputs (Xu et al., 2016). Researchers may be more comfortable publishing in disciplinary journals, rather than in IDR journals, because publishing in their field stands a better chance of counting towards their promotion and tenure.

Table 1

Literature Review: Multilevel Barriers in IDR Teams

Level	Barriers	Cited in
Individual Level	Loyalty to One's Own Discipline	Aagard-Hansen, 2007; Lau & Pasquini, 2008; Lynch, 2006; Salazar et al., 2012; Siedlok & Hibbert, 2014
	Insufficient Knowledge and Skills	Carayol & Thi, 2005; Hein et al., 2018; Salazar et al., 2012; Schuitema & Sintov, 2017; Stein, 2004
	Domain Disparity	Hein et al., 2018; Ju et al.,2015, Salazar et al., 2012
	Negative Perceptions and Attitudes Towards IDR	Hein et al., 2018; Rafols et al., 2012; Rijnsoever & Hessels, 2011
	Low Levels of Engagement and Motivation	Ju et al., 2015
Team Level	Distance Between Disciplines	Kaplan et al., 2016; McNeill, 1999; Rekers & Hansen, 2015; Rijnsoever & Hessels, 2011; Valentin et al., 2016
	Differences in Language and Paradigms	Aagard-Hansen, 2007; Bracken & Oughton, 2006; Daniels et al., 2007; Choi & Pak, 2007; Ju et al., 2015; Stein, 2004
	Power and Hierarchy	Aagard-Hansen, 2007; Choi & Pak, 2007; Salazar et al., 2012
	Communication and Team Functioning	Choi & Pak, 2007; Matthiasson, 1968; Morse et al. 2007; Pischke et al., 2017; Salazar et al., 2012
	Geographic Dispersion	Kiesler & Cummings, 2002; Salazar et al., 2011; Rekers & Hansen, 2015
	Team Member Characteristics	Choi & Pak, 2007; Lynch, 2006; Halvorsen et al., 2016
Institutional Level	Departmental Structure and Rules	Boden & Borrego, 2011; Lynch, 2006, National Academies, 2005
	Unfavorable Reward Structures	National Academies, 2005; Carayol & Thi, 2005; Hein et al., 2018; Rijnsoever & Hessels, 2011; Siedlok & Hibbert, 2014

Table 1 Continued

Level	Barriers	Cited in
Institutional Level	Double-Duty	Boden & Borrego, 2011; National Academies, 2005
Community Level	Lack of Support and Resources	Boden & Borrego, 2011; Choi & Pak, 2007; National Academies, 2005; Rekers and Hansen, 2015; Rosenfield, 1992; Schuitema & Sintov. 2017
	Varying Authorship Traditions	Creamer, 2005; Schuitema & Sintov, 2017; Smith & Master, 2017; Wagner et al., 2011

In conclusion, although interdisciplinarity is an inspiring pursuit, findings from this literature review reveal a diverse range of individual, team, institutional, and community level barriers that hamper IDR teams. In the next section, I explore IDR team leaders' roles and responsibilities and how they can facilitate teamwork and overcome barriers.

Leading an Interdisciplinary Team

Along with institutional context and support, leadership is key to the success of an IDR team (Gray, 2008; Lyall et al., 2013; National Academies, 2005). Because interdisciplinarity is influenced by multiple factors, IDR team leaders must nurture the entire system (Porter et al., 2006), ranging from organizational factors, such as the nature of awards or funding, to team factors, including team size and communication. In addition to managing multiple levels, then, IDR leaders' unique position requires them to be adept at handling interpersonal and intellectual integration in teams (Gray, 2008; Lyall et al., 2012; National Academies, 2005; Porter et al., 2006).

In this section, I present a review of the literature on the role of IDR leaders, which generated information about their responsibilities, potential techniques to facilitate teamwork, and methods to overcome barriers. I organize the findings by role (see Table 2): managing intellectual direction and integration, managing interpersonal interactions, and administrative tasks or project management.

Table 2

Literature Review: Summary of IDR Leader Roles

Leader Role	Barriers	Cited In
Intellectual Direction	Establish a Vision ad Frame Issue/ Problem	Klein, 2008; National Academies, 2005; Stedman & Adams-Pope, 2019
	Integrate Viewpoints, Languages, Paradigms, Knowledge from Different Fields/ Disciplines	Gray, 2008; Jakobsen, Hel, & McLaughlin, 2004; Klein, 2008; National Academies, 2005; Stedman & Adams-Pope, 2019
	Self-Reflection	Edelenbos et al., 2017; McLeish & Strang, 2014; Stedman & Adams Pope, 2019
Interpersonal Interactions	Create a Psychologically Safe Environment	Edmondson, 2003; McLeish & Strang, 2014.
	Manage Team Functioning, Build Trust, Design Group Meetings, Garner Team Buy-In, And Handle Conflicts	Gray, 2008; Salazar et al., 2012l Stokols et al., 2008
	Be Supportive, Empowering and Flexible, And Inspire Team Members	Aagard-Hansen, 2007; Choi & Pak, 2007; Salazar et al., 2012
Project Management	Clarify Tasks, Develop Strategies, And Determine Deadlines for Deliverables	Halvorsen et al., 2016
	Identify Team Member Roles and Establish Expectations	Carne et al., 2012; Gray, 2008
	Facilitate Boundary-Spanning Activities and Brokerage	Gray, 2008; Kaplan et al., 2016

Managing Intellectual Direction and Integration

A leader equipped with a clear vision can motivate IDR team members to step beyond their disciplinary boundaries and facilitate a search for creative solutions (Gray, 2008). To achieve this mission, an intellectual leader encourages and oversees cognitive tasks such as envisioning and framing ideas (Klein, 2008), managing meaning, integrating knowledge, introducing desired goals, and providing strategies to achieve these goals (Stedman & Adams-Pope, 2019).

The National Academies (2005) report suggests that leaders with the ability to envision a project, communicate effectively and manage teams can effectively integrate disciplines. The report also points out that an IDR leader has to envision how disciplines represented in the team overlap and lead to scientific breakthroughs, communicate their vision, and help team members break out of pre-existing mental models, which are often grounded in their own disciplinary assumptions and beliefs.

Several authors asserted that IDR leaders are required to play the role of an integrator (Gray, 2008; Jakobsen, Hel, & McLaughlin, 2004; National Academies, 2005; Stedman & Adams-Pope, 2019). Integrating knowledge from different disciplines requires an IDR leader to coordinate scientific analysis, synthesize findings (Cerveny, Blahna, Stern, Mortimer, & Freeman, 2010), and share knowledge with others in the team (Edelenbos, Bressers, & Vandenbussche, 2017). According to Klein (2008), leaders are also in charge of managing tensions among different approaches and methodologies, as well as communicating systematically with all stakeholders. Because disciplinary differences can hamper communication and understanding within an IDR team, leaders

in interdisciplinary teams must be uniquely positioned to see the bigger picture and understand how members from different disciplines fit together (Edmondson, 2003).

When integrating various methods and approaches, leaders need to recognize potential problems posed by language and paradigms (Gray, 2008). By identifying and anticipating the issue of different languages, leaders can help develop a common language. One idea is for teams to co-create a glossary of terms, which is likely to foster respect for each team member's discipline and also help overcome confusion and misunderstandings regarding jargon and methodologies (Gray, 2008).

Along with facilitating integration of knowledge and the discussion of a team vision, IDR leaders must pay special attention to the frequency of interaction and communication when bridging internal interactions (Edelenbos et al., 2017). Frequent interaction and communication is likely to encourage team members to engage in knowledge sharing (Edelenbos et al., 2017).

Reflexivity and Reflection

The kind of leadership required for successful IDR teams is at odds with traditional leadership theories that encourage individual progression and hierarchies (McLeish & Strang, 2014). To engage in interdisciplinarity, IDR leaders and team members alike are required to check their egos, be patient, communicate in a way that researchers from other disciplines can comprehend, and learn from their fellow collaborators (McLeish & Strang, 2014).

Reflexivity, or self-reflection, is a prerequisite for IDR leaders, as integrating ideas from different disciplines requires individuals to explore new languages

(Holbrook, 2013). Self-reflection also helps researchers to be open to alternative ways of conducting research (Edelenbos et al., 2017). IDR teams work with various disciplinary frames and models of thinking and, as a result, being receptive to learning from other disciplines is critical (Edelenbos et al., 2017). To master self-reflection, leaders should practice skills like comparing, contrasting, clarifying, and synthesizing knowledge from different disciplines. IDR leaders must also reflect on their leadership behaviors and how these behaviors could affect the success of their team (Stedman & Adams Pope, 2019).

Managing Interpersonal Interactions

Expertise and knowledge in a particular field or area cannot be the only parameter for determining IDR leadership. Because IDR leaders work with team members from different disciplines, they must be proficient in mediating personalities, integrating goals and perspectives (Lakhani et al., 2012), and managing group interactions (Fiore, 2008; Gray, 2008; National Academies, 2005; Stedman & Adams-Pope, 2019). Team leaders should likewise possess skills in such areas as management, coordination, and planning (Cerveny et al., 2010).

Gray (2008) refers to the handling of a team's interpersonal tasks as "processual tasks." Processual tasks include a whole host of activities from determining group rules, building team trust, and designing group meetings to garnering buy-in from the team and managing conflicts (Gray, 2008). Although some processual tasks resemble project management tasks, others require interpersonal skills.

Creating a Psychologically Safe Environment

IDR team leaders must create a safe and conducive environment where team members feel free to share their suggestions, observations, and questions. (McLeish & Strang, 2014). Edmondson (2003) stresses the importance of team members voicing their observations, questions, and concerns. Speaking up helps to build shared experiences in terms of what is working and what is not. Open dialogue can facilitate the emergence of idea and suggestions, which may improve team processes (Edmondson, 2003).

To create a psychologically safe team atmosphere, leaders have to ameliorate power differences, which is critical to note as an IDR team in an academic setting may include individuals with varying levels of power: students, postdoctoral scholars, assistant, associate, and full professors. Edmondson (2003) found that leaders who acknowledged their fallibility and articulated a rationale for a change helped reduce power differences among team members.

IDR Leader Behaviors for Managing Interpersonal Interactions

Scholars vary in their articulation of desirable IDR leader behaviors and characteristics. While some note that leaders have to develop a shared vision, direction, and hope (Bennis, 1997; Young, 2000), others argue that leadership is a paradoxical mix of humility and professional will (Collins, 2001). The need for leaders to display humility and benevolence is also reflected in Young's (2000) conceptualization of leadership. Stokols and colleagues (2008, p. 101) call our attention to transformational leaders, who are able to "enhance fellow-members' motivation and performance by

offering them a strong vision of collective success, bringing out the best in each member and empowering her or him to reach personally and collectively important goals."

In addition to the technical skills, interdisciplinary team leaders are required to possess a wide range of interpersonal skills. Since cross-disciplinary teams are prone to conflict and disagreements, leaders with effective conflict management skills are an asset to IDR teams (Salazar et al., 2012). Stokols and colleagues (2008) found that leaders who are supportive, democratic, empowering, and promote cooperation tend to enhance cross-disciplinary collaborations. Halvorsen and colleagues (2016) note that patience and flexibility are critical IDR leader traits as team members are learning and being introduced to new concepts and ideas. Furthermore, the authors add that, an individual's commitment to the project can help leaders sustain team member engagement, even if they are frustrated with some of the processes. Bennis (1997) concludes that generating and maintaining trust among team members is a critical role of a leader.

As previously indicated, developing team trust and psychological safety could improve team engagement and commitment. In addition to developing and maintaining team trust, IDR team leaders need to motivate and coach team members (Lakhani et al., 2012), so as to harness team members' potential (Lyall et al., 2013). When encountering failures, leaders have to display active listening, empathy, and re-direct the team toward achieving their goals (Gray, 2008).

Managing Administrative Tasks

In line with what Gray (2008) posits, Carne and colleagues (2012) suggest three main functions of a leader: allocating roles and establishing expectations, establishing and maintaining a shared mental model, and facilitating team effectiveness. According to Stedman and Adams-Pope (2019), the PI of an interdisciplinary team must don the hat of a manager and/or administrator. Additionally, IDR leaders also have to work with members of the team to clarify tasks, develop strategies, and establish deadlines for deliverables (Halvorsen et al., 2016). Similarly, Gray (2008) notes that the structural tasks of a leader should include creating a system of accountability with regard to meeting deadlines, defining objectives, and recruiting team members. To ensure that systems are developed and maintained throughout the life of the grant, leaders must recognize the challenges of IDR and, accordingly, both identify individual responsibilities and actively serve as team manager (Gray, 2008).

Leaders engaging in structural leadership can create bridges among the unconnected members of a team by undertaking two main tasks: boundary-spanning activities and brokerage (Gray, 2008). As previously noted, IDR teams consist of team members from various disciplines, making integration of knowledge and communication challenging. Boundary-spanning activities help teams convey information to groups outside their boundaries. Maintaining institutional commitment, seeking funding for new research projects, and building bridges over disciplinary silos constitute boundary spanning activities (Gray, 2008).

Brokerage, a form of boundary-spanning, occurs when individuals "link members, who are otherwise not connected with each other" (Gray, 2008, p. 127). According to Gray (2008), brokerage makes up a vital part of the structural task of a leader. Brokers build linkages, increasing information flow among disconnected members. Because brokers have access to a wide range of information and their feet in different camps, they can iron out conflict and misunderstandings among different groups (Gray 2008). Since most interdisciplinary and transdisciplinary teams consist of members ranging from senior researchers to junior researchers to graduate students, brokers can also help ameliorate power differences between members (Gray, 2008).

Kaplan and colleagues (2016) argue that students are critical links or brokers in IDR teams because they link faculty, who may already have strong ties with each other, but may be separated by cognitive distance or incommensurability and political barriers. Furthermore, the authors suggest that students working with scientific equipment is a symbiotic relationship that can address some of the cognitive challenges individuals experience in IDR teams.

One Leader or Multiple Leaders?

Effectively serving as an intellectual leader, managing interpersonal facets of a team, and wearing the hat of a project manager can be a tall order for a single individual. While a single leader may suffice for a small team, multiple leaders are needed for larger projects in order to bridge the gap between disparate groups of people and disciplines (Gray, 2008).

Additionally, because IDR teams involve team members from different areas of expertise, it is almost impossible for one leader to possess the skills and abilities to lead *all* aspects of an IDR team (Pearce & Manz, 2005). As a result, shared leadership may be a valuable avenue for IDR teams to consider. Pearce and Manz (2005) define shared leadership as "a simultaneous, ongoing, mutual influence process within a team, that involves the serial emergence of official as well as unofficial leaders" (p. 134).

Traditional notions of leadership have been dominated by the idea that one leader is the source of all knowledge and wisdom (Pearce & Manz, 2005). In teams and organizations where the nature of work is heavily based on intellectual expertise, however, relying solely on a "heroic" leader is not adequate. In fact, several scholars suggest that in IDR teams, shared leadership is likely to naturally emerge (Lakhani et al., 2012, National Academies, 2005, Pearce and Manz, 2005). Because of the nature of IDR teams—which are not very rigid, and yet have a stable core—mature teams may be able to share the leadership role based on the problem at hand and the expertise necessary to address it (Lakhani et al., 2012). Ultimately, having more than one leader can likewise enable subteams to buy-in to the mission and goals of the project.

In the case of multiple IDR team leaders, an effective process for coordination and information exchange is critical. Gray (2008) refers to Dhanaraj and Parke's (2006) conceptualization of innovative networks. In an innovative network, the leaders are connected, but do not have the authority to give commands, nor are the members required to comply. Leaders of innovative networks must manage the network and ensure there is information transfer, even if team members come and go (Gray, 2008).

Peripheral Themes: Outcomes Associated with Effective Leadership

After a careful review of the literature on team leadership, the National Research Council (2015) notes that leadership styles and behaviors can enhance team performance, provided leaders foster positive interpersonal processes. According to Gray (2008), appropriate leadership can not only help increase team effectiveness, but also the satisfaction of team members. Mäkinen, Evans, and McFarland (2019) note that depending on the leadership style, researchers' roles can vary, which can impact collaboration and the research process.

A study by Cerveny and colleagues (2010) of IDR team leaders within the context of the National Environmental Policy Act (NEPA) seems to bear out these researchers' conclusions. NEPA requires leaders and agencies to work with multiple disciplines to understand the effects of actions on the environment. Participants of Stern and colleagues' study ranked effective team leadership as one of the top factors attributed to the success of NEPA processes (in Cerveny et al., 2010). In addition, according to Cerveny and colleagues' findings, prior experience with leading IDR teams could be a desired quality in NEPA IDR leaders.

Team Members and Contextual Factors

Stokols and colleagues (2008) discuss the role of contextual factors in IDR teams. Since the ecological model perspective is the theoretical framework I use for my study, it is important to view leadership in context. Team members' collaboration readiness can influence how teams function and the barriers leaders might encounter. Collaboration readiness can consist of members' flexibility with methodology, positive

perception of collaboration, and willingness to have a cooperative spirit (Stokols et al. 2008). Team members' skills with regard to interpersonal communication, team development, and conflict resolution could likewise affect the team. Stokols and colleagues (2008) argue that contextual factors are important determinants of collaborative success. Any changes in policies (institutional or federal), funding opportunities or limitations, and time pressure could lower team members' psychological safety and trust (Stokols et al., 2008). Innumerable factors— whether intrapersonal, interpersonal, organizational, environmental, technological, or political and societal— ultimately have a bearing on team effectiveness.

Further Research on IDR team leaders needed

The behaviors of principal investigators, especially in IDR teams, is an important topic that has not been discussed among researchers (Stedman & Adams Pope, 2019), even though PIs play a vital role in alleviating numerous challenges that IDR teams face (Bruce & Ricketts, 2008). Cerveny and colleagues (2010) note that studies concerning IDR team leaders are rare, as opposed to research on leadership in the management literature, which the authors remark is common. They also state that further research is required in order to understand the qualities sought in individuals leading IDR teams (Cerveny et al., 2010).

Chapter Summary

In this chapter, I presented a review of the literature on two main topics: barriers encountered by IDR teams and the different roles of leaders in IDR teams. Although IDR helps address today's challenging questions and problems, a number of obstacles

impede the successful integration of knowledge. The findings from this literature review point to a diverse range of individual, team, institutional, and community level barriers that hamper IDR teams and leaders.

In the second part of the literature review, I presented findings relating to IDR team leaders. A leader guiding the cognitive direction of an IDR team provides a vision that motivates researchers to "step beyond their disciplinary lens, relax old assumptions, and search for creative frame-breaking solutions" (Gray, 2008, p. 130). Managing interpersonal interactions in an IDR team ensures that team members are well-connected, feel psychologically safe, and are continually motivated to engage in IDR. Finally, as a project manager, an IDR leader is required to set deadlines and achieve team goals in a systematic manner. As noted in this chapter, there is variability in the literature regarding what behaviors and traits are valuable in IDR leaders.

CHAPTER III

METHODOLOGY

In this chapter, I describe the research methodology guiding my study. In addition to my data collection and analysis procedures, I discuss my paradigmatic identity, positionality, and the context in which my study occurred.

My Paradigmatic Identity

"A paradigm is a way of looking at the world" (Mertens, 2014, p. 8). Each paradigm is guided by a set of assumptions and beliefs, which dictates the topic of study, data collection, and analytic procedures (Bryman, 2006). Scholars classify educational and psychological research into different paradigms, such as positivism, postpositivism, constructivism, pragmatism, and critical theory, to name a few (Lincoln & Guba, 1985; Mertens, 2014).

Each paradigm is defined by four major types of questions (Guba & Lincoln, 2005): a) ontological questions explore the nature of reality; b) epistemological inquiry delves into the nature of knowledge and the relationship between the "knower and the to-be-known" (Lincoln & Guba, 2016, p. 40); c) methodological questions ask how the knower can obtain the knowledge; and d) axiological inquiry sheds light on the nature of ethics (Guba & Lincoln, 2005; Mertens, 2014).

From a Pragmatist's Lens

I identify myself with the pragmatist worldview. In the following section, I describe my ontological, epistemological, methodological, and axiological assumptions and beliefs.

Ontology

Pragmatists avoid using concepts like "truth" and "reality" (Mertens, 2014). Ideas that are considered paradoxical in other paradigms—a belief that there is a real world out there and individuals have their own interpretations of the world—can co-exist in the pragmatic worldview (Kaushik & Walsh, 2017). In other words, the pragmatic worldview rejects the dichotomy between objectivity and subjectivity (Biesta, 2010). I believe that there is a real world and individuals have their socially constructed interpretations of that world.

Epistemology

Unlike positivists, who assert that the researcher is objective, and constructivists, who argue that knowledge and reality are relative, pragmatists embrace these extremes and offer a flexible approach to research design (Feilzer, 2010). As a result, a pragmatist researcher can choose a design and methodology best suited to answer his/her research questions (Kaushik & Walsh, 2017; Tashakkori & Teddlie, 1998).

With regard to the role of the researcher and the relationship to the phenomenon of study, I do not believe that I am an objective onlooker. I agree with Lincoln and Guba's (1985) notion that, in qualitative research, the researcher is the primary data collection instrument. As a result, my beliefs, values, and experiences will inform my data collection and analysis. In order to be transparent to the reader, I discuss this further in the section titled "Positionality."

Methodology

Pragmatists reject the idea that, in social science research, a single method can assess the nature and reality of a phenomena (Maxcy, 2003). According to Tashakkori and Teddlie (2010), quantitative, qualitative, and mixed-method designs are all compatible with the pragmatic paradigm. Research questions dictate the method a researcher employs (Tashakkori & Teddlie, 2010). Qualitative methods are best suited to answer my research questions because I am interested in learning about participants' experiences. The tenets of pragmatism allow me to use qualitative methods to study my research questions.

Axiology

Axiology is concerned with the nature of ethics and what researchers value (Biddle & Shaft, 2015). Although postpositivist researchers may acknowledge the value-laden nature of theory, they attempt to minimize the influence of values to maintain objectivity and increase validity (Teddlie & Tashakkori, 2009). In contrast, as a pragmatist, I acknowledge my axiological position by discussing my positionality and reflexivity. I do this not only with the intention of being transparent about my biases and assumptions, but also to demonstrate how my values and ethics continue to shape my experiences and process of inquiry (Biddle & Shaft, 2015).

Positionality

Researcher characteristics like "personal attributes, qualifications, experience, relationship with participants, assumptions, and presuppositions" may influence the study (O'Brien, Harris, Beckman, Reed, & Cook, 2014, p. 1247). Because qualitative

research is highly interpretive, readers must be made aware of a researcher's perspectives and assumptions and how they may have influenced data collection and interpretation (Lincoln & Guba, 1985; O' Brien et al., 2014). Qualitative reporting standards such as Standards for Reporting Qualitative Research (SRQR) and Consolidated Criteria for Reporting Qualitative Research (COREQ) also recommend describing characteristics of the researcher (Côté &Turgeon, 2005; O'Brien et al., 2014; Tong, Sainsbury, & Craig, 2007). In this section, I outline some of the characteristics and experiences that have shaped my understanding of IDR.

My educational background is multidisciplinary in nature. I was trained in Indian classical music, dance, and art in high school. During my undergraduate study in English literature, I learned how to view the world using different lenses: feminist, postcolonial, and ecological, to name a few. After earning my bachelor's degree, I obtained a master's degree in public service and administration, where I gained an understanding of public policy formation, public finance, public management, and statistics.

Although I was trained in quantitative methods during my master's studies, I was exposed to both quantitative and qualitative methods of conducting research in my doctoral program. My multidisciplinary background has led me to believe that IDR is valuable and can help solve complex problems. In other words, I am biased towards and in favor of conducting IDR.

My interdisciplinary experience is further enriched by the fact that I have both led and contributed to IDR teams. During my master's studies, I led a capstone research project that was interdisciplinary in nature. The capstone team was comprised of team

members from differing backgrounds and distinct beliefs and worldviews. As a leader, I was responsible for planning and delegating tasks, leading weekly meetings, holding team members accountable, managing conflicts, and developing a positive working environment for the team. My experience leading the capstone project showed me firsthand that IDR leaders need to manage both technical and interpersonal components of a team.

Another significant ID experience for me was my participation in the Interdisciplinary Research and Evaluation (IDRE) team. As a graduate assistant on the team from 2018-2020, I had the opportunity to work with an interdisciplinary group of Texas A&M University faculty and doctoral students. Funded by the Office of the Vice President for Research, the purpose of the team is to evaluate the T-3 and X-Grant Initiative at TAMU for three grant cycles and to create an assessment system that could be used for subsequent rounds during the proposed 10-year cycle of funding. The IDRE team is employing a multilevel, mixed-methods, and longitudinal research design. My involvement on the team convinced me that assessing multilevel factors is critical to gaining a deeper understanding of a phenomenon, which is reflected in my choice of a theoretical framework to guide this study.

Because of my association with the IDRE team, I have had interactions with some participants of the X-Grants, which may have facilitated rapport-building during interviews. As participants of this study are faculty members at TAMU, power differentials may hinder free flow of information, which, in turn, can affect the quality and richness of data. To overcome this differential, I was accompanied by Dr.

Beyerlein—who is the PI of the IDRE team and the chair of my doctoral committee—when conducting interviews.

Context

In 2017, the president of TAMU launched a 10-year initiative comprising two internal seed grant programs (T-3 and X-Grants) to promote IDR (Office of the President, 2019). Triads for Transformation, or "T-3" grants, are smaller grants that fund 100 triads of faculty members (representing at least two different colleges) every year for one to two years. The funding amount for T-3 grants is $30,000. X-Grants, on the other hand, target larger teams of faculty, funding awards for eight IDR teams every year for three years. The X-Grant funding amount ranges from $100,000 to $1.5 million.

As per the application requirements, PIs and co-PIs of every team must hold a PI-eligible position at TAMU, which is limited to tenured and tenure-track faculty, with exceptions. The X-Grant application guidelines also note that while there is no limit to how many members can participate on a team, a minimum of three members are required for an interdisciplinary team. X-Grant teams have 11 members, on average.

In 2018, some 251 T-3 triads applied for 100 awards. During the first round of X-Grant funding, 262 faculty members participated on the teams submitting proposals. Eight teams, with a total of 90 members, received funding.

Research Design

In this section, I describe in detail my methodological approach for the study. I also outline my data collection procedures—including sampling, recruitment, and data collection sources—and data analysis procedures.

Unlike quantitative research, in which researchers use statistical procedures to explore causal relationships and generalize findings, qualitative methods rely on letting the "phenomenon of interest unfold naturally" (Patton, 2001, p. 39) in real-world settings. In the process of research, the goal is to understand the phenomenon of study, not to control or predict the outcome (Lincoln & Guba, 1985). It is also critical to note that qualitative methods are compatible with the pragmatic paradigm (Tashakkori & Teddlie, 2010), which allow the researcher to choose from a wide range of methods (Kaushik & Walsh, 2019).

Qualitative Case Study Approach

To answer my research questions, I used a case study approach to explore the experiences and barriers of PIs leading IDR teams. A case study is an inquiry that examines a "phenomenon in-depth within its real-life context" (Yin, 2009, p. 2). According to Merriam (2009, p. 40) a case study is: "... an in-depth description and analysis of a bounded system." Because this methodology lets researchers study a phenomenon and its context, a case study provides researchers with a holistic understanding of a problem or an issue (Hesse-Biber, 2017).

Not only does a case study generate a full picture about the role of PIs, the barriers they face, and how they overcome these barriers, but it also provides insights into the influence of the context or setting in which PIs are embedded. As noted in Chapter II, studying the context in which IDR teams operate (team, department, college, and university) both contributed to a better understanding of the multilevel barriers

found in interdisciplinary teams and highlighted how the context influences a PI's role and behavior.

Merriam (1998) defines a qualitative case study as "an intensive, holistic description and analysis of a single instance, phenomenon, or social unit" (Merriam, 1998, p. 21) and notes that case studies can be employed when using quantitative and qualitative methods. When conducting a qualitative case study, however, Merriam posits that the objective is to generate meaning; not to test hypotheses. While the goal of a quantitatively driven researcher is to suggest a cause-and-effect relationship and to confirm a hypothesis, a qualitative researcher "aims to explore and discover subjective meaning" (Hesse-Biber, 2017). The goal of this dissertation study was to explore the *experiences* of PIs in IDR teams, not to test a theory or confirm a hypothesis. Therefore, I believe qualitative methods were best suited to address my research questions.

It is important to note that I did not seek to generalize findings from this study to other groups of IDR team PIs in different settings. External validity or generalizability, in quantitative research, refers to measures that a researcher takes to ensure the applicability of results in different contexts or subjects (Lincoln & Guba, 2016). In qualitative research, generalizability is not the aim (Lincoln & Guba, 2016). Instead, Lincoln and Guba (2016, p. 104) note that "applicability of the findings and interpretations are to be determined by those who want to apply the findings and interpretations."

Boundaries of the Case Study

A critical aspect of case studies is boundaries. Merriam (1998) views a case "as a thing, a single entity, a unit around which there are boundaries" (p. 27). A case can be a person, a team, a group, and a program (Yazan, 2015). This study is bound by setting (Texas A&M University), program (X-Grants), time (funded in 2018), and role of participants (PIs). The boundaries of this case are explained further when discussing sampling and recruitment of participants.

Unit of analysis

A fundamental component of what constitutes a case is determining the unit of analysis (Yin, 2009). Because I was interested in exploring PIs of IDR teams, barriers they encounter, and how they overcome these barriers, the unit of analysis was at the individual level. In other words, the sole participants of this study were leaders of IDR teams; I did not study these phenomena at the team or organizational level. The individual level of analysis is not to be confused with a multilevel approach in the social ecological model. Studying PIs at the individual level may generate information on multilevel factors hindering IDR teams.

Exploratory Case Study

Based on the research questions and methodology, Yin (2009) categorizes case studies into three types: exploratory, descriptive, and explanatory. An exploratory design allows researchers to gain new insights into their research question and to generate new ideas and theories (Yin, 2009). A descriptive case study *describes* a phenomenon of interest and its setting or context (Baxter & Jack, 2008). Associated with a quantitatively

driven case study, an explanatory case study helps test out a hypothesis (Hesse-Biber, 2017) and explain causal links (Baxter & Jack, 2008). I used an exploratory case study approach because it aligned with the goal of my dissertation, which was to *explore* the experiences of PIs of IDR teams. Furthermore, an exploratory case study facilitated my understanding of the phenomena by providing new insights into my research questions and aiding in theory formation (Hesse-Biber, 2017).

Single Case Study Design

Besides identifying what type of case study (exploratory, descriptive, explanatory) to utilize, a researcher must also consider if he/she wants to conduct a single case study or a multiple case study (Baxter & Jack, 2008). Yin (2009) states that a single case study is analogous to a single experiment. If a researcher is able to uncover a phenomenon that has not been widely studied, Yin (2009) notes a single case study is justified because of its revelatory nature. Although the number of IDR programs and teams is growing, not many studies have explored the PIs of IDR teams and the barriers they face, which, according to Yin (2009), is an opportunity to use the single case study design.

A multiple case study design permits a researcher to study a phenomenon within and across settings (Baxter & Jack, 2008). This design does not lend itself to my study because there are no multiple settings. If I were researching the experiences of PIs in the X-Grants program at TAMU and MCube program at the University of Michigan, using a multiple case study design would be more appropriate. The context of this study,

however, was limited to Texas A&M University's X-Grants program. Therefore, I used a single case study design as a research methodology for this study.

Data Collection

Qualitative researchers do not make generalizations about a pattern or degree of a problem, instead they are interested in how individuals attribute meaning to a situation (Sullivan & Forrester, 2019). Therefore, qualitative researchers are interested in selecting a purposive sample (Hesse-Biber, 2017) and seek participants who have particular characteristics relevant to the study (Crowley, 2019).

Participant Selection and Criteria

Because this study explores the experiences of PIs leading IDR projects, I sought participants who were PIs of X-Grant teams. X-Grants are an internal seed grant initiative at TAMU, which aims to promote interdisciplinarity among faculty (Office of the President, 2019).

In line with the boundaries of the case study methodology, I recruited PIs whose X-Grant teams were funded in 2018. Participants who had led their teams for over two years (since 2018) were likely to have richer insights into their role, the barriers they encountered, and how they surmounted these barriers. Additionally, since PIs of X-Grant teams are either assistant, associate, or full professors at TAMU, they could comment on the research from a departmental, college and university-wide perspective, which could reveal the larger context in which the X-Grant operates, facilitates, or hinders IDR. In total, eight X-Grant PIs met the study's criteria and, as a result, they are my sample.

Recruitment

I contacted the eight participants via email using an IRB-approved script (see Appendix A). Because only eight PIs met the sampling criteria and boundaries of this case study, they were the primary group I recruited. If participants showed interest in participating in the study, I sent the informed consent (see Appendix B) detailing the purpose of the study, risks and associated benefits, as well as their right to withdraw from the study at any time.

Per IRB guidelines and in the wake of the Coronavirus outbreak, I interviewed virtually via Zoom, Skype, or Google Meet or by telephone, based on participants' preference and convenience. Participants—whether they wanted to meet virtually or talk via telephone—received a link to the interview and a copy of the informed consent prior to the interview. With permission from each participant and as outlined in the informed consent, interviews were audio recorded.

As noted earlier, I am a member of the IDRE team. This team is funded by the Office of the Vice President for Research to evaluate the T-3 and X-Grants Initiative on campus. As a graduate assistant on the team, I was part of the planning and data collection process of the team in the summer of 2019. For this study, I used the data collected in the summer of 2020, during which I contacted, recruited, and took the lead on all eight interviews with PIs of X-Grants.

Interview Format

To address the research questions guiding this study, I used a semi-structured interview format to collect data. Semi-structured interviews permit researchers to

prepare questions in advance and let participants address the questions in an order with which they are comfortable (King & Hugh-Jones, 2019). By utilizing this particular format, researchers demonstrate their commitment to understanding what is important to the interviewee, rather than steering the interview along a predetermined route (King & Hugh-Jones, 2019). An additional advantage of using a semi-structured interview format is that it allows thoughts and ideas to emerge organically, even those that are unanticipated by the researcher (King & Hugh-Jones, 2019). Accordingly, questions asked during the interviews for this study were open-ended to uncover the experiences of participants, thereby allowing an opportunity to ask follow-up clarification questions where needed (see Appendix C for interview guides).

Protecting Participant Identity

Due to the research design, size of the sample, and explicit mention of participants' job titles, departments, and colleges, participants could potentially be easily identified (Jones, Torres, & Arminio, 2014). This identification issue was compounded by the fact that as X-Grant recipients, their information—including names, department affiliations, job titles, and title of IDR projects—is publicly available. Even without stating a participant's name, by doing something as simple as mentioning his/her department, I could risk revealing a participant's identity.

Anticipating the issue of participant identification, I took two steps to guarantee that participants' responses or quotes were not directly attributed to them. First, instead of using their official names, I referred to them as Participant A, B, C, and so on. When analyzing and reporting my findings, this precaution ensured that quotes were not

attributed to any particular individual. Second, I avoided explicitly stating any information that pointed to participants' identities. Instead of mentioning a specific department or college, I indicated a broad area of study. For example, if a participant's department is Educational Administration and Human Resource Development, I stated that the participant was from the social sciences.

Using Additional Sources of Data Collection

One of the defining features about a case study design is its emphasis on using multiple sources of data (Merriam, 2009; Yin, 2009) for a comprehensive understanding of the topic. After a preliminary analysis of my data, I found additional information to contextualize and corroborate findings emerging from the semi-structured interviews. Using additional data sources created a rich profile of each PI and highlighted the context of their work as IDR team leaders.

Along with using semi-structured interviews, I reviewed participants' publicly available curriculum vitae (CV). Perusing through each respondent's CV generated information about their prior experience with IDR projects and their educational background.

Furthermore, I conducted bibliometric analysis (on a descriptive level) for X-Grant teams. Bibliometrics is the analysis of publications and their properties (Gingras, 2016). Data from the VPR's office contained a list of publications and external grant awards. Reviewing the volume of publications, co-authors, and the journals in which they were published revealed information about how X-Grant teams collaborated. I reviewed the citations, published articles, characteristics of journals in which they are

published with the goal of providing insight into PIs' publications in and outside their primary field. Analyzing bibliometric data is a time-consuming process and requires technical expertise I do not possess. So, my analysis was at a descriptive level.

Bibliometric data is not to be confused with social network analysis (SNA). SNA focuses on structure and dynamics among connections within networks (Patterson, Lemke, & Nelon, 2020). The theoretical underpinning of SNA is social network theory, which proposes that certain characteristics of a network—such as size, composition, and type of ties among network members—can shape members' beliefs and impact how they interact and exchange resources, among other things (Patterson et al., 2020; Valente, 2012).

I also studied formal announcements about X-Grants, including press releases on the purpose of the initiative, communication and marketing, and application processes and deadlines. Studying formal announcements provided insights into the context and guidelines of the initiative and its processes.

Another data source I used was promotion and tenure (P&T) documents for the university at large and for individual departments and/or colleges, as necessary (depending on the findings). Using P&T documents provided information about policies regarding interdisciplinarity at the department, college, and university levels and also revealed cases in which the policies did not align. Furthermore, I also paid attention to the composition of the teams to understand if the size of a team contributes to PIs discussing specific barriers.

Using Archival Data

Archival data, in a broad sense, can refer to data that is stored to be used at a later date. Researchers generally re-analyze data that is collected for a different project to answer new research questions (Gibson & Riley, 2019). According to Gibson and Riley (2019), archival data may prevent a researcher from reinventing the wheel and going through the process of data collection because a researcher can access and use the data (collected by another individual) to answer his/her research questions.

To use archival data, researchers have to create an inventory of the data they can access and familiarize themselves with the data and source (Fischer & Parmentier, 2010). Researchers are not only required to understand the limitations of the archived data, but are also expected to be aware of and consider how the data was collected, limitations in the process of data collection, individuals involved in the process, information included and omitted from the data, and how the phenomenon is portrayed (Fischer & Parmentier, 2010).

As I noted earlier in the section outlining my positionality, as a graduate assistant of the IDRE team, I was involved in initial discussions around the team's research design, data collection and analysis from 2018-2020. Because of my participation in the IDRE team, I was uniquely positioned to use the data collected in the summer of 2020, during which I contacted, recruited, and took the lead on all the eight interviews with PIs of X-Grants.

Data Analysis using a Thematic Approach

To analyze data from the interviews, I used a thematic analysis (TA) approach. TA is a method that helps researchers identify, analyze (Freeman & Sullivan, 2019), interpret, and report patterns or themes in a dataset (Braun & Clarke, 2006). The authors classify qualitative analysis tools into two categories or camps. The first category stems from a theoretical or paradigmatic position that inevitably results in "limited variability in how the method is applied" (p. 78). The second type of qualitative analytic method, in which TA falls, is "independent of theory and epistemology" (p.78) and as a result, TA can be used across various theories and epistemologies. Due to its theoretical freedom, TA is compatible with various epistemologies and aligns with my worldview and research design.

Theoretical Approach to Thematic Analysis

A researcher can adopt an inductive or theoretical approach to TA. In the inductive TA approach, the process of coding is emergent. When coding the data, researchers do not align the codes with their pre-existing ideas or preconceptions (Braun & Clarke, 2006). Instead, researchers let the codes emerge during their immersion in the data. In contrast, a theoretical approach is driven by a researcher's interest in a particular aspect of the data (Braun & Clarke, 2006). Although a theoretical approach might not lend itself to a comprehensive description of the data, it offers detailed insights into a particular or specific aspect of the data (Braun & Clarke, 2006). For this study, I used a theoretical approach to coding as it helped uncover codes, themes, and ideas that participants discussed concerning specific questions I was interested in exploring, such

as the role of a PI, barriers they experienced when leading an IDR team, and how they navigated these barriers.

Six-Step Approach

I used Braun and Clarke's (2006) six-step approach for data analysis, which includes: a) familiarizing oneself with the data; b) identifying an initial set of codes; c) searching for themes; d) reviewing themes; e) defining and refining themes, and f) producing the report. I describe each of the steps below. For a short summary of the steps, refer to Table 3 on page 66.

Familiarizing oneself with the data

The first phase involved transcribing the data. I transcribed the interviews using Konch ™, an automatic transcription platform that generates transcriptions in a few minutes. Upon the completion of the automatic transcription, I assigned speakers, added punctuation marks where needed, and combed through the transcript to edit words and phrases that had been wrongly generated. During the editing process, I cross-checked the accuracy of the transcript with the audio recording of each interview. This process of transcription allowed me to spend prolonged periods of time with each transcript, facilitating my familiarization of the data.

Because TA does not require a very detailed transcript, I used a playscript format—resembling a script for a play—for analysis (Gibson, 2019). A Jeffersonian transcript (often utilized in conversation analysis), on the other hand, is used to draw attention to "the structure of talk, sequence of interaction, and the numerous things people do when having an everyday conversation" (Forrester, 2019, p. 260). As a result,

the Jeffersonian transcript is detailed and fine-grained (Gibson, 2019). A playscript format is sufficient for TA as long as a participant's quotes are not altered in any way because the focus is on what the participant communicates, not the structure of the conversation or sequence of talk (Freeman & Sullivan, 2019).

Table 3

A Breakdown of Data Analysis

Data Analysis by Step	Description
Familiarizing oneself with the data	Automatic transcription using Konch ™.
	Assigned speakers, added punctuation marks where needed, and edited words and phrases.
	Cross-checked the accuracy of transcripts with audio recordings.
	On an average, spent 3 + hours per transcript.
Generating Initial Codes	Used Susanne Friese's (2012) NCT model—noticing, collecting, and thinking about things—as a guide—when coding.
	Divided words, phrases, and paragraphs into chunks, so that the meaning could stand on its own (Lincoln & Guba, 1985).
Searching for themes	Sorted codes into larger themes or family of codes.
	Analyzed the already generated codes and collated them into overarching themes.
Reviewing Themes	Reviewed, grouped, and re-grouped data during multiple rounds of coding.
	Worked with the data and added/subtracted as categories evolved (Creswell, 2013).
	Some themes identified in phase 3 required revising, collapsing into larger themes, or breaking into smaller themes.
	Reviewed codes and data associated with each code to ensure coherence.
Defining and Refining Themes	Defined each theme identified in the previous phase and also finalized the label or title for each theme.
Producing the report	Reported/ communicated my findings.

Generating Initial Codes

The second phase involves identifying an initial set of codes. According to Boyatzis (1998), a code is a feature of the data that is "the most basic segment, or element, of the raw data or information that can be assessed meaningfully regarding the phenomenon" (p. 63). Because I applied a theoretical TA approach, I coded the data with specific questions in mind using Atlas.ti's cloud-based platform, a software that aids in qualitative analysis. I used Susanne Friese's (2012) NCT model—noticing, collecting, and thinking about things—as a guide during the coding stage. Although it might sound sequential, Friese (2012) states that coding is an iterative process that involves "moving back and forth between noticing, collecting, and thinking" (p. 92).

Searching for themes

Once I coded the transcripts, I sorted the codes into larger themes or families of codes. This process involved analyzing the already-generated codes and collating them into overarching themes. I did not abandon the initial codes, as Braun and Clarke (2006) point out that coding is cyclical. The process of iterative coding, or coding the data multiple times, helps me ensure that the quotations fit the assigned theme or code.

Reviewing Themes

Some themes identified in phase 3 required revising, collapsing into larger themes, or breaking into smaller themes. I reviewed the codes and the data associated with each code to ensure they were coherent. I then examined the themes in the whole data set to see how they fit together. Braun and Clarke (2006) recommend rereading the

entire data set during this phase for two reasons: a) to ascertain if the themes align with the data set, and b) to code pieces of data missed in the first round of coding.

Defining and Refining Themes

During this phase, I defined each of the themes identified in the previous phase and also finalized the label or title for each theme. Braun and Clarke (2006) elaborate that this step involves "identifying the essence of what each theme is about (and the themes overall) and determining what aspect of the data each theme captures" (p. 92). So, for every theme, I identified the story it captures and analyzed how it fits into the larger story in the data set.

Producing the report

This phase involved writing up the findings from the thematic analysis to tell the story of the experiences of PIs in IDR teams. Upon the completion of data analysis, I reported the findings of this study and organized them thematically.

Establishing Trustworthiness

Because of diverse approaches to qualitative research (phenomenology, ethnography, to name a few), evaluating the rigor of a qualitative study can be difficult (Anney, 2014). Internal and external validity, reliability, and objectivity are criteria with which the rigor of quantitative research is assessed. Lincoln and Guba (1985) contend that the aforementioned criteria are positivist in nature because they fit the epistemological and ontological assumptions outlined in the positivist perspective, with which quantitative methods align. Because qualitative inquiry has a different set of epistemological and ontological assumptions, Guba and Lincoln (1982) proposed a

distinct set of criteria from which we can ascertain the rigor of qualitative research. They note that "internal validity should be replaced by that of credibility, external validity by transferability, reliability by dependability and objectivity by confirmability" (pp. 3-4).

In this section, I outline the strategies I used to ensure the trustworthiness of my data. Lincoln and Guba (1985) define "trustworthiness" as the quality of an inquiry. Trustworthiness helps readers discern whether researchers' findings are a result of a systematic process and if the researchers' interpretations and findings are valid (Lincoln & Guba, 1985).

Table 4

Establishing Trustworthiness

Criteria of Trustworthiness	Strategy	Explanation
	Standards for Reporting Qualitative Research (SRQR)	Complied with SRQR, a list of 21 items developed by O' Brien et al. (2014) to guide my reporting.
Credibility	Triangulation	Used secondary sources of data including P&T documents, CVs, and application guidelines.
	Member Checks	Sent transcripts to participants, giving them an opportunity to make changes and/or edit their quotes.
	Peer Debriefing	Sought the guidance of Dr. Goodson—with whom I met regularly during data analysis—and Dr. Beyerlein.
Transferability	Thick Descriptions	Detailed the context in which the study took place including its setting and description of program and teams.
Dependability	Audit Trail	Documented research process and decisions, creating an audit trail of raw data, recordings, transcripts, interview notes, memos, and team member profiles.

Table 4 Continued

Criteria of Trustworthiness	Strategy	Explanation
Confirmability	A combination of aforementioned strategies	Achieved confirmability using audit trails, reflexive journals, and triangulation. (Anney, 2014; Lincoln & Guba, 1985).

First, I complied with the Standards for Reporting Qualitative Research (SRQR) to be transparent about my research procedures and decisions. SRQR is a list of 21 items that O' Brien and colleagues (2014) developed to provide a framework for qualitative reporting standards (see Appendix D for a list of all items). According to O'Brien and colleagues (2014), a qualitative study "includes consideration of the importance of the research question, the rigor of the research methods, the appropriateness and salience of the inferences, and the clarity and completeness of reporting" (p.1245).

Credibility

"Credibility is defined as the confidence that can be placed in the truth of research findings" (Anney, 2014, p. 276). It establishes whether the information presented is drawn from the data and whether it represents what participants intended (Lincoln & Guba, 1985). To ensure my data were credible, I engaged in data triangulation, member checks, and peer debriefing. I describe each of the strategies below:

Triangulation

Triangulation "involves the use of multiple and different methods, investigators, sources and theories to obtain corroborating evidence" (Onwuegbuzie & Leech, 2007, p.

239). According to Stake (2005), using multiple data sources can help clarify meaning and is also a tool necessitated by the case study methodology. Besides semi-structured interviews and memos, I used secondary sources of data, including P&T documents, CVs, communication regarding guidelines and application, and bibliometric data. Using multiple sources of data created a rich profile of each PI and informed me about their background, experience, and context.

Member Checks

Member checks involves sending the interpreted data to participants so that they can determine if the interpretations made by the researchers are in line with what they intended (Anney, 2014). Once the interviews were transcribed, I sent participants their transcripts to give them an opportunity to review and make changes to their transcripts. Participants were instructed to use track changes on Microsoft Word to edit either their raw transcripts. I gave participants one week to make changes, with time extensions granted upon request.

Peer Debriefing

Peer debriefing involves researchers seeking support and/or guidance from professionals and scholars who have a deep understanding of the subject and research methods (Anney, 2014). This can include academic staff or members of a researcher's dissertation committee (Anney, 2014). I worked with my dissertation committee to gather members' feedback and insights into my research processes. Soliciting my committee's feedback and incorporating their suggestion provided me with an

opportunity to develop my insights and thoughts, while also ensuring that my data collection and analysis processes were credible.

Transferability

Comparable to generalizability in quantitative research, "transferability" refers to the degree to which the findings from one study can be applied or transferred to other contexts (Anney, 2014). Strategies like thick descriptions can enable researchers to replicate my study "using similar conditions in other contexts or setting" (Anney, 2014, p. 12).

Thick Descriptions

Researchers can use thick descriptions of the context and research process when communicating their findings in a report (Anney, 2014). Thick description refers to researchers elucidating or describing the context of the study, data collection, and analysis processes (Anney, 2014), so as to enable other researchers to replicate a study in a different setting. In my dissertation study, I detailed the context in which the study was taking place, including such factors as setting, X-Grants program description, X-Grant teams, and X-Grant projects. These description will enable future researchers to compare the TAMU context to other settings, where they might want to replicate this study.

Dependability

Dependability refers to "the stability of findings over time" (Bitsch, 2005, p. 86). For research to be dependable, individuals must be transparent and clearly document the research process (Tobin & Begley, 2004). Using an audit trail, I demonstrated the processes I used and the decisions I made regarding the data and analysis.

Audit Trail

Following Guba and Lincoln's (1982) suggestion, I created an audit trail containing the raw data, recordings, transcripts, interview notes, memos, and team member profiles so that my data collection, analysis, and research decisions can be verified and cross-checked. Birks, Chapman, and Francis (2008) note that having notes on decisions relating to sampling issues, data collection activities, or analytical procedures can communicate the progression of the study and demonstrate how conclusions were reached, which is vital to ensuring dependability.

Confirmability

Confirmability is "concerned with establishing that data and interpretations of the findings are not figments of the inquirer's imagination, but are clearly derived from the data" (Tobin & Begley, 2004, p. 392). Researchers can achieve confirmability using audit trails, reflexive journals, and triangulation. (Anney, 2014; Lincoln & Guba, 1985). I used two of the three aforementioned strategies when discussing dependability and credibility. Guba and Lincoln (1989) also posit that researchers establish confirmability when they achieve credibility, transferability, and dependability.

Limitations

Although the researcher is the primary data collection instrument in qualitative research (Lincoln & Guba, 1985), relying on a single coder may be a limitation. O'Connor and Joffe (2020) note that multiple coders who share a data-coding system (inter-coder reliability) can reassure the readers that the data analysis "transcends the imagination of a single individual" (O'Connor & Joffe, 2020, p. 3). The authors also

acknowledge that single- versus multi-coder is a controversial topic in the qualitative research community, with some scholars noting that inter-coder reliability is unnecessary (O'Connor & Joffe, 2020). To overcome potential single-coder limitations, I worked jointly with members of my dissertation committee. Seeking their guidance and incorporating their feedback during my data collection and analysis processes enabled me to base my interpretations on the evidence and data.

Secondly, the boundaries of the case may have limited the variety of experiences that could have otherwise been captured if I were to interview a diverse range of participants representing different disciplines, colleges, ethnicities, and genders. I did not seek out extreme cases or unusual case and study the experiences of PIs funded in 2019 and 2020, for instance.

It is standard for researchers utilizing a case study to partake in participant observations. Doing so gives the researchers the opportunity to learn more about participant behaviors in their natural environments. Although I would like to observe participants and team meetings, I was not able to do so due to the COVID-19 pandemic.

Chapter Summary

In this chapter, I discussed all aspects of my study's research methodology. Because a researcher's paradigmatic identity and positionality are vital aspects in qualitative research, I discussed my pragmatist worldview and how my beliefs and assumptions shaped this study. When outlining my positionality, I explained my experiences with interdisciplinarity and how my role as a graduate assistant in the IDRE team made me uniquely positioned to collect and analyze data required for this study.

Furthermore, in an effort to be transparent about my research process and decisions, I acknowledged my biases and assumptions with regard to my study.

With my research questions as the north star, I used a qualitative case study to understand the barriers interdisciplinary leaders encountered and their role as principal investigators. The boundaries I used to define my case led me to interview eight principal investigators of X-Grants, an interdisciplinary internal grant program at TAMU. Although semi-structured interviews served as my primary data collection instrument, I also used secondary data and documentation to supplement and triangulate the findings from interviews. The tenets of thematic analysis formed the basis of how I analyzed the data. In closing, I highlighted the various tools and strategies I used to establish trustworthiness. In the next chapter, I elucidate the findings obtained from this study.

CHAPTER IV

FINDINGS

In this chapter, I report the findings from my interviews and supplement it with secondary sources. Prior to presenting my findings, I reiterate the purpose of this study, with the aim of aligning my findings with the study's purpose and research questions.

The purpose of this dissertation study is two-fold: i) to explore the barriers encountered by leaders of interdisciplinary research (IDR) teams, who I also refer to as principal investigators (PIs); and ii) to understand how PIs perceive their role. The following research questions guide this study:

1. What barriers (if any) do PIs encounter when leading IDR teams?
    a. How do PIs of IDR teams overcome these barriers?
2. How do PIs perceive and describe their role as leaders of IDR teams?

As noted in Chapter III, I employed a qualitative case study design to answer my research questions. I used semi-structured interviews to capture participants' ideas, thoughts, and experiences. To supplement and triangulate participants' responses, I utilized secondary sources of data, including promotion and tenure documents, PIs' curriculum vitae, lists of each team's research outputs and publications, and X-Grants application guidelines. Upon the completion of my data collection, I applied the tenets of thematic analysis to analyze the data. In this chapter, I present the findings of my study after thorough analysis of interview transcripts, secondary sources of data, and peer-reviewed literature (where necessary).

This chapter is divided into four sections. First, I begin with an overview of the coding process and provide a snapshot of the themes associated with the dataset. In the following section, I present a brief portrait of participants and their teams to inform the readers of respondents' backgrounds and the structure of X-Grant teams.

Next, I discuss my findings in response to the first research question regarding barriers to IDR, organizing the findings—in accordance with the social ecological model—into the following levels: individual, team, institutional, community, and policy. When presenting the findings concerning this research question, I also address how participants surmount some of these barriers.

In closing, I present my findings in relation to the second research question regarding participants' perceptions of their role. In keeping with how I presented my literature review in Chapter II. I organize the findings based on the leader role: thought leader, people leader, and project manager. My analysis has led to a deeper understanding of the barriers my interviewees encountered and their perception of the PI role.

How I Coded My Data

After transcribing the interviews, I coded the data multiple times (as noted in Chapter III). At the end of the first round of coding, 212 codes were associated with the dataset. Because coding is a cyclical and iterative process, I combed through the data a few more times, often developing new codes and coding chunks of data I missed in earlier rounds. Overall, I revisited the transcripts five times. The first three times, I read through the transcripts with the purpose of noticing, collecting, and thinking about things

(Friese, 2012). I then coded the data targeting specific research questions. Finally, in the last round of coding, I collapsed certain codes if they were repetitive, and broke down a few codes into newer codes if the theme needed to be granular. After five total rounds of coding, I ended up with 138 codes (see appendix E). I classified the codes into six categories based on my research questions and related themes. Table 5 below presents a snapshot of code categories and definitions.

Table 5

Overarching Themes from Data Analysis

Themes/Categories	**# of codes**	**Definitions**
Barriers	35	Participants' perceptions of obstacles in applying, conducting, or managing an IDR project/ team.
Managing Barriers	12	Strategies or tools respondents employ to overcome/manage barriers/ challenges.
PI Role	30	Participants' perceptions of their role as a PI and what responsibilities the role entails.
Team	10	Interviewees' mention of anything team-related that does not directly relate to RQs 1 and 2, including structure, size, and composition of the team.
PI: Thoughts/Beliefs about IDR	17	Participants' perceptions and beliefs related to interdisciplinary research.
Other	34	I list other themes in the data and indicate the number of codes in parathesis: Observations/notes regarding PI's leadership (15) Participants' descriptions of project aims and objectives (2) Perceptions of administrative support (3); Graduate students (4) COVID-19 (5) Resources (3) Mentoring (2)
Total Codes	138	

Participant Portraits

In the interest of protecting participants' identities and ease of identification based on markers such as departments, title of project, and area of study, I refrained from providing a detailed profile of each PI. Instead of using respondents' official names, I refer to them as Participants A, B, C, D, E, F, G, and H. I also ensured that, nowhere in the data, did I reveal the gender of the participant.

I grappled with how to present certain quotations because participants shared certain details unique to them. For instance, one participant shared the number of years at TAMU. Because participants' names are publicly available, it is easy to obtain their CVs and uncover the identity of a participant on his/her years of experience at TAMU. Therefore, when respondents commented on specific details unique to them, I avoided attributing those quotes. Instead of stating, "Participant A said…", I presented the quote as "one participant said…"

As per the application requirements outlined on the X-Grants website, PIs and co-PIs of every X-Grant team need to hold a PI-eligible position at Texas A&M University (President's Excellence Fund, n.d). A PI-eligible position is limited to tenured and tenure-track faculty, with exceptions, although the website does not clarify or list the exceptions (President's Excellence Fund, n.d).

Interviewees in my sample represented a diverse group in terms of demographics (gender, age), college and disciplinary affiliations, varying levels of experience, and job responsibilities. I interviewed three female and five male participants. Most PIs in my sample hailed from the "hard sciences."

Respondents were either assistant, associate, or full professors representing a wide range of colleges across the university, including the Colleges of Agriculture and Life Sciences, Architecture, Engineering, Geosciences, Medicine, and Science.

Although all PIs were either tenured or on the tenure track, their career paths and range of experience varied immensely. Some PIs were "new" and just beginning to establish their areas of research, whereas some others had more years of experience under their belts, ranging anywhere from eight to 25 years. I calculated participants' work experience based on the years of work and/or research each PI undertook upon completion of his/her doctoral degree. The year of completion of each faculty member's doctoral degree is publicly available on their curriculum vitae.

Each PI had varying levels of responsibility within their academic department and college. While it is typical for faculty members to be involved in teaching, research, and service, some PIs had other duties and titles along with their regular faculty position. For instance, some PIs managed centers, ran their own labs, and had joint appointments in secondary departments.

Prior Experience with Interdisciplinary Research

While most interviewees indicated that they had worked in IDR settings, some had even led IDR projects prior to leading their X-Grant teams. Participant D, for instance, recounted working with more than 30 co-investigators from a wide array of disciplines on a research grant. Even though several respondents reported prior experience with IDR, some had not worked on a project as "large-scale" as the X-Grants. Participant E pointed out having a "little bit" of experience at a previous

position, but quickly added that this experience was “nothing on this scale.” The participant said, “Seed grants [are] usually quite small. You are typically in smaller teams. The [X-Grant] program is large enough that you can have a pretty large-scale research project you can put together, which is unique. I hadn't really seen anything like that before.”

Participant F expressed difficulty in ascertaining major differences between an X-Grant and a National Science Foundation (NSF) grant, but went on to point out a key difference between the two:

> *“What is different, I think, is the degree of cross-disciplinary effort with this [X-Grant]. It is not something I've seen in other grants and I've worked with people in psychology and linguistics. So, I'm used to working on teams with people outside [my field]. But I've never seen the variety of disciplines that converge into a problem in the way that I see on X-Grants.”*

Structure of X-Grant Teams

X-Grant leaders, who are a part of my sample, belonged to the first cohort of PIs funded by X-Grants in 2018. Not all X-Grant teams are similar in their size, composition, and funding. The size of the teams ranged from 15 to 30 team members. I gathered this information by combining interview data—in which participants discussed the size and composition of their teams—with team rosters obtained from Texas A&M’s Vice President for Research (VPR) Office. With very few exceptions, X-Grant teams were centered around PIs and co-PIs, with graduate students serving as significant links in the integration of knowledge across disciplines. Some teams harnessed the skills and

expertise of postdoctoral scholars, undergraduate students, and even research associates. The disparity in the funding amount X-Grant teams received could be the answer to why some teams employed postdoctoral scholars and others did not. According to the website (President's Excellence Fund, n.d.), the X-Grant program has two categories of funding every year: large and small grants. When submitting an X-Grant proposal, larger projects can request a funding amount in the range of $500,000 and $1.5 million, whereas smaller projects can request funding between $100,000 and $325,000.

Working in Subteams

Because of the large number of individuals per team—ranging from 15 to 30 individuals—most participants noted working in subteams. "Subteams" refer to "smaller subsets of members nested within a larger team that work interdependently within and between one another for the benefit of an overall team" (Kirkman & Harris, 2017, p. 118). Participant A explained this further:

> "*Given the size of the team, we split ourselves into subgroups, each one working on a specific idea. For example, there is a team improving artificial intelligence. There is another team that's trying to develop advance materials synthesis and discovery. Another group is looking on how to create data in a 3-D printing platform. And the fourth group is looking at how can we use all these processes to actually close the loop."*

Another participant, E, alluded to adopting a similar structure: "[T]he way we structured the project was kind of in three subgroups." In addition to leading the whole

team, this respondent also led a particular subgroup and was in charge of its research direction and activities.

Not only were X-Grant teams collaborating in subteams when working on their research, some teams also adopted a similar structure when applying for external grants. External grants often refer to funding awarded by institutions and agencies other than the institution with which an individual is affiliated. Grants offered by the National Science Foundation and the National Institutes of Health are examples of external grants. In the words of Participant G:

> *"The new grants have not encompassed the whole team. It is hard to find grants that fit the whole team perfectly. The entire team is involved in some form or fashion in National Science Foundation grants. But for other kind of grants that usually have very specific things that they want done, we work in subteams."*

Participant A's team also adopted a similar structure:

> *"We typically go as subteams [for external grants]. For example, the project that we have got with the National Science Foundation recently has me and another junior faculty member [as leaders]. There is another proposal we got with the National Science Foundation that has one of my team members as a PI and me and another member of our team as co-PIs."*

Barriers to Interdisciplinary Research

The theme "barriers" encompasses interviewees' perceptions of specific obstacles, hurdles, or challenges in applying, conducting, or managing their X-Grant teams. Thirty-four barriers emerged during the data-analysis process. As noted in

Chapter I, barriers and challenges have different meanings, but I use the two terms interchangeably in this study. As seen in Table 6, I organize the findings in response to the first research question based on the social ecological model framework, starting at the individual level and, later, exploring barriers and challenges at the team, institutional, community, and policy levels.

Table 6

Data Analysis: Multi Level Barriers to IDR

Themes	Description and Sub-Themes
Individual Level Barriers	Barriers related to individual attitudes, skills, and perceptions such as: • Time • Motivation • Lack of Systems View
Team Level Barriers	Barriers participants experienced at the team level: • Finding a Meeting time • Managing Geographical Dispersion • Distance between Disciplines • Communication • Data Ownership • Authorship Order • Recruitment • Role Definition and Delegation • Phenomenon of the Quick Expert • Student-Related Challenges
Institutional Level Barriers	Barriers related to rules and regulations at the institutional level, including: • Promotion and Tenure (P&T) Guidelines • Power Dynamics and Hierarchy • Budgetary Challenges
Community Level Barriers	Barriers concerning shared values and beliefs at the community level: • Journal Guidelines • Career-Related Barriers for Students and Postdoctoral Scholars

Table 6 Continued

Themes	Description and Sub-Themes
Policy Level Barriers	Barriers regarding policies at the local, state, and federal level. COVID-19 Policies led to: • Delays in Timeline • Travel Restrictions • Methodological Challenges • Less Interaction with Administrators

Barriers at the Individual Level

"Individual level" refers to characteristics of the individual, including factors like attitudes, beliefs, behavior, and skills (McLeroy et al., 1988). Participants discussed three main obstacles at the individual level: time, motivation, and a lack of systems view.

Individual Level Barrier: Time

Not having enough time to engage with their X-Grant teams was a recurring theme in the data. Although all participants enjoyed collaborating with their team and engaging in IDR, several struggled to find time to work with the team. Participant B aptly stated that "time is your currency" in academia and that there are not enough hours in the day to engage in research. Participant C stated: "If I have to point to a challenge, it is in terms of being able to find more time to work with the team."

Participant D provided a possible explanation for this challenge, adding: "Time is a barrier. In any faculty member's role, there are so many demands on your time. And so, finding ways to build time into X-Grants, I think, would be good. The one quantity you can never have enough of is time to make these things work."

Participant G concurred with the sentiment expressed above and stressed how demanding it is to be a faculty member: "[W]ith teaching and all these other things that are going on, [faculty members] run projects, run labs, and do the best we can, but it is too hard to keep up."

Because of increasing demands on a participant's time, one respondent shared the decision to step down from an administrative role on campus: "I can't be responsive to what needs to be done in the day-to-day operations of something like [the administrative role] and maintain my sanity."

Delving into promotion and tenure guidelines provided further insights into why faculty members are so hard-pressed for time. A tenure-track professor is often evaluated on his/her achievements in teaching, research, and service (TAMU Dean of Faculties, 2020). Teaching includes course and curriculum development, instruction of courses being taught, directing graduate students or postdoctoral scholars, grading, and other tasks. Research responsibilities include publishing, securing funding from grants, and participating in research projects. Service responsibilities comprise membership and/or leadership of subcommittees or task forces, mentoring a colleague, service to college or university, and service to discipline or field (TAMU Dean of Faculties, 2020). Balancing teaching, research, and service responsibilities can leave faculty members overworked and asking for more hours in the day to fulfill their responsibilities.

Individual Level Barrier: Motivation

With X-Grant team members—faculty and students—involved in multiple projects and having additional responsibilities to fulfill, some PIs struggled to engage

and sustain team members' motivation for the life of the grant i.e., two years. Participant E acknowledged that wavering motivation in an IDR setting is a hurdle: "In some cases, we had certain faculty who were really enthusiastic about the project, and then others who weren't quite as excited about it. In the end, they were not really involved as much as others. It depends on their level of interest, as well."

Personal motivation and engagement in an IDR collaboration is important to consider (Ju et al., 2015) when recruiting team members. Researchers with high levels of engagement are likely to be excited in an IDR collaboration, and as a result, they may be active members in the project and its decision-making. Non-responsive or inactive individuals can cause frustration among team members and dampen group morale (Ju et al., 2015).

Individual Level Barrier: A Lack of Systems View

Only Participant F highlighted that a lack of systems view among team members is an obstacle when collaborating with an IDR team. A "systems view" refers to an individual's ability to see the bigger picture and understand how the work of subteams contributes to the team's objectives and goals. F highlighted some team members' inability to see the forest for the trees.

> *"I would say the biggest challenge [is] making sure that we all, including the students, have a systems view. Students get bogged down with details and sometimes lose perspective of what we are after. Making sure that students and faculty understand how what they are doing is connected to everything else is the main challenge."*

According to this participant, only two members in the team have a systems view:

> *"Co-PIs [X and Y] who lead core teams understand the details of what they are doing, but are not systems individuals. You need both [those who are detail-oriented and those who can have a systems view]. I wouldn't be able to do the work that X and Y do, because my brain doesn't work that way with the level of detail they keep in their mind."*

Barriers at the Team Level

At the team level, participants discussed several challenges, which I divide into three dimensions: i) logistical barriers, including scheduling a meeting time and managing geographical dispersion of team members; ii) intellectual barriers, such as distance between disciplines, communication, data ownership, and authorship order; and iii) personnel-related barriers, such as recruiting, role definition and delegation, managing competition between team members, the phenomenon of quick expert, and a few student-related challenges.

Team Level Barrier: Scheduling a Meeting Time

At the individual level, almost all PIs of X-Grant teams expressed "not having enough time" as a challenge to IDR. Not having enough time at the individual level translated into a team level challenge. Respondents shared that finding a common meeting time and bringing team members together for a meeting were challenges they encountered. With the size of X-Grant teams ranging from 15 to 30 members—including undergraduate, graduate, postdoctoral students, and faculty—it is unsurprising that leaders faced difficulties in bringing everyone together for team meetings. According to

Participant C, “We try [to meet], but it is difficult. The last time we met [as a whole team] was in late 2019” [six months prior to the interview]. One factor that limited teams’ ability to meet was the COVID-19 pandemic.” Participants experienced several challenges as a result of state and local policies during the pandemic. These challenges are discussed at length when exploring policy level barriers later in the chapter. Echoing the thoughts of Participant C, PI E remarked:

> *“It is not that easy to find a time where everybody can talk. The biggest [challenge] is faculty schedules. It is hard finding a time when everyone is available. So, we didn't really have many project meetings because faculty are quite busy. With 15-plus faculty, it is hard to get everyone together. So early on, we had several project meetings. But then recently, everyone has been doing their own thing. We've just been communicating by email after that.”*

Not being able to identify a common meeting time impacted how often X-Grant teams met, as PI E noted above. Several PIs alluded to getting together with their teams only once or twice a semester. To overcome a feeling of being disconnected, Participant C, met with students one-on-one during the course of the grant:

> *“We always meet one-on-one every week, so the students that work as part of the X-Grant have the possibility to work together. I know they meet from time to time to keep in touch about their parts. Since COVID, I'm meeting with them on a bi-weekly basis. I have about a two-hour meeting every other week with each one of them separately.*”

Because of the pandemic, almost all respondents stated meeting their teams virtually using Zoom. One interviewee noted, “It is a lot easier by Zoom than meeting physically.” Halvorsen and colleagues (2016) argue that researchers need extra time to conduct interdisciplinary research compared to research focused on a single discipline because of the cognitive distance between participants. Team meetings may serve as opportunities to bridge the cognitive and disciplinary distance among individuals representing multiple disciplines (Halvorsen et al., 2016). Therefore, finding a common meeting time is an important step in the integration process of IDR teams.

Team Level Barrier: Managing Geographical Dispersion

Although the X-Grants website states that the internal seed grant is “open to all faculty, researchers, and staff at Texas A&M University, Texas A&M University-Galveston, Texas A&M University-Qatar, Texas A&M Engineering Experiment Station, Texas A&M Engineering Extension Service, AgriLife Research, AgriLife Extension, or TTI” (President’s Excellence Fund, n.d.), most X-Grant teams are based in College Station with very few team members located in other cities. PI H, who works with a team member in another city, attested to the difficulty of using a virtual platform to communicate with the team member:

> *“The distance was really tricky because one team member is in [another city]. To overcome the issue of geographical distance, we would Zoom. The technology stuff really was awful. Having like the geography of being really decentralized was a challenge. We overcame it by having Zoom, but we weren't at all used to it like we are now, right?”*

Because of the pandemic, Participant H lightheartedly added that everyone on the team is now an expert at Zoom: "Everyone should get a certificate on the wall that says they can Zoom. But initially [before the pandemic], technology and the distance were real problems."

Geographical and social proximity are valuable in IDR contexts because of the already existing cognitive distance between collaborators. Geographical proximity can be an asset to IDR teams because it allows for creation of social relationships, which is important for effective collaboration, considering that researchers in IDR teams come from a plethora of backgrounds (Rekers & Hansen, 2015). Spatial co-location has the potential to increase accidental encounters, stimulate the development of trust among team members, positively impact interpersonal relations and teams (Kiesler & Cummings, 2002), and even reduce costs associated with communication (Rekers & Hanson, 2015).

Team Level Barrier: Distance between Disciplines

Distance between or among disciplines was a significant barrier in the literature, as presented in chapter II. Several respondents readily acknowledged these difficulties, expressing three distinct dimensions associated with this barrier: differences in paradigm and language, communication issues, and progress occurring at different rates. I discuss each dimension below:

Differences in Paradigm and Language

Participant H aptly summed up how conflicting paradigms or worldviews hindered the team. Embedded in a worldview is epistemology, or what a researcher views as knowledge.

> *"What is considered knowledge for a lawyer is different from what is considered knowledge or research for a social scientist, an engineer, or a political scientist. So even in political science, I mean, if you were to talk to [team member Z], I'm sure you should know, Z is learning a lot about economic geography and I'm learning a lot about finance. So even though we are in the social sciences more generally, that doesn't give you a pass that everybody's on the same page."*

To overcome this dimension of distance between disciplines, H introduced qualitative methods to individuals who were otherwise heavily trained in and only exposed to quantitative methodologies. The interviewee recounted that postdoctoral scholars trained the team on codebooks and the nuances of qualitative analysis.

Another factor contributing to the distance between disciplines is the diversity of disciplines and languages (Choi & Pak, 2007). Some of the terms could have distinct meanings across disciplines. Words like "sensitivity" and "significance" could mean different things depending on the academic area (Choi & Pak, 2007). Furthermore, team members themselves could be speaking their own languages as a result of years of socialization in a particular field. Participant C illustrated this issue and also recommended that leaders be patient with team members when they are struggling to communicate.

"There is a lot of times when we don't speak the same language in terms of our scientific backgrounds. But we are all very patient with each other when it comes to that. When there's a big workshop and somebody is talking about surface energy balance, the social scientists are rolling their eyes [laughs]. So sometimes, even though I know the answer, I will, on purpose, say can you explain this acronym to everybody? We try to make it accessible so that everybody in the room can contribute as much as possible."

Participant C strived to make the team environment as "candid" as possible by asking for feedback in meetings and in electronic communication. C added, "So maybe we are setting that stage right away. I think that makes communication easier."

Communication

Because interdisciplinary team members speak multiple disciplinary languages and view the world through unique lenses, respondents pointed to challenges in communication. According to one participant:

"The only major barrier I see this moment in very junior members of the team is a lack of communication. This issue of very junior members of the team not understanding that other members of the team don't get what they are saying has been the only [barrier]. We haven't had any real issues even with the direction of research."

The respondent further explained how a lack of communication could occur between two members who are not exposed to each other's fields.

"An imaging student—who has never picked up a pipette in life—has had issues getting samples from those trained in tissue culture because they are busy and try to interpret what the imaging person needs. The imaging person doesn't really understand what they need because they've never done tissue culture."

Co-PIs on the team suggested cross-training students to develop a shared language and common understanding of a problem or topic: "The solution is to have people go and look at the imaging system and actually see and understand how the imaging process works. An imaging person has to go and learn tissue culture. And that's the only way to manage those two components."

Some other PIs facilitated cross-training by requiring students to present at weekly meetings. As weekly meetings are attended by team members representing multiple disciplines, participant A noted that this exercise enabled students to understand jargon and boundaries.

"We have weekly meetings where students are required to present their update. It is an intimidating environment in some ways because if I were a grad student, I'm not only talking to my own professors, but half a dozen other professors who are part of this project, with whom I need to connect. It is a very challenging environment. But it has been an enriching experience for grad students because they know how jargon and boundaries work."

Progress occurring at differing rates

It is clear that having distinct worldviews or paradigms and speaking various languages can contribute to difficulties in communication. A surprising element that

leads to and even further widening of cognitive distance is how researchers representing a spectrum of fields interpreted time and progress. One participant highlighted that the concept of progress varies according to discipline:

> *"I've learned time constraints are very different from discipline to discipline. I can sit with a student and say try this algorithm out and [the student] can go back and clean it up, sometimes in a couple of days, sometimes in a couple hours. When you are dealing with materials or optical circuits, we are talking about weeks of planning, which caught me by surprise. That's one thing that I have gained an appreciation for - understanding that things progress at different rates."*

When reviewing the literature, several scholars stressed that the distance between disciplines can be a barrier to IDR (Kaplan et al., 2016; McNeill, 1999; Rekers & Hansen, 2015; Rijnsoever & Hessels, 2011, but not many examined the issue of how long progress takes across disciplines. Halvorsen and colleagues (2016) were among the few who noted that social and natural scientists spend varying amounts of time in the field. As a result, the time to complete a project or data collection may be different, depending on the field a scientist represents (Halvorsen et al., 2016).

Team Level Barrier: Integration

"Integration in IDR is perhaps the greatest challenge researchers face" (Pischke et al., 2017, p. 1017). Two key challenges emerged for participants: i) deciding on the boundary or scope of a project when there are countless possibilities to explore; and ii) identifying conceptual commonalities. Because of the wide range of questions and

possibilities ID teams can investigate, narrowing down of a topic and its boundaries can be time-consuming. Participant C recalled a meeting in which the team explored the possible angles they could investigate: "It is a social problem, it is endless. So that's why every time we talk about it, we are like, okay, so where do we stop?"

PI H expressed struggling to integrate a team member's ideas into the team's work plan and commented that it is important to find conceptual commonalities:

> *"There are some fundamentals around knowledge that are different and you need to understand those core differences, if you are able to accommodate and engage them. There are certain things that are different in terms of what is valued as knowledge not only by an individual, but by an entire discipline. Working [with an] interdisciplinary team is one thing, but you can't ignore the fact that people still operate in their discipline simultaneously."*

H suggested that the solution is "continued engagement and being a supportive colleague of [team members'] research." Bracken and Oughton (2006) argue that when crossing disciplinary boundaries, teams need time to develop a shared framework and language. In a study conducted by Pischke and colleagues (2017, p. 1017), they concluded that "social and natural science teams had trouble lining up their field seasons temporally, and so working together closely to integrate questions, communities, and methods was difficult."

Team Level Barrier: Data Ownership

Data ownership is concerned with the possession and distribution of data and/or information. It refers to power and control over information, including who has access to

create, modify, distribute, and assign these privileges to others (Loshin, 2002). The issue of who owns the data is significant on an IDR team because subteams may be responsible for collecting different pieces of data and may believe that they own the data they helped collect. Therefore, IDR teams must have extensive discussions to clarify if subteams own the data they collected and analyzed, or if the data belongs to the whole team. Participant G recalled how the issue of data ownership became a challenge on an IDR team:

> *"They [subteams]have a sense of ownership over their own data that they generated. Even though the graduate students did it, there was this feeling that it is still my data and I'm the only person who can necessarily publish with that data. That was a challenge for me as a PI - knowing how to present our work and making sure everybody was properly credited without stepping on anyone's toes."*

Team Level Barrier: Authorship Order

Academic researchers must navigate promotion and tenure processes, but those engaging in IDR face additional tensions caused by a lack of common standards to evaluate researchers' contributions (Schuitema & Sintov, 2017). Such systems, the authors argue, are not set up to evaluate ID contributions. How do IDR teams publish or credit team members when the authorship order guidelines are unique to fields? Respondent G highlights this very challenge:

> *"Even things like the sequence of authors are so different in different fields. For example, in chemistry, the last person on the paper of co-authors is usually the*

corresponding author because that's usually the person funding the project in a lab. In our field, it is the first or second author who is important. Some of the PIs are very protective of their Ph.D. students, which they should be. And in their particular field, if you end up with too many authors, then you can't see that they did the lion's share of the work, even though they are the first author."

This interviewee navigated the issue by empowering subteams to publish their research. Because the number of publications and research outputs are evaluated by a faculty's promotion and tenure committee, G noted, "one of our faculty members said that we need to ask departments to judge by number of downloads and number of citations—not impact factor—because disciplines have different senses of what is helpful." Journal guidelines and challenges relating to promotion and tenure are explored further in this chapter.

Team Level Barrier: Recruiting team members

As noted earlier, funding for an X-Grant team ranges anywhere from $100,000 to $1.5 million. All projects are funded for two years. With teams setting out to find solutions to complex problems, team leaders are tasked with recruiting the right personnel to achieve the team's research objectives. Although X-Grants announcement documents have clear instructions on team member qualifications, it does not outline how PIs can recruit team members. Participant C acknowledged this issue:

"Finding good people to work with [is a challenge]. I didn't know many people on the team personally. I just cold called them because of their expertise and hoping it would work. So, it is been pretty successful, actually. I would go on

department pages and scroll through faculty and look for keywords and things like that."

For a faculty member who has only been at TAMU for less than 10 years, it was difficult to find collaborators with whom to work:

"*Finding good students and recruiting [is a challenge]. We also had quite a challenge in recruiting a good postdoc. We didn't really have anyone internally [at TAMU] and it took quite a long time to recruit someone and bring them to Texas A&M. There was a pretty big delay in getting the postdoc, which is why, for grad students, we tried to recruit folks who were already on campus."*

Some PIs leveraged their team members' or collaborators' networks, building and maintaining these relationships. In the words of participant H:

"It was initial discussions around people that I had known like academic acquaintances from campus. After that, it became targeted outreach to scholars on campus who may have a skill that we need to bring onboard. I had known many of them [team members] in different contexts. Honestly, I remember reaching out to them and saying, Hey, guys, do you want to [apply for] an X-Grant? Here's an idea. What do you think?"

After assessing the gaps in expertise, Participant E reached out to colleagues within the department. "Colleague X had already worked with Y before. Y, then, introduced me to the whole computer science group at that time."

Because the composition of a team and its organization can make or break the research and team process (Choi & Pak, 2007), finding the right researchers and

collaborators is critical. Halvorsen and colleagues (2016) note that recruiting team members with technical and interpersonal skills can offset some challenges IDR teams face. For example, team members with strong interpersonal skills are likely to "get through the delicate work of navigating disparate professional identities, boundaries, and norms" (Halvorsen et al, 2016, p. 3). The authors also suggest jump-starting the recruiting process by drawing on existing networks of colleagues.

Team Level Barrier: Role Overlap and Delegation

With a large number of individuals in X-Grant teams, one PI struggled to find a way to delegate responsibilities. Participant G recalled a time during the project's initial stages when it was challenging to develop a mechanism to delegate work:

> *"I learned that just because people can do something doesn't mean they should. [Individuals from] different disciplines can do a lot of the same things. We had three different partners in different fields who can scan using an electron microscopy. What it did is it created competition about roles and whose right it was to complete a task. I realized, as a PI, that I should have written down what people's roles are. We were pretty loose at the beginning. Consequently, you ended up with people feeling that their roles were intruded upon."*

A lack of clarity regarding team member roles and tasks not only creates competition among team members, but the perception of being intruded upon by other team members can also generate frustration and conflicts. Participant D shared such a situation:

"Well, I think one of the biggest challenges is how we basically spread the workload, because I think as individual PIs, we are often very focused. You can what needs to be done on a daily basis. But when you have so many moving pieces, developing good mechanisms for tracking who needs to do what and assigning those tasks are really critical."

Team Level Barrier: The Phenomenon of Quick Experts

When pursuing an undergraduate degree in the mid-1980s, "in the olden days before there was internet and Google," interviewee G recalled how long it took for an individual to become an expert in one's field.

"You had to go to school, you had to get specialized training. Nowadays, with Google and with everything being so open, you have this sense that people teach themselves all sorts of things. I mean, they teach themselves outside their own discipline. That, I think, is part of what creates this friction. It is also this kind of feeling that somebody can very quickly, after a few hours or a few days of reading, grasp some of the bigger issues and elements of another field."

As this interviewee pointed out, IDR teams could experience friction when experts, who have devoted years of study on a topic, interact with individuals who have spent very little time studying a field, yet speak authoritatively about the same research area.

Team Level Barrier: Student-Related Challenges

A few PIs ventured into their respective X-Grant projects anticipating disagreements related to research direction and language differences. PIs said they were surprised, however, when they noticed student-related challenges in their teams.

When students in H's team would present in weekly meetings, they often forgot that the audience was interdisciplinary. Similarly, G expressed how students "would just simply throw out words and throw out acronyms." There were even times when students "didn't put units on tables, which made it difficult for individuals from other disciplines to comprehend what they were trying to communicate." In short, "they forgot to tell everybody else what that acronym meant or what that particular method was supposed to do." As a result, oftentimes, team members "were in a fog" and "didn't know what [students] were talking about." To overcome this challenge, the team leader would "dead stop them in the room" and remind the students that they were speaking to an interdisciplinary audience. The team leader encouraged other members to do the same.

Another hurdle associated with students is competition. When high-achieving students get together in IDR teams, their competitive natures often prove detrimental to team cohesion. According to one interviewee:

> *"It is easy to get very competitive. We have some phenomenal students here at Texas A&M. A lot of them are used to being top of their class. And so, they can easily start competing against each other, not realizing that while competing against each other, you can also offend somebody else sometimes."*

In addition to competition issues, Participant B pointed to student mentorship challenges:

> *"Students are not very good at being mentors. When they have mastered a technique, I get the impression—I mean, it is based on personality—that [they] can be pretty confident and arrogant. They find it difficult to accept that some people enter the lab and just can't do something for the first couple of weeks. It is just not in their wheelhouse [to know how to mentor]."*

This participant recalled a time when a graduate student commented, "I don't understand how someone can just not get it." After diagnosing the situation, this interviewee concluded that students did not know how to mentor peers who are novices in a particular field. A possible reason for not having mentoring skills could be due to a lack of a frame of reference, the PI said. The interviewee stressed that students learn by repetition and by example.

> *"It dawned on me that students have no frame of reference. We [faculty] all are a little bit more aware when we ask our graduate students to teach other students who are green. There is a very special way of doing that. It certainly doesn't involve pulling your hair out and telling them, why aren't you getting this? My grad students had issues with that. So, I had to step in with other PIs and say, look, you've never taken someone literally off the street and taught them [basics of a field]. This is basically what you do and how we go about this."*

In addition to leading by example and teaching students how to teach other students, this interviewee also suggested partnering students with their peers. Doing so

could prove particularly helpful, Participant B continued, when students felt isolated from the rest of the team.

Barriers at the Institutional Level

In a study conducted by the National Academies (2005), some 71% of the respondents believed institutional barriers are major impediments to IDR. As noted in chapter II, some of the key barriers to IDR include rigid departmental structure and rules (Lynch, 2006; National Academies, 2005), unfavorable reward structures (Rijnsoever and Hessels, 2011; Siedlok & Hibbert, 2014), lack of funding opportunities (Boden & Borrego, 2011; Lynch, 2006), and lack of support and resources (Boden & Borrego, 2011; Rekers & Hansen, 2015). While there were some common themes between the list of barriers (above) and challenges participants expressed, interviewees highlighted some unique themes as well. Overall, respondents identified four key institutional level challenges to IDR: promotion and tenure, power and hierarchy, a paucity of resources, and challenges relating to how funds are allocated.

Institutional Level: Promotion and Tenure (P&T)

Traditional academic reward systems—overseeing hiring, and tenure and promotion decisions—are substantial barriers to IDR (National Academies, 2005). Systems within department units and colleges are not set up to evaluate IDR contributions and are oftentimes evaluated with a single discipline's norms and rules. The result is rigidity within the overall rewards system (Sieldok & Hibbert, 2014). One PI remarked:

"We, in our department, have an approved list of journals. When some of the stuff that we contributed to ended up getting published in the journals of other disciplines, that didn't count for our tenure and promotion. That created some frustration. How can we align the university's agenda to become interdisciplinary if [the P&T guidelines are not conducive to IDR]?"

This interviewee raised a highly pertinent issue. Due to the nature of the study and topic, it is likely that traditional journals (or journals highly regarded in a field) may not accept interdisciplinary articles or manuscripts. As a result, authors may seek to publish in IDR-specific journals or in fields other than their own. When P&T guidelines are not conducive to IDR, not only do they discredit a researcher's contribution, but also can dissuade researchers from engaging in interdisciplinarity altogether.

One PI, who is the interim chair of a promotion and tenure committee, asked:

How do you quantify contributions to team science? We try to assess every dossier, in a complete way, but [inaudible] biases can creep in. When you see an article in Nature Medicine and the candidate is the second corresponding author, second from the end, I'd be inclined to say, well, I know what they did to get that. We have to formalize this process so promotion and tenure committees value and treat multidisciplinary contributions the way they should."

This participant brought up yet another important point. Because this X-Grant leader is aware of the authorship guidelines in *Nature Medicine*, for instance, the respondent understood that the corresponding author is the second one from the last. But,

in social sciences, the first author is the corresponding author. How do reviewers in P&T committees familiarize themselves with various disciplinary cultures and protocols?

TAMU promotion and tenure guidelines (TAMU Dean of Faculties, 2020) provided insights into this matter. The document stated that candidates are to describe their discipline's protocols in terms of authorship order in their application packet, perhaps to help reviewers understand the norms of a particular field. Furthermore, the document urged P&T committees to "make a special effort to understand the customs of other disciplines on co-authorship, sequence of authors…" (p. 21). When a candidate is engaged in interdisciplinary or multidisciplinary research, the document encourages reviewers to consider the applicant's annotated CV, further adding, "interdisciplinary activities should be evaluated and valued the same as those that are discipline specific" (TAMU Dean of Faculties, 2020, p. 19).

While the TAMU P&T guidelines seem friendly to IDR, each college has its own rules for evaluating P&T application packets. The College of Medicine's (2019) P&T guidelines aligned with the university's:

> "The evaluation should take into account the successful accomplishments of team-based research efforts in which candidates have participated…Furthermore, team science projects often create grant proposals with multiple co-Principal Investigators or co-Investigators, as well as publications with multiple authors. The contributions of the candidate to these efforts must not be discounted because of the number of participants on a research project. Therefore, Promotion and Tenure Committees shall ask candidates to provide information

on their specific roles on, and the importance of their contributions to, multi-investigator grant proposals and papers" (College of Medicine, 2019, pages 7-8).

Although the TAMU P&T guidelines seem to be conducive to IDR, there are some discrepancies in how multidisciplinary and interdisciplinary contributions are valued at the university level vis-à-vis at the college and school level. The College of Architecture suggests that when evaluating ID research, committees must strive to select reviewers from different fields (College of Architecture P&T Guidelines, 2013). Assigning the right reviewers is a crucial step in ensuring that ID researchers are evaluated fairly and on par with those engaging in monodisciplinary research. However, this issue is not addressed in any other P&T documents.

One interviewee struggled to ensure that team goals and team members' contributions fit within the university's P&T guidelines:

> *"It has been a learning experience trying to navigate to figure out how to align with the university's expectations and still provide for my team. I'm not evaluated as much yet on service as I am on productivity and papers and grants. So, if I'm running the team, I do have to spend an outsized amount of time on project management, which is not given the recognition as much in the tenure promotion process."*

As leaders, Participants G and H expressed a few challenges they experienced trying to maneuver the varying P&T guidelines of their team members as each department and college has varying rules and procedures. According to G, "First, I was trying to get everybody to take one paper. In other words, if we had five disciplines, we

would end up with five papers, so that everybody would be on a publication. But that process didn't seem to appeal to the team in the end because of the situation other P&Ts [guidelines had]."

Respondent G reconciled this issue by working with the team and deciding that "everybody gets to write their own paper and they can include the number of people they want; they don't have to include everybody. That probably worked out better because then people could stay within their disciplinary journal. So that's kind of how we finally reconciled that." The interviewee suggested that teams could present their research using a different lens for different audiences.

PI H went so far as to concede that varying P&T requirements coupled with authorship order created tension in the team: "I'd have to say, all right, let's figure out what each person's tenure and promotion requirements are. And, we will have to try to shoehorn everybody into the same paper. I think that created tension, to be honest."

Individuals on tenure track are evaluated at the department, college, and university level, indicating that P&T is a hierarchical process. In the next section, I discuss how the intrinsic hierarchical nature of a university environment can hinder certain aspects of IDR.

Institutional Level: Power and Hierarchy

Universities are a very hierarchical place, according to PI G. This participant described the various stages of the academic pecking order and how they hindered the team from accomplishing certain tasks:

"You are supposed to progress through different stages. First, you are a grad student and you are assisting the professor, then you are an Assistant Professor and so on. This pecking order made it a little complicated for me to feel completely comfortable interrupting a meeting, if it was going off in the wrong direction or if there were sidebar conversations. It is easier, obviously, for me to say that to somebody who is in a different kind of a lower rank. It is hard for me to reprimand someone who is above my rank, which I did, at one point rather jokingly and I was given a stare."

As the PI experienced, when a lower-ranked team member interrupts a meeting, higher-ranked members can respond with an attitude of superiority, indicating that the lower-ranked member does not know their place or has not adequately progressed through the established academic hierarchy. The interviewee recalled how a team member struggled with a decision, fearing negative repercussions concerning P&T.

"We had somebody on our team, who wanted to make some decisions that he couldn't make in the research because he was really worried about how full professors would perceive him, which may have negative consequences for him. The ramifications could be too grave for him in terms of getting tenure."

Although the team member ended up making a decision "which was for the better," the participant recounted the struggles the individual went through "because of the realization that it could have consequences on him and his family and things like this."

Institutional Level: Budgeting

All X-Grant teams receive funds for two years ranging from $150,000 to $1.5 million. A few respondents expressed challenges regarding budgeting. Participant E, for instance, pointed out that the manner in which funds were transferred and to whom they were transferred did not work well for the team.

> *"The way the budget was allotted didn't really work quite as well. They kind of lumped [the money]. We had three groups and they gave the group leader all the budget. And then, the other faculty who had, part-time grad students were supposed to use their account. It'd have been nice if they had separated it into 15 different sub-accounts [one for each co-PI]."*

The respondent recalled having some money left over, which could have helped some subteams hire a student or a postdoctoral scholar. If the participant could do it all over again, the interviewee would push for each co-PI/subteam to have their own accounts.

Institutional Level: Resources

PIs of X-Grants are engaging in cutting-edge research and working in converging areas of new fields and disciplines. As a result, several respondents expressed frustration over a lack of proper resources to conduct their research. Participants mentioned specific challenges concerning equipment and support.

Equipment

One respondent experienced "lots and lots of issues and hurdles" when trying to contract out services to a new company for a specialized type of data. In particular,

hurdles with the TAMU contracts and purchasing office caused unexpected delays, said the participant: “First of all, they are a private and the only company in the world that could do this. So, we really have to work through them. [The purchasing office] took over three months [to finalize the contract].” Finally, the participant sought the aid of the college’s research dean, who helped with the purchasing process. When the team finally received the data, the team concluded that the data was not useful and, as a result, the team had to develop new algorithms to overcome the issue.

PI A said the single most challenging thing for the team concerns equipment and resources:

> *“The challenge that we have been facing is mostly related to the resources because the experiments tend to be extremely expensive. We have a one-of-a-kind machine, which is finicky. There is nothing that anybody can do about it except that finding a way to patiently deal with the way the machine wants to work. If I were to talk about a challenge, it would be that. I think it is an important problem, right? If the machine doesn't work, then, nothing can be done.”*

Support

Participant D believed that the X-Grant teams should receive more “support resources” especially with regard to how research is disseminated. The participant suggested:

> *“I think it would be quite beneficial if there were ways to help provide mechanisms for disseminating information on these grants more broadly. If there was a dedicated website person, who would help the X-Grants team, set up the*

website, even just talk about what they are doing, I think that would help to spread the word better and would give them more visibility and a footprint."

Barriers at the Community Level

Participants discussed two key barriers at the community level: unfavorable journal guidelines and career challenges for junior faculty and students. Navigating the cultures of individual disciplines was a key challenge for participant G:

"Those silos are quite deep, so at times, it has slowed us down. I will give you an example. We, in our department, have a kind of approved lists of journals and then some of the stuff that we contributed to ended up getting published in the journals of other disciplines. And that didn't count for our tenure and promotion and all this good stuff."

While this quote highlighted issues related to P&T (discussed in the previous section), the participant also alluded to the organization of journals along disciplinary lines. Scholars have extensively discussed how journal guidelines are not favorable to early career researchers and ID researchers and that journal guidelines hinder certain career opportunities, as well.

There was some variation in the publishing patterns of X-Grant teams with regard to the journals in which teams published and the number of authors credited in a paper. In analyzing each team's research outputs (publications and conference proceedings), my review revealed that most teams published in their own discipline's journals, although there were very few teams that ventured outside the PI's primary field and published in a range of fields, representative of its team members. When analyzing

bibliometric data, I found that most publications had multiple authors with some papers crediting almost sixteen authors in a publication. It is also important to note that there were single-authored publications.

Negative perceptions about IDR, coupled with the belief that it contributes to challenges in career-advancement opportunities (Hein et al., 2018) can discourage junior faculty and researchers from engaging in it. Many junior faculty and early career researchers perceive IDR involvement as a roadblock preventing them from obtaining tenure (Hein et al., 2018; Rafols et al., 2012; Rijnsoever and Hessels, 2011). This negative mindset about IDR could be partly attributed to a traditional academic reward structure that values monodisciplinary outputs. One PI said:

> *"PhD. Students needed to go off and get jobs, they needed to show that they were grounded in their discipline. If you have a Chemistry student in there and you are publishing in an Architecture journal - is that going to potentially hurt their chances of getting a job as an Assistant Professor if they are perceived as flipping around through different disciplines, or will it help them? There was this kind of nervousness that it might hurt them if you have universities evaluating them and are more conservative."*

The interviewee's quote encapsulated the current challenges IDR early-career researchers—particularly students—frequently face. When seeking positions in academia, students are often required to provide evidence of their grounding in a particular discipline. Engaging in IDR and publishing in journals outside of their field

may leave ID researchers at a disadvantage. Furthermore, as discussed in previous sections, junior faculty may be unfavorably evaluated during their P&T review.

Barriers at the Policy Level

Also referred to as SARS-COV-19 and COVID-19, the coronavirus has led to catastrophic global economic, social, and health crises. In the higher education context, the situation was no different. Institutions of higher education switched to virtual classes in early March and continued to operate online in the summer and fall of 2020.

Faculty members had to re-orient themselves to the new normal. They not only had to teach online and make adjustments to their syllabi to accommodate virtual learning, but they also had to learn to operate online learning platforms. While the intent of my original study was not to explore the barriers research teams are facing due to the pandemic, challenges related to the coronavirus emerged during interviews. Barriers related to COVID-19, as a theme, encompasses challenges PIs experienced in the course of leading their IDR teams during the public health crisis. Among the 14 codes that were associated with COVID-related barriers, participants mentioned facing delays in their timeline; challenges related to travel, executing certain methodologies, meeting the team, and interacting with administrators.

COVID-19: Delays in Project Timeline

Almost all PIs commented on COVID-19 disrupting their research projects. Participant B recounted the team's difficulty in making progress because of the lockdown and shelter-in-place restrictions: "In terms of practical work, we didn't do

anything in March and April, probably even May (of 2020). We are starting to very carefully resume our practical research."

Similarly, PI F noted encountering delays because of COVID. Leading a team that heavily relied on lab and computer-related work, PI E added that some members were classified as "essential workers" by the university, enabling the team to continue its work and research. But even with essential workers of the IDR team, Participant E said the pandemic "slowed the team down quite a bit because they [the team members] were only coming in for like half a day or a shortened work schedule."

While PI A's team did not face any major setbacks, the team missed meeting internal deadlines:

> *"There were some setbacks in terms of meeting stringent targets that we had set for ourselves. We wanted to have completed [task A] by the spring, which we could not. I think we are getting close and we should be able to finish by the summer. I wanted to make sure I captured the fact that there have been some slight modifications, but no major change in the focus of the project."*

Similar to respondent A's team, PI C also made a few changes in the way the team operated. In contrast to PI A, participant C added that trying to adjust was a "big challenge." Although this PI's team did not travel, C recognized the difficulty travel could pose for teams that rely on conducting interviews and meeting human subjects in person to gain qualitative data.

> *"For this X-Grant, there was no travel involved. So, it really hasn't slowed us down a whole lot. But yes, definitely everything that's field-related has been*

canceled and postponed. When you have to handle interviews and stuff like that, it is probably very, very difficult."

A few PIs whose teams rely on lab work and equipment pointed out that they were not able to access their research labs and/or equipment. According to PI F:

"[the challenge is] only in terms of having access to the equipment, general equipment when the facilities were shut. Fortunately, as soon as we are able to get back to work, I think in June, we will be able continue some of the work.

Interviewee G also discussed experiencing issues with accessing laboratories during late spring and summer. PI B and the team had to use a different research facility for "logistical reasons related to COVID, [which] slowed the team down a bit and narrowed our bandwidth."

COVID-19: Travel-Related Challenges

Several PIs in our sample readily acknowledged the difficulties their team members faced because of travel restrictions imposed on them during the pandemic. PI F stressed that "traveling was the main problem." Other PIs shared their thoughts on this challenge:

"We've had some delays with COVID because we [the university] was shut down for a while. We don't have the facilities to do [project-related work] at A&M. And so, there have been some delays with COVID. I've had the same problem with all the research that I do with human subjects – it has come to a halt because of COVID."

PI G highlighted another challenge:

> *"We won a grant as result of this [X-Grant project] to basically travel around the world, to visit a lot of labs. It meant that we had to reconfigure our research to virtual research where we are collecting data through interviews and things like that. It is obviously not quite as exciting because this idea of actually being in those locations and seeing things long before they will ever be fully published is a real gift."*

The ability to travel before the pandemic likewise enabled G's team to build connections, attend international conferences, and visit other researchers' labs, none of which they could now do.

When lockdown was announced, a postdoctoral scholar of another PI was in Australia conducting fieldwork. That situation, the PI recalled, was particularly stressful:

> *"One of our postdocs was doing her fieldwork in Australia in March. And we were wondering if the postdoc could get back in the country. Another postdoc had already done her major face-to-face interviews in November. We are lucky in that we did the chunk of our face-to-face (interviews) before COVID hit."*

COVID-19: Methodological Challenges

One Participant surmised the methodological challenges faced by the team as a result of COVID:

> *"The COVID thing really threw us off because we are global. What we were able to do with that, however, is ask for a no cost extension [from the administrators]. We took a hard look at our methodology and because we had done a lot of face-*

to-face work before COVID, especially with our international partners, it actually opened up the possibility of doing the follow up work virtually. The methodology we are using, it is possible to do via Zoom."

Similarly, PI G's team, who received a grant that required them to travel extensively, had to put their heads together to re-imagine how to conduct their research. Instead of collecting data through face-to-face interviews, the team ended up conducting interviews virtually.

COVID: 19: Meeting the team

Because of lockdown and stay-in-place restrictions, several participants mentioned the inability to meet their team members in person. According to PI A:

"I have not been in my office since February and I have not seen any of my team members in person ever since. I led them through calls and remote meetings. You can do only so much because of that, which, to be honest, is a constraint."

Family health concerns also affected team members during the pandemic. According to G: "[A team member] who has been working here, has a family member with health challenges, and it would be quite dangerous for him to get COVID 19 and transfer to his family member. So that definitely slowed things down."

Although several X-Grant teams faced challenges because of the pandemic, one PI explained how the team's structure was beneficial in uncertain times.

"*In our team, we have our PI, but we also have an army of amazing postdocs, graduate students and undergraduate students. We have a large team and each*

member has specific tasks that they are doing. And so, that's that kind of structure has been quite helpful in these sorts of uncertain times."

COVID-19: Less Interaction with Administrators

All X-Grant leaders met with administrators at the TAMU Vice President for Research (VPR) Office once every four to six months. As participants in my sample belong to the first cohort of PIs funded by X-Grants, meetings were an effective way for administrators to communicate with the PIs. As some respondents noted, these meetings also helped PIs nurture their relationships with fellow X-Grant leaders and learn how their peers were overcoming barriers. On the administrators' side, the meetings presented an opportunity to learn about the progress of these grants. Oftentimes, PIs would share updates about external funding they applied for and grants they were awarded, as well as provide publication-related information. According to PI F:

"Initially, we were meeting every three months with them [the administrators]. We have a meeting over at the admin building, during which we report progress and see how everybody else was doing. But since COVID, we haven't had much interaction. Those meetings have come to a halt. I think the last one may have been in February."

Managing COVID-Related Barriers

Although respondents did not have control over when stay-in-place orders and travel restrictions were lifted, several of them discussed how they handled certain challenges imposed by the pandemic. All eight PIs found the no-cost extension offered by the VPR office very advantageous. Teams were originally funded from fall 2018 to

summer 2020, but acknowledging the additional hurdles of the pandemic, the VPR's office extended the duration of the grant to fall 2020.

According to Participant C: "It was two years. We will extend [our deadlines] because we haven't spent all the money yet. In theory, it should be finishing this summer." Another PI remarked: "Yeah, actually, I think there's a few things we'd like to get wrapped up by December. And so, hopefully, we are in good shape to wrap up most of the project with this extension."

Silver Lining

Clearly, COVID-19 led to several challenges for X-Grant teams and leaders. However, some PIs reflected on ways their teams used the pandemic to accomplish tasks like submitting papers for publication. Although one participant's team could not work for a few months in the spring of 2020 due to stay-in-place restrictions, it certainly was not wasted time as the team "got quite a few papers published and three proposals out.

Another PI remarked, "I guess the silver lining is that we are now, out of necessity, creating new methodologies that we can write and publish in. So, this sort of COVID-19 pandemic has made us quite nimble in terms of how we need to adjust." This PI continued: "We had already been working on our systematic reviews, so we were already well informed on the kinds of remote work that we can introduce in a particular methodological approach."

No Key Barriers

Some PIs were quick to say neither they, nor their teams, had faced any particular barrier when applying and conducting their research projects. One X-Grant PI noted:

> *"I mean, you would expect in an interdisciplinary team [that] people would have trouble understanding each other's language and so on. But since we have mature experts representing each discipline, they have the empathy for the expertise and the knowledge other individuals bring to the table. They are naturally curious people, which worked out really well."*

According to a PI:

> *"Compared to other institutions, A&M seems to be reasonably open to interdisciplinary culture. And, within [my] College, where I am seeking most of my resources, resources are available. I work a little bit with [faculty from] other departments. People are very friendly and accommodating. So, the quick answer is no. I don't think that there was a serious barrier."*

In summary, interviewees pointed to barriers to IDR at various levels, including ones at the individual, team, institutional, community, and policy levels. Anticipated barriers to working across disciplines include a lack of time, motivation, and systems view at the individual level; logistical, intellectual, and personnel-related hurdles at the team level; promotion and tenure guidelines, paucity of resources, and fiscal challenges at the institutional level; obstacles related to career and journal guidelines at the community level; and hurdles relating to COVID-19 at the policy level.

Exploring the Role of IDR Leaders

Because of the range of multilevel barriers IDR teams experience, IDR leaders are uniquely positioned and required to manage the intellectual direction, interpersonal interactions, and logistics of an IDR team. According to TAMU's standard administrative procedure (2016), a PI is an individual responsible for "overall administrative, fiscal, scientific and technical direction and conduct of a sponsored project within the terms and conditions of the award and in accordance with University and System rules and regulations." Although this definition offers a roundup of the role and responsibilities of a PI, there are no guidelines by which X-Grant PIs are required to abide. Each PI therefore conceptualized his/her role differently; however, there were some overlaps and commonalities in how leaders characterized their roles.

The theme "PI Role" captures interviewees' perceptions of their function and responsibility as the leader of an X-Grant project. I classified the 28 codes associated with this theme into three broad categories: Thought Leader, People Leader, and Project Manager.

Participant H described the different hats one has to wear as a PI, stating:

> *"It is conceptual, it is budgetary, it is management. But it is also trying to really use this as a way to leverage and raise up each one of the members on the team as well. And I guess the third is also someone who's more forward thinking. While the postdocs and the graduate students are kind of toiling away and doing their task and we are pushing things forward to get it over the line."*

In Table 7, I provide an overview of the thought leader, people leader, and project manager categories, along with the sub-themes or codes associated with each of them.

Table 7

Data Analysis: Three Dimensions of the IDR Leader Role

Role	Sub-themes
Thought Leader or Managing Intellectual Direction	• Envisioning Goals and Strategizing • Integrating Knowledge from Different Disciplines • Recruiting Team Members • Tracking External Grant Opportunities • Conducting Research and Learning

People Leader or Managing Interpersonal Interactions	• Creating a Positive Team Culture
	• Providing Support to Team Members
	• Mentoring
	  ○ Junior Faculty
	  ○ Students

Project Manager	• Tracking Milestones • Leading Meetings • Planning • Coordinating and Communicating • Managing Budgetary Responsibilities

Thought Leader

One of the most critical roles of a PI is leading the technical and research directions of a team, which includes decisions regarding the project's vision, scope, and data collection and analysis. Because several themes fall under the broader category of the thought leader role, I explore them individually in this section. These themes include envisioning the goals of a project and strategizing, integrating ideas and perspectives,

recruiting team members, tracking external grant opportunities, and conducting research and learning.

Envisioning the Goals of the Project and Strategizing

By establishing a project vision, individuals in an organization provide themselves with a roadmap to meet common goals (Marquis, & Huston, 2015). During the interviews, all participants shared their vision for their project. However, I only present a few quotes to offer a glimpse into the IDR leader role. PI C shared having a "10-year vision" for the X-Grant project:

> *"What we are really trying to do is build a workflow in a way that can be applied in multiple places. What do we need in order for all of our stakeholders to be able to: 1) share their data across them and their expertise? 2) how do we utilize everything so that we can make better decisions? We really want broad engagement and have as many stakeholders as possible at the table, not just scientists; and 3) the third section is having these workshops where everybody can bring their own expertise and tabulate what evidence and information are available and ask how can we make it compatible [to our project]."*

Another participant said:

> *"We would like to have a major center level activity, a Center of Excellence, focusing on materials discovery because I think we can do really well. It is a confluence of Manufacturing Center, the Manufacturing Systems Institute, the Data Science Institute on campus, as well as Materials Institute. If we bring these*

three clusters together, there are some very interesting possibilities that can be engendered."

Participant B remarked:

"We found that when we all got together and tried to envision what a proposal might look like, the outcome was always a multi-project kind of program/ grant. When we brainstormed that, we knew that we have to be NIH funded before even looking at a multi-component program style grant. Some of us were funded externally through one mechanism or another (NIH, NSF, DOD), which made putting together a program grant a little bit difficult. For P30 project grants, we know from experience that you really need to have that, a kind of a locked to loaded funding history before you even apply. We backpedaled and decided to form subcommittees to generate meaningful proposals and that would break through that initial hurdle."

While vision communicates the goal of a team or organization, strategy outlines the concrete steps that the team will take to achieve the vision. If vision explains the "what," strategy outlines the "how." According to one PI:

"In terms of strategy, one of the things that I try to do is to melt or bring together the big ideas from each individual field. For example, [team member X] who is a materials expert, thinks about materials five - six years down the line. Similarly, [team member Y] gives us the idea of what should be the next focus on Artificial Intelligence based methods. I try to bring this from the manufacturing standpoint. So, the idea is to combine these frontier parts from individual disciplines to put

together a, weave together a common strategy. I think it is an exciting as well as challenging part of strategization."

Another PI developed strategies by conducting "coordination meetings":

"Specific to the X-Grant, we would have coordination meetings basically to decide, here are the projects that we have seeded. Where are they now? What are the outcomes looking like for those things (applications)? What projects do we want to fund next in terms of investments of small amounts of student support?"

Participant F gave us a sneak peek into the team's strategy. After having the proof of concept, the next step would be to "bring professionals from kinesiology and start recruiting participants" for further study. "Then, the next step would be, I think, to start thinking about how you manufacture these things cheaply."

PI H discussed what these intellectual decisions may involve. "I have different hats, right? I think conceptually, I'm kind of the conceptual leader in this project. I see and understand the different pieces that are involved [in the project] and try to keep those moving. So, it is really that big picture role of making sure that all of our objectives are being attended to and we've got the right people working on them and they are making progress."

Integrating Knowledge from Different Disciplines

As a team leader with members socialized in multiple fields, it is the duty of the PI, or the leader, to integrate. To integrate is "to combine two or more things in order to become more effective" (Merriam-Webster, 2020). PI F concurred with the idea

that leaders are not just integrating different types of expertise, they are also integrating different types of thinking.

Respondents pointed to two facets of integration: making decisions about the scope of their X-Grant research projects and exploring conceptual commonalities. Because of the range of questions ID teams can investigate, deciding on the scope of a project and its boundaries is time- consuming. Participant C recounted: “When it is a social problem, it [the scope] is endless. So that's why every time we talk about it, we are like, OK, so where do we stop?”

Another participant, D, utilized meetings and workshops to brainstorm ideas and integrate different viewpoints to determine the team’s research direction:

> *“We spent a lot of our time kind of focusing on running collaborative workshops to develop and think about these big ideas and the challenges. Our major partner in most and all of these projects has been [a university located in the Northeast of United States]. We would hold online workshops. We would present on the research, talk about the ideas and think about how we can tie these questions together. What are the big questions? What's unknown? That helps kind of define who needs to be on our team, but also where the interesting questions are.”*

Despite F’s prior experience with IDR projects, he stated that the degree of integration for this X-Grant project was higher than expected:

> *“I was talking about a project that I've had with somebody from linguistics for a number of years. To some extent, we could operate in parallel. At the end, we have to integrate both efforts. But it was not that high level of integration that*

I've seen on the X-Grants, where integration happens every week. At least at this point, if you talk about year 1, it was a bit more decoupling. But in year 2, the integration, the crossing bridges from one discipline to the other happened every week."

During the course of the X-Grant, F's team spent more than three months "trying to figure out" a problem. This issue required all team members to come together, said the PI:

"It is built into the project that members have to be able to work together because, like I said, the materials sit on top of optical circuit and wait until the optical circuit is designed by somebody in the process. The three pieces have to be put together. We have to make sure the parts work together. If the team that was developing the optical circuits on the chip is not talking to the students developing the materials, we will not have results."

To familiarize the team to new disciplinary cultures, languages, and equipment, participant G took the team on department and lab tours, in an effort to introduce individuals in the team to the labs of other team members. During the interview, PI G shared pictures from the lab tours, commenting:

"[The goal is] to get people used to an ID culture and the different types of things that are precious to a particular discipline. My team, we are all touring and getting tours of their [other team member's] equipment, X-ray diffraction spectroscopy units and also about bond stretching and things like this. It is getting us to each other's nomenclature, language, I felt was really important."

Another participant said crossing over to talk to one of the team's engineers (X) was the hardest bridge to cross. However, this interviewee continued that another engineer on the team ("a systems guy") helped translate certain discussions. The responded added that the challenge, per se, is not with this team member, but "with engineering as a whole [because] we are looking at a question from a social science and political, economic, social dynamics and institutional approach, where technology is critical."

> *"Technology is really important to understand, there are limits to what can be done and that it bears on regulatory regimes and legal constraints. And that doesn't change for [team member X]. So, it is been harder to integrate [X] in these other questions because [X] already had the technology. There's been some interesting challenges around trying to look at a question from the approach that we are all trying to think about it. We don't want to default to say, and therefore [team member X's] solution is what we should do. It is always been a balance of like how do we have those conversations which are inclusive, but not determinative to a one technology solution outcome, if that makes sense."*

Recruiting Team Members

Recruiting team members with the desirable expertise and social skills is a critical role for IDR leaders. In addition to envisioning the research goals and methods, leaders are required to develop and build networks since having the right individuals on the team can influence the degree of integration (Salazar et al., 2012).

Team member recruitment showed up around 30 times in the data set, making it one of the most frequently occurring codes. PI F detailed the need for the right expertise on an IDR team:

> *"This is the most complex project that I've ever been involved in, because you need somebody [who] needs to know about how light interacts with matter, somebody else needs to know how different, how to deposit different chemicals, somebody else needs to know how to get light in and out of [a] device, somebody else needs to know how to understand the signals that are coming out of the device."*

Some respondents leveraged their existing professional network to gain the expertise needed on their team, while others established new connections with individuals from their team members' networks. A few PIs even reached out to previously unknown individuals for the first time. A response from H illustrated the different ways in which PIs recruited their team:

> *"How do we get people together? It was initial discussions around people that I had known, right? Academic acquaintances from campus. After that, it became targeted outreach to scholars on campus who may have a skill that we need to bring onboard."*

One participant's professional network is not yet well established, in the interviewee's own words. The leader noted that senior members of the team came to the rescue and introduced the respondent to several researchers in their networks.

"The X-Grant program came just a couple of years after I joined. And so, I didn't really know a lot of the people. At that time when they announced the first round, I essentially started talking to people that I knew from my department and then essentially reaching out to collaborators [who] were already there. Then, seeing where the gaps are, what do we need filled. Team member A is leading [a center], and had already worked with B before, who then introduced me to the whole computer science group at that time."

Seeking specific areas of expertise, Participant C scoured TAMU departmental websites, cold-calling and emailing faculty members who might prove a good fit for the team: "I didn't know many people on the team personally. I just cold called them because of their expertise and hoping it would work. I would go on department pages and scroll through faculty and look for keywords and things like that."

In contrast to Participant C, PI A had worked with the majority of the team before.

"I would say about 80 percent of our team, we have been working with each other on one occasion or the other. We trusted each other and respected each other's capability and expertise. So, when we sat together, we figured out what are the gaps in terms of disciplinary expertise that are needed to address this effectively. We essentially looked around as to who within our A&M system could be best equipped. And, we found the right set of people with the right expertise."

Tracking External Grant Opportunities

Among the many tasks PI undertook, the most frequently mentioned was tracking external grant opportunities—an activity noted 39 times in the dataset. It is

important to note that external funding is an important metric for faculty when their applications are reviewed by their P&T committees. The quality and impact of their research is evaluated using two factors: i) publications in refereed journals and books, and ii) the acquisition of federal or external funding (TAMU Dean of Faculties, 2020). In the words of H:

> *"Going back to the question of what's the role of a PI? I think it is also the role of me to look forward and to identify what are those next opportunities that we need to think about and move into once the funding is over? So, that's been definitely on my agenda and we've been pushing that forward."*

When discussing what an X-Grant leader role entails, F said:

> *"Making sure that we are making progress, making sure that meetings are productive, keeping an eye on publications, keeping an eye on funding making students understand how what they are doing is impacting or affects or interacts with what everybody else is doing."*

Another participant was quick to mention that a high priority goal is to seek external funding:

> *"The immediate goal, I will be honest, is to get external funding. Commercialization will be the next one. I think those are the main two. Center-wise, I think we are still early in the process that in terms of the next one, two years, I'd say that's, that'd be jumping too many steps at once."*

Participant D acknowledged utilizing an X-Grant as a launch pad for larger grants:

> *"We had to submit for one of the smaller X-Grants, really to kind of pilot some initial projects, but at the same time, we also focused our team on going after some very large sector grant proposals. And really, we spent much of the past two years writing a lot of really big proposals, some of which has successfully been funded. We are happy about that by that outcome."*

Several principal investigators perceived X-Grants to be pilot projects, which they can use as springboards to seek external grants, such as those funded by the National Science Foundation, National Institutes of Health, and the Department of Defense, for example. PI A's team actually factored grant applications into its timeline, indicating that the team valued and sought to apply and receive external grants.

PI B commented:

> *"Our understanding of the premise for the X-Grant program was to generate a sustainable consortium that could be funded long term. Initially, we thought we could jump straight in and generate a really good large multi-component grant. But when we looked at it, the logistics weren't looking good in that respect. We just got to get a couple of R01s in the bank before we move forward with the big stuff."*

As of November 2020, the eight X-Grant teams were awarded more than 30 external grants with sponsors ranging from Engineering Research and Development Center to National Institutes of Health, National Science Foundation, and Department of

Defense. While the total amount of funding exceeded $29 million, individual awards ranged from $25,000 to $6 million.

Conducting Research and Learning

Even though PIs facilitate and lead discussions about the research and technical directions of their teams, one participant reminded me that leaders are researchers first and must conduct their own research, as well:

> *"I also have my own segment. I am a mostly a hardware and data type of a person. The whole project would be implemented on the machine that I manage. We have a 3-D printer, where we can actually synthesize materials and we actually will be able to create tools for automating the latest operation from this mission, so that the new recipes that are autonomously generated through a computer can be executed on our machine."*

Leading IDR teams also provide PIs with chance to feed their scientific curiosity—a benefit participants noted is a "perk" of their roles. Such opportunities enable leaders to engage in learning new methods, ideas, and ways of conducting research. One PI stated:

> "*I get to learn about new methods and new conceptual framework that I may not have had time to engage in previously or had the depth of knowledge to truly understand. It allows for that learning between people. I think from an intellectual standpoint being, just generally curious person, being able to have these conversations with colleagues and learning about systems dynamics model, which I hadn't thought about before, but now I'm incorporating in something else*

I'm doing. It allows me and others as well, to force more thought about how to communicate our ideas, so that we are clearer with each other."

People Leader

In addition to managing the role of thought leader—as illustrated in the previous section—respondents listed working with, supporting, and mentoring team members as key responsibilities of IDR leaders. Besides managing meetings, one PI remarked that a critical part of the leader role is ensuring that "everybody [on the team] has what they need to perform their components of the project." Another participant stressed the importance of developing human resources:

"We are developing that human resource all the time, in every meeting. That is critical for me. My philosophy is that, especially in social science, I don't know what it is in engineering, people are central. And so, we need to have good people and mentor people and keep our human resources trained and advancing in their own careers, right?"

Creating a Positive Team Culture

PI G added that the X-Grant project is not just about the science:

"It is important to realize that it is not only about the science, it is also about being careful to make sure the team members are respected and heard and included because that will help everybody want to work with each other."

One PI incorporated team members' feedback of having informal mixers:

"They [the team] suggested to me that I should actually have more informal mixers, as PI, to unite them or maybe go out. We were a pretty intense group and

we had a lot of meetings. Toward the end, some of them asked for pizza. So, I started to bring in and order pizza for the meetings. We probably should have had more, a little bit more play time."

Mentoring Junior Faculty

A salient dimension of the "PI role" theme was that of mentorship. Every respondent alluded to the importance of mentoring junior faculty and students. According to one participant: "I also feel like, as PI, I'm a mentor to everybody. I'm a mentor to the postdocs, graduate students, undergraduate students and even my colleagues who are earlier in their career than I am. That's important role and I'm happy to do that."

Participant A consciously roped in some junior faculty into the X-Grant team to address specific gaps and challenges in the project. Inviting junior faculty, the participant noted, was an excellent way to expose them to IDR, so "they [junior faculty] are better off executing grand challenges."

PI B recommended that junior members initiate conversations with senior faculty in mixers and that they steer the conversations where there is common ground.

"I tell junior faculty to start networking now. If you are in a mixer or on the CPI [Council for Principal Investigators], talk to someone who is doing agriculture [in a field different from yours]. Just dig a bit deeper. You never know when something comes up."

PI D, when meeting with junior faculty, offers suggestions on how to move their ideas forward: "At least in the college, I was meeting with all of the junior faculty once a

year, everyone always brings up something about T-3 or X-Grants. And so, there are folks who have talked to me about their experiences, folks who want to participate in it have asked kind of, well, what do I need to do to get, to get going?"

Another PI noted that by mentoring junior faculty, senior members in the team have been able to illustrate the expectations and requirements involved in putting together IDR projects:

> *"Because leading these types of larger proposals is a serious effort, not just on the part of the PI, but on the part of all of researchers, we try to get our junior faculty off the ground by getting their funding set up, getting their individual projects going, and having opportunities where they can begin to work in a team environment."*

While all PIs indicated taking active steps to mentor junior faculty, some PIs, who themselves are junior faculty, commented on the mentorship they received from senior members of their teams. While having a mentor is considered vital in the home department, PI C remarked that finding a mentor had to be an organic process. The X-Grant project, according to the interviewee, presented an "opportunity to find people I can work with, learn from, and who also appreciate where I'm coming from." The PI added that "there are a couple of people on this team that I definitely look up to for advice and as mentors."

Another PI was surprised to receive mentorship as part of the X-Grant experience, describing the opportunity as a "big plus." The respondent added:

"That [having a mentor] was unexpectedly a bonus because I needed that kind of mentorship, which is not easy to get in my department because our department is [not traditionally established in the academy]. To get that kind of mentorship from these full professors who helped us apply for NSF grants, was a big plus. And I really appreciated the fact that they took it very seriously and really guided me."

Mentoring Students

Instead of solely focusing on meeting team goals, PI H captured the salience of mentoring students and helping them meet their professional goals:

"Our postdocs and students are making progress not just towards the objectives of our program, but are also achieving their own professional objectives. So, we try to make sure we have a dialogue with them to integrate those together, to meet those joint goals together."

One X-Grant leader has been "rolling up sleeves" training some students. This PI cited an example of devoting a whole week to training an imaging student in cell biology. Because the student had never done a partition culture before, the respondent trained the student so that the student "can speak the same language" as those engaging in cell biology. The PI's driving force "is to take people along with you, train students and then watch them flourish down the line."

PIs A and G encouraged students to present their research before their IDR teams. Training students to speak in an ID setting enabled them to be mindful about presenting their research, using jargon unique to a particular field, and understanding

disciplinary boundaries. Similarly, participant F—who spent three hours a week with students—regularly asked them to prepare an experiment. F recalled guiding them through the process by asking questions and offering suggestions: “What would you do next? What does this [experiment’s] result mean? This is how you present things in a way that is easier for everybody to understand.” The PI continued: There's a balance between telling what to do every step of the way and letting them figure things out on their own and then helping them understand what the data they obtained means.”

Besides training students, some PIs empower postdoctoral scholars to mentor undergraduate and graduate students, which they term a “win-win.” The PI explained: What the postdocs have done is engaged with the DeBakey program on research on campus, which is a training program for undergraduate students. It gives postdocs an opportunity to train and guide undergraduates. I don't need to do too much supervision because they [undergraduate and graduate students] are well supervised by the postdocs.”

Project Manager

Project management involves initiating, planning, executing, monitoring, and completing a project (Project Management Institute, n.d.). Project managers have to pay close attention to project time and cost (Project Management Institute, n.d.). Several respondents indicated that a key part of their role involved project management, including monitoring milestones, leading meetings, planning, and coordinating.

Tracking Milestones

Because PI H juggled many roles, this participant relied on the team's postdoctoral scholars to develop and manage the work plan, including internal deadlines and deliverables:

> *"I'm not going to take on the project management role myself. When it comes to decisions around finances and allocation of resources and planning, yeah, that's what I do. But organizational stuff, notes like agendas, I give to the students. We've taken what would be one person's job and just like divvied it up amongst the group."*

While one team member organized the team's Google Drive, ensured that the agenda for meetings were up-to-date, and created an "underlying organization as to how we operate", another postdoc worked with undergraduate students and made sure they met the team's targets and deadlines. The third postdoc mentored students and communicated with the team's external advisory committee, in addition to transcribing interviews. Although the work plan was detailed and had many components, it was also flexible to accommodate for life events, added the PI:

> *"For example, last year, one of the postdocs had a baby, so she was out for a while. We just did some rearranging and reallocation. My view is, is that if everyone does one thing or has a set of tasks to run project management in their portfolio, it is not just on one person, but on several, then you have more flexibility when life happens."*

Another PI cited the example of a project management in the world of construction vis-a-vis academia and commented that some disciplines and team members may not be used to and be comfortable with a detailed GANTT chart, a tool used for project management:

> *"In the world of construction, [there] tends to be a pretty laid out GANTT chart with milestones. I set up some milestones at the beginning of a project using a collaborative scheduling exercise with Post-it notes on a wall on a big horizontal sheet of paper. It comes from my background in project management, where we always have a thorough documentation of everything, but, and I realized in academia, the team wasn't always so enthusiastic about that."*

Leading Meetings

As project managers, PIs engage in scheduling and leading meetings. Due to the inherent cognitive incommensurability (Kaplan et al., 2016), finding commonality and a point of convergence may be difficult. As a result, team meetings provide the opportunity to engage with team members from other disciplines. Respondents explained that meeting types varied according to purpose:

> *"We have different kinds of meetings. When we first started, we had—we call them—all hands meetings, which meant everybody in the project would meet in a really big room. And then, as we started to move towards research activities, we would have smaller meetings depending on the research objective. Not everybody would be at those meetings. Whoever is on that task, they would meet."*

Participant E alluded to conducting a lot of meetings, which was another common strand across the X-Grant teams. Meeting often could give members time to converge, integrate knowledge, and communicate about their plans and updates. In Participant E's words:

> *"We have a lot of meetings and there is lots of coordination. From the standpoint of just the X-Grants, we would typically have about four coordination meetings a year to focus on project outcomes, goals, targets, proposal outcomes. A lot of this is also done offline because once we've laid out, okay, who's going to focus on what the coming year, then the PIs will carry that forward."*

Participant D recounted the mission of coordination meetings:

> *"We would have coordination meetings basically to decide, OK, here are the projects that we have seeded. Where are they? What are the outcomes looking like for those things? What projects do we want to fund next in terms of investments of small amounts of student support?"*

In addition to participating and leading team meetings, PI G also had a thorough documentation of meeting minutes, which would later be combined with pertinent graduate student notes.

Planning

According to participant B, X-Grants are a multi-component grant with many moving parts. Because of the nature of IDR projects, participant F stated that project management can involve weeks of planning. As noted previously in this chapter, one participant highlighted the issue of progress occurring at different rates. Because the

notion of time and progress are perceived differently across disciplinary lines, the PI noted having to engage in weeks of planning: “When you are dealing with algorithms, progress takes days to weeks, depending on the complexity of the algorithm. However, in qualitative research, progress can take weeks or even months.” Furthermore, when the team is trying to execute a novel idea, the PI wants to “cross all the T's and dot the I's before I go down that path.”

Coordinating and Communicating

Several PIs mentioned coordination as a key function of their role. For instance, in Participant A’s words, in addition to managing team performance, “I do a little bit of coordination.” While coordination means different things, it is “the organization of different things or people so that they work together” (Merriam-Webster, n.d.). PI E rather lightheartedly referred to having many meetings: “we have a lot of meetings, [laughs]. There's a lot of coordination. From the standpoint of just the X-Grants, we would typically have about four coordination meetings a year to kind of focus on project outcomes, goals, targets, proposal outcomes.”

As most X-Grant teams operate in subteams, the responsibility falls on the PI to coordinate tasks and communicate information. To coordinate and ensure that different pieces of the project work together, it is vital for PIs to communicate—a point stressed by Participant E. PI E argued that subteams have to communicate with each other. If not, “the team will not have results.” The interviewee’s team spent close to three months trying to understand and find solutions to a problem. The team did not know if the problem was with subteam A or B. “It turned out it was in between,” added the PI. In

the example the participant discusses, communication was critical; without it, the team would not have been able to identify where the problem lay. The PI continued: “These projects never work if the individual disciplines were not communicating with each other.”

Recognizing the salience of communication in an IDR team, another participant jokingly said, “Not only do we meet as a team every week, but we also live on Slack [a communication app/tool]. Everything is in Slack. We have a lot of really good lines of communication. If there's anything about the way I run it, it is that we don't lack communication.”

Participant E aptly commented that “the main thing is just trying to get communication across the groups. For the most part, actually our groups were pretty independent, like many people are just kind of doing their own thing. With 10 + faculty, it is hard to get everyone together. So early on, we had several team project meetings [with all team members]. But then recently, everyone's kind of been doing their own thing. And so, we've just been communicating by email after that.”

Participant C confessed that a key leadership responsibility is to “keep everybody up-to-date about what different subgroups of the X Grant group might be doing. And also, to keep inviting everybody to participate in one aspect or the other of the project. As a result, I do a lot of coordination. That's one of the things I like about being a faculty and doing research is that, yes, I can do stuff in my own vacuum, but it is so much more interesting to bring people together and work as teams.”

The PI further added: Well, I feel a duty to my team to keep them in touch with what we are doing. We are not working very closely altogether all the time. And so sometimes months can go by and I realize, oh, I haven't really talked to them. But it is always a reminder for me contact them and let them know what we are up to."

Managing Budgetary Responsibilities

Besides managing the administrative and technical direction of the team, respondents believed their role also involved managing the fiscal or financial aspects of a grant. H stated:

> *"Not only do I have to make sure the project gets done and that we are achieving our goals, I also have to make financial decisions, right? Like during COVID, when we couldn't do certain things, not only do we have to make an intellectual decision around our research activities, but I make a material one by deciding where the money goes. I have a budgetary responsibility, a fiduciary responsibility to make sure things are done."*

This participant further added that the project is international and involves extensive fieldwork: "We were able to do some of it, but we've restructured our plans so that I was able to move money over so that I can extend the postdocs."

Participant E said that because of the way funds were disbursed, the team's budgeting process did not work well. PI E explained that the funds were lumped together and given to the PI of each team. Because each team had subgroups, the PI preferred for the subteam leaders to directly manage sub-accounts for his or her group. "Other faculty

who had part-time grad students were supposed to use their account. I guess that was too much work for the accounting [department]."

Shared Leadership

In teams and organizations where the nature of work is heavily based on intellectual expertise, relying solely on a "heroic" leader is not adequate. Several scholars have suggested that shared leadership is likely to emerge in IDR teams (Lakhani et al., 2012, National Academies, 2005, Pearce & Manz, 2005). Because of the nature of IDR teams—which are not very rigid, and yet have a stable core—mature teams may be able to share the leadership role based on the problem at hand and expertise necessary to address it (Lakhani et al., 2012).

One participant explained the team's structure, noting that seven individuals provide "core leadership" for the X-Grant team:

> *"We have leaders from materials; computation; data science; other one from the controls and AI. There are many other people listed as part of our team and we made sure we involved all of them. This is actually a very dynamic group. Seven of us are core leaders. Others supplement some of our efforts. Depending on the need that a particular sub-challenge generates, we involve people for both meetings and to address those challenges."*

Participant D pointed to an advantage of having a shared leadership framework, adding that leadership functions and responsibilities do not come down to one person: "What's nice about having such a deep bench, is that it doesn't come down to a single PI. It comes down to the core team who can really carry all of these steps forward across

multiple agencies, entities, across the university, the different departments. I just feel, I've just been fortunate, that any of these folks can be PI."

Although PI F is the leader on record, the respondent recalled how the X-Grant was a team effort: "I am the PI on record. In a way, the manager, but this is a team effort because I can't tell [team member Y] how to do conduct material science research or [team member Z] how to work on nanophotonics. It is a distributed effort with four people [team member names] and myself. On paper, I am the PI, but I don't see myself as a manager.

Chapter Summary

In this chapter, I presented a summary of key findings in relation to barriers to interdisciplinary research and the role of principal investigators of IDR teams. I gathered the data from eight PIs of X-Grants, an interdisciplinary internal seed grant initiative, using semi-structured interviews. Interspersed with participants' voices are archival and secondary data from pertinent documents.

Respondents discussed several barriers and challenges to IDR. In accordance with the tenets of the social ecological model, I classified the barriers into five levels. At the individual level, participants expressed challenges concerning time, motivation, and a lack of systems view. Most barriers were concentrated at the team level. Interviewees encountered logistical difficulties, including identifying a common meeting time and managing geographical dispersion among team members. Some PIs faced intellectual challenges bridging distance between disciplines, communicating across disciplinary boundaries, and facilitating discussions around data ownership and authorship order.

Besides the logistical and intellectual barriers of the team members, participants expressed facing obstacles regarding recruiting, defining team members' roles, and delegating responsibilities and tasks, in addition to managing competition and student-related challenges. At the community level, participants pointed to challenges they encountered with regard to journal guidelines and career progression. Finally, participants expressed challenges they faced as a result of COVID-19 policies, leading to delays in their meeting deadlines, travel restrictions, methodological challenges, and decreased interaction with administrators.

I divided the themes relating to the PI role into three categories. The first role is intellectual responsibilities which involves envisioning the goals of the project and strategies to achieve the targets; integrating multiple viewpoints, methodologies, and ways of thinking; recruiting scholars and experts; tracking external grant opportunities; and conducting research. The second role involves facilitating interpersonal interactions, supporting team members, and mentoring junior faculty and students. A third facet of the PI role, concerning project management, refers to tracking deadlines, leading meetings, planning, and budgeting.

CHAPTER V

DISCUSSION AND IMPLICATIONS

Introduction

I organize this chapter into two sections. In the first section, entitled "discussion," I synthesize and interpret findings I reported in the prior chapter. Next, I present the implications of my findings on theory and practice. Although this chapter is dedicated to the discussion and implications sections, I begin by reiterating the purpose of the study, thereby anchoring my interpretations with the study's intent.

The purpose of this dissertation study is two-fold: i) to explore the barriers encountered by leaders of interdisciplinary research (IDR) teams, who I also refer to as "principal investigators" (PIs), and ii) to understand how PIs perceive their role. The following research questions guide this study:

1. What barriers (if any) do PIs encounter when leading IDR teams?
    a. How do PIs of IDR teams overcome these barriers?
2. How do PIs perceive and describe their role as leaders of IDR teams?

Discussion

In line with Goodson's (2017) conceptualization, I turn to scholarly work and literature in this section to address two key aspects: a) the meaning of my findings, and b) possible explanations for why a phenomenon occurred. Interspersed in my discussion section are recommendations for future research.

Salient Themes

The discussion section begins with an overview of salient themes. I characterize salience of a code or theme based on the following criteria:

- High density or frequency of occurrence: Codes which occur with a high frequency fall into this category. For example, as part of their PI role, all participants mentioned tracking external grants. Tracking external grant opportunities, as a code, appeared in the data 38 times. Due to the high frequency of its occurrence, I consider this theme salient.
- Uniqueness: In contrast to frequency, uniqueness refers to ideas that a particular participant discusses that no one else points to. I also define codes as unique if they are underexplored in the literature. For instance, one participant highlighted the challenges associated with data ownership in an X-Grant team. Data ownership in IDR teams has not been a topic of study in the published literature, so I consider this theme salient.

It is important to note that salience does not correspond to importance or value. Upon classifying a code as salient, I summarize the crux of the code and turn to literature in an attempt to understand why participants faced certain challenges and why they characterized their PI roles the way they did.

Time as an Individual Level Barrier

Due to the nature of faculty members' responsibilities—often involving research, teaching, and service—several participants struggled to find time or mentioned needing more time to lead their X-Grant teams. Although some prior scholars pointed to a lack of

time in IDR teams as a challenge, their notion of time was different from what emerged in my findings.

In the literature, scholars refer to not having enough time to complete a project as an obstacle to IDR teams. Researchers argue that IDR teams warrant longer-than-usual startup times because of the cognitive distance between individuals and the time it takes for team members to learn each other's disciplinary language (Boden & Borrego, 2011; Rekers & Hansen, 2015). In a National Academies Report (2005), scholars likewise contend that since IDR involves collaborating with individuals from different disciplinary languages and backgrounds, researchers may require additional time to build consensus and learn new methods of conducting research. Boden & Borrego (2011) also point to administrative holdups in the initial stages of an IDR project that can cause delays when waiting for facilities, offices, space, and funding to be assigned.

The reason behind the salience of this theme could lie in the fact that not many scholars have studied IDR teams in higher education settings. Studying the unique nature of a faculty member's role may reveal barriers hindering them from actively participating in IDR projects. One study conducted in a university setting found that time was an issue in IDR teams because all members were overcommitted in their personal and professional lives (Soltano, Meyer, & Larrivee, 2016). Time as a dimension associated with faculty members needs to be explored further in future research, especially because the interest in funding IDR projects is growing among universities (Jacobs & Frickel, 2009; Leahey, Barringer, & Ring-Ramirez, 2019).

Motivation as an Individual Level Barrier

With X-Grant team members—both students and faculty—taking on multiple projects and having other responsibilities to fulfill, some PIs noted that efforts to keep team members motivated and engaged for the entire duration of the grant was challenging. I classified this theme as salient because of its uniqueness.

The size and structure of X-Grant teams could contribute to this lack of motivation. Roughly 15 to 30 members make up a typical X-Grant team. As that number increases, new challenges are likely to emerge, especially with regard to communication and role delegation (Mäkinen, Evans, & McFarland, 2019). Though Mäkinen and colleagues (2019) did not link team size to member motivation, future studies could investigate that relationship in a higher education setting. The structure of an X-Grant team, based on participants' descriptions, consists of a few members at the core, and others at the periphery. Due to the large number of individuals and their varying roles and responsibilities, sustaining motivation of all team members seems like a tall order for IDR leaders.

Literature offers other explanations for low engagement and motivation in IDR teams. Edelenbos and colleagues (2017) point out that disciplinary differences could cause misunderstandings and conflicts, which, in turn, might lead to low levels of engagement. Additionally, clarifying team member roles and ensuring proper delegation of tasks among individuals could improve motivation and engagement (Edelenbos et al., 2017).

Ju and colleagues (2015) assert that researchers with high levels of engagement are likely to be excited in an IDR collaboration and, as a result, take on active roles both in team decision-making and in the project as a whole. Conversely, researchers with low levels of motivation may be inactive. Sustaining motivation of peripheral or inactive members could be more challenging than engaging active members.

Another significant reason for a lack of sustained motivation among team members is that most members work part-time on their X-Grant teams. Because individuals are involved in other research projects and have additional responsibilities to fulfill, sustaining their motivation on an X-Grant team could prove to be a herculean task for PIs, especially if these team members are inactive. Future research could explore how PIs engage their team members and determine strategies leaders can use to keep them engaged.

Lack of Systems View as an Individual Level Barrier

Participant F brought up another impediment to ID team success: a lack of systems view among team members. I characterized this theme as salient because of its uniqueness. To the best of my knowledge, scholars have yet to study this theme as an obstacle to interdisciplinarity.

Systems view is the ability to see how "a set of...parts are coherently organized and interconnected in a pattern that produces a characteristic set of behaviors" (Meadows, 2008, p. 188). In other words, it entails a holistic view or the ability to see how different pieces of a puzzle fit and work together. Although individuals on an ID team are required to operate from their disciplinary base, team members must be

acquainted with how different disciplines, methods, and ideas fit together (Bracken & Oughton, 2006).

Possessing a systems view is critical to those engaging in IDR, especially when interdisciplinary teamwork involves working in and with subteams. I recognize that team members, having been socialized in their respective disciplines, have differing perspectives, languages, and worldviews. Although some members may have the ability to see the big picture, others may be detail-oriented, as respondent F pointed out. However, it would be highly beneficial if team members understood not only how one subteam contributes to the larger vision of the project, but also how the work of all subteams is integrated and synthesized. Although only one participant mentioned "a lack of systems view" as a barrier, I believe that this theme warrants further research to ascertain whether or not this is a common challenge IDR leaders encounter.

Identifying a Meeting Time and Geographic Dispersion as Team Level Barriers

Another team-level barrier identified by participants is scheduling meeting times around conflicting professional and personal commitments. Only a few studies—including Salazar and colleagues (2012) and Soltano and colleagues (2016)—briefly underscore this challenge. Because of their uniqueness, I characterize these theme as salient.

The settings in which most IDR-related studies take place—research centers and institutes—could explain why this theme is understudied in the literature. As noted earlier, the faculty role is demanding and involves teaching, grading, research, mentoring, service, and so much more. Because faculty members and students are pulled

in different directions, finding a meeting time is, perhaps, a very common challenge in higher education settings.

The negative effects of geographical dispersion of teams have been explored in the literature (see Morrison-Smith & Ruiz, 2020; Kiesler & Cummings, 2002; Rekers & Hanson, 2015), but it is noteworthy in light of the COVID-19 pandemic. Rekers and Hansen (2015) state that geographical proximity in interdisciplinary teams facilitates social interactions, allowing individuals to meet, talk, and experience accidental encounters. In their review of the literature, Morrison-Smith and Ruiz (2020) came up with similar findings and maintain that trust is hard to build in geographically dispersed teams.

Working virtually may have its demerits, but during the Coronavirus pandemic, many organizations switched to operating virtually. Because of the ubiquity of virtual communication today, it may be valuable to study if geographical distance truly impedes IDR teams, specifically in terms of communication, trust, and team building.

Distance Between Disciplines as a Team Level Barrier

Because the challenge of distance between and/or among disciplines is rampant in the literature, I was not surprised when several respondents readily acknowledged the difficulties associated with this issue. Interviewees expressed three distinct themes contributing to this barrier: differences in paradigm and language, communication styles, and progress occurring at different rates.

In line with what my participants said, scholars note that paradigmatic challenges can add a layer of complexity to IDR teams (Aagard-Hansen, 2007; Bracken & Oughton,

2006; Daniels et al., 2007; Stein, 2004). Conflicting worldviews can lead to difficulties in generating a shared framework (Aagard-Hansen, 2007; Bracken & Oughton, 2006; Daniels et al., 2007; Stein, 2004).

Another factor contributing to distance between disciplines is language (Choi & Pak, 2007), particularly as it pertains to team members' distinct scientific training and backgrounds. Within the umbrella of language, the use of acronyms and jargon familiar to only those from a particular field can cause confusion to members from other academic areas. Bracken and Oughton (2006, p. 375) note that "language may determine the positionality of the researcher, the way in which the research question is framed, the translation of the 'field' to the academy and the development of the theoretical context." Therefore, when working in IDR teams, members need to consciously make an effort to define and clarify jargon.

One surprising element that widens cognitive distance is how disciplines and individuals interpret time and progress. Halvorsen and colleagues (2016) argue that IDR teams need to factor in issues relating to research and site during data collection and analysis because social and natural scientists complete their fieldwork (or data collection and analysis) at different times (Halvorsen, 2016).

While distance between disciplines has been explored in the literature, few studies have investigated the many dimensions of this specific phenomenon. Future studies of this topic can deepen our understanding of IDR teams and help to mitigate certain challenges by shedding light on the multiple aspects contributing to cognitive incommensurability (Kaplan et al., 2016).

Data Ownership as a Team Level Barrier

Data ownership is concerned with the possession and distribution of data and/or information (Loshin, 2002). Because X-Grants operate in subteams, one PI noted that team members had a sense of ownership over the data they or their subteam generated. As a result, some individuals believed they had exclusive rights to publish manuscripts based on the data they owned.

In large scientific teams—where subteams often collect different aspects of data—it is critical to have discussions around data ownership. For instance, a social scientist in an ID team may collect qualitative data, whereas a statistician may take the lead on quantitative data. In this case, does the social scientist and his/her subteam own the qualitative data they gathered? Or does the larger ID team own the data? Conversations around data ownership are vital and necessary, ideally during the initial stages of team formation.

Data ownership influences what stories teams decide to tell in a publication and where they publish. If a social scientist who "owns" qualitative data decides to submit his/her manuscript to a qualitative or social science journal, he/she will abide by authorship guidelines as outlined in the field. Adopting such a system allows researchers to work independently in subteams.

By working in silos, researchers can miss out on telling a complex and rich story—one that is possible when team members combine subteams' data with their own. Referred to as "sub-optimization" in the literature, this phenomenon occurs when each

subteam's pursuit of its own, separate objectives leads to outcomes that are overall sub-optimal for the team (adapted from Hood, 1976).

Authorship Order as a Team Level Barrier

Similar to data ownership, the challenge of authorship order was brought up only by a few participants. The role and order of authors varies across disciplines (Schuitema & Sintov, 2017; Wagner et al., 2011). One participant explained the "sequence of authorship [guidelines] being so different across fields" is a barrier to IDR. Citing an example, the PI noted that in chemistry, for instance, the last co-author is the often the corresponding author. Conversely, in social sciences and liberal arts, the first author is "the most important" contributor and also the corresponding author. To add to the complexity of varying authorship guidelines is the value attributed to single- and multi-author publications by different fields. A participant pointed out that in certain fields, having too many authors may also be a problem.

Debates around authorship in research teams are not uncommon (Dance, 2012). However, it is important for IDR team leaders to facilitate open discussions around authorship order and establish ground rules. For example, a team could co-create a guideline stating that "only people who actively contribute to the writing process" (Creamer, 2005, p. 42) will be listed as authors.

Recruitment as a Team Level Barrier

With teams setting out to find solutions to complex problems, team leaders are tasked with recruiting the right personnel to achieve the team's research objectives. In listing some obstacles to ID collaboration, participants mentioned "finding good people

to work with" and "finding good students and recruiting [team members] were challenges." Many authors have attested to the difficulties IDR teams encounter especially those concerning team creation (Campbell, 2005; Morse et al. 2007). Halvorsen and colleagues (2016, p. 315) suggest that these "challenges can be reduced through highly selective choices of diverse team members."

Because the composition of a team and its organization can make or break the research and team process (Choi & Pak, 2007), finding the right collaborators to work with is critical. Recruiting team members who have both technical *and* interpersonal skills can offset some challenges IDR teams face and enable team members to navigate disciplinary boundaries and norms (Halvorsen et al., 2016). The authors also suggest jump-starting the recruiting process by drawing on existing networks of colleagues.

Participants did not mention recruiting individuals based on interpersonal skills. Instead, most team members had worked together before. As noted in the previous chapter, some leaders leveraged their connections, while others harnessed the professional networks of their colleagues. Furthermore, a few PIs even "cold-called" or emailed colleagues with whom they had not collaborated before.

Role Definition and Delegation as Team Level Barriers

Role definition and delegation can be troubling for PIs and team members alike. These two codes are salient because of their uniqueness. For team members, confusion regarding roles and responsibilities can create role ambiguity, overlap, and competition. For instance, one interviewee pointed out that several members in the team knew how to scan with an electron microscope. As a result, the PI found it difficult to delegate the

task. The interviewee added that a lack of clarity regarding team member roles and tasks not only creates competition among team members, but can lead to a perception of being intruded upon by other team members, resulting in frustration and conflicts.

Youngwerth and Twaddle (2011) maintain that the absence of clear roles for team members is one of the most cited barriers to teamwork. However, it is important to recognize that intrinsic nature of IDR work often requires functioning with ambiguity, complexity, and flexibility. Due to its very nature, then, IDR lends itself to "role blurring."

Role ambiguity and competition can hinder successful collaboration (Youngwerth & Twaddle, 2011). Nancarrow and colleagues (2013) note that IDR leaders need to recognize how their own role fits within the team and differs from that of other team members. The authors urge leaders to make roles and responsibilities explicit to the team, although the task may be a difficult one. In the initial stages of an ID project, when leaders are beginning to understand different facets of the project, they may not have a clear vision of the role of each team member.

Participants likewise acknowledged that one of the major challenges they faced was figuring out "how to spread the workload," or delegate responsibilities, which contributes to a lack of role clarity. Muddied roles can lead to distrust and exclusion, which also impedes information exchange between subgroups.

Phenomenon of the Quick Expert and Competition as Team Level Barriers

One of the most surprising discoveries was the idea of "a quick expert"—a phenomenon explained in detail by Participant G. While, in actuality, it takes years for

an individual to become an expert in his/her field, G said, in the days of the internet, someone who has simply read up on a topic automatically considers himself/herself an expert. This practice is closely related to competition among team members and is relatively unexplored in the literature. As this interviewee pointed out, IDR teams could experience friction when experts who have devoted years of study to a topic interact with individuals who have spent considerably less time in the same field, yet speak authoritatively about a research area. This topic is worth investigating further.

Student-Related Barriers at the Team Level

While many PIs went into their X-Grant teams expecting challenges due to disciplinary differences, some expressed surprise at encountering issues related to students. When students in H's team would present in weekly meetings, for instance, they often forgot that the audience was interdisciplinary. Similarly, G expressed how students "would simply throw out words and acronyms," which often confused the rest of the team. The investigation of student-related barriers in IDR teams has been limited in the literature. Because of its uniqueness, I explore this theme further.

Other obstacles PIs experienced with students were competition and a lack of skills in mentoring fellow students. When students who are at the top of their classes come together in IDR teams, a sense of competition often ensues. One participant also observed that students were not great mentors. This participant recalled a time when a graduate student who was mentoring another student commented, "I don't understand how someone can just not get it." The PI noted that student often struggle to be mentors.

Soltano, Meyer, and Larrivee (2016) explored the experiences of undergraduate and graduate students in IDR teams. Although they discussed other challenges, faculty members in their sample did not seem to report challenges similar to those that my sample brought up.

Promotion and Tenure (P&T) Guidelines as an Institutional Level Barrier

A few participants commented that current P&T guidelines hinder how they approach and conduct IDR. One PI recounted that the department supplied an approved list of journals. If faculty published outside this list (like in an ID journal), the PI said, their contributions were not valued at par with monodisciplinary outputs. Additionally, one participant struggled to align "the university's agenda to become interdisciplinary" with P&T guidelines, which the interviewee considered unfavorable to IDR.

In interdisciplinary teams, individuals typically represent multiple disciplines. Upon obtaining proof of concept or results, IDR teams may seek to publish their research in "non-traditional" journals or journals that are not organized along disciplinary lines. In other words, members of an IDR team may end up publishing in a journal or field other than their own. Because P&T guidelines do not recognize and/or value ID work at par with monodisciplinary research, the contribution of faculty members engaging in IDR may not be fairly evaluated. Unfavorable P&T reviews not only discredit a researcher's contribution, but can also dissuade researchers from engaging in interdisciplinary projects altogether.

Scholars stress that tenure procedures are firmly entrenched and rooted in disciplinary ways of thinking (Mallon, 2006; Hein et al., 2018) and also highlight

challenges related to reviewers. Although tenure grants a faculty member job security, P&T processes represent acute barriers, making the pathway for tenure challenging for those participating in IDR (Hein et al., 2018). Several universities have made an attempt to represent multiple disciplines in a P&T committee, although evaluators often mirror the expectations of an "established discipline rather than an emergent field" (Borrego & Newswander, 2008, p. 5). Reviewers who do not see the merit of IDR often devalue research and intellectual contributions lying outside the purview of their discipline (National Academies, 2005). Furthermore, Borrego and Newswander (2008) point out that reviewers are so used to valuing individual achievement and contributions that they might not appreciate cross-disciplinary collaboration. The authors describe this mindset as "unfair" due to the amount of work and effort required in cross-disciplinary research.

Another issue associated with P&T reviews is the hierarchy, or structure, of review. P&T review begins at the departmental level and moves to the college and university level, with both faculty and administrators charged with reviewing a faculty member's tenure application. Even though the TAMU P&T guidelines are conducive to IDR work, solving the problem at the departmental level is not all that is required, but does seem to be the most important step in the chain.

P&T committees must consider how to quantify contributions to team science and the alignment of departmental-, collegial-, and university-level P&T guidelines. Due to the complexity of this topic, I believe P&T guidelines in IDR could be the focus of a study in itself and could provide insights into how universities' P&T systems are adapting (or not) to reviewing IDR.

Resources as an Institutional Level Barrier

As IDR teams are finding new and creative solutions to society's problems, having the right resources to conduct an experiment, for example, is critical. One respondent experienced "lots and lots of issues and hurdles" when trying to contract out services to a new company for a specialized type of data. After long delays, when the team finally received the data, the information was not useful. As a result, the team had to develop new algorithms from scratch to rectify their problem. Another X-Grant leader recognized a similar barrier and noted that the team had been facing challenges "related to resources."

When scholars refer to resources as a barrier, they point to funding opportunities and (increased) time or duration of a grant as resources that facilitate IDR. Unlike disciplinary research, which is well supported by structures and systems in universities, interdisciplinary research does not have the necessary support from academic units and university systems (Boden & Borrego, 2011; Rekers & Hansen, 2015). Rosenfield (1992) notes that teams are more likely to transcend disciplinary barriers and develop an understanding of other disciplines if continually supported and funded.

A few researchers noted that when team members do not share a common building or office, difficulties in finding a space to meet (Boden & Borrego, 2011; Rekers & Hanson, 2015) can impede knowledge creation and integration. The duration of a grant, funding opportunities, and a shared meeting space are crucial elements to consider in an IDR setting. However, my participants also expressed a different

dimension—one related to equipment and technology access to successfully conduct their research—which warrants further investigation.

Journal and Career-Related Barriers at the Community Level

Participants discussed two key barriers at the community level: unfavorable journal guidelines and career challenges for junior faculty and students. The topic of unfavorable journal guidelines has been touched on in earlier sections. However, considering it is an integral part of the academic community, I explain further.

Scholars have extensively discussed how journal guidelines are not conducive to early career researchers and ID researchers, hindering career opportunities, as well. Publishing in highly sought after journals can be difficult for all academics; however, the challenge of publishing IDR is greater because journals are typically organized in a disciplinary fashion (Schuitema & Sintov, 2017) and target specific audiences (Lau & Pasquini, 2008). Moreover, not many journals value IDR publications (Lee, 2006). Scholars go as far as stating that journals encouraging IDR are rare and are generally perceived to be of lower impact (McNeill, García-Godos, & Gjerdåker, 2001; Lau & Pasquini, 2008; Rafols et al., 2012; Schuitema & Sintov, 2017).

Journals that seek IDR publications struggle to evaluate the articles they receive (Lau & Pasquini, 2008). As opposed to monodisciplinary journals, which require reviewers to be knowledgeable about a discipline or related disciplines, IDR not only requires experts from all involved disciplines, but also requires those who understand how these different disciplines are integrated (Schuitema & Sintov, 2017). As noted in Chapter II, biases against IDR are not limited merely to peer-review processes, but are

also evident in how journals are ranked (Rafols et al., 2012), which according to Van Noorden (2015) suppresses the citation impact of IDR outputs three years after publication.

Because monodisciplinary pursuits are rewarded and incentivized (Hein et al., 2018; Rijnsoever & Hessels, 2011), early career scientists have a higher number of monodisciplinary research outputs (Carayol & Thi, 2005; Hein et al., 2018; Rijnsoever & Hessels, 2011) and perceive their participation in IDR as a career risk. In academia, Mallon (2006) highlights the presence of conventional wisdom, which dictates that junior faculty wait until they are tenured to pursue interdisciplinary research projects Frickel and Gross (2005, p. 211) explain the reason behind the conventional wisdom: "[W]ith proven track records in research and the security of tenure behind them, established scholars are in possession of more scientific and social capital to invest in [a new interdisciplinary field] than either younger or less distinguished colleagues."

The perception of IDR as a hurdle to early career researchers and faculty could also be attributed to a traditional academic reward structure that values and rewards monodisciplinary outputs. Because of this widespread prejudice against IDR, junior faculty and early career researchers perceive such interdisciplinary pursuits as a risky move for their career progression that leads to difficulty in obtaining tenure (Hein et al., 2018; Rafols et al., 2012; Rijnsoever and Hessels, 2011).

Along with the impact on early career researchers and faculty, participants mentioned potential career-related barriers to IDR for graduate students, as well. One participant posed, "If a doctoral student in chemistry has published in architecture

journals, how will this affect the job search?" Most often, universities require candidates to demonstrate their grounding in a field or fields. Many participants shared a concern that research unrelated to the hiring department's core discipline might be discounted during the review process, which could deter graduate students from participating in IDR projects.

Challenges related to the Pandemic at the Policy Level

At the policy level, participants shared barriers they experienced because of the ongoing COVID-19 pandemic. Originally, I did not intend to explore this question in-depth because I was unsure of its relevance to my research question. However, with each interview, I began to see an emergence of distinct challenges participants and teams were encountering due to the pandemic and shelter-in-place restrictions. Participants mentioned several barriers in this regard: delays in timeline, travel restrictions, methodological challenges, lack of access to labs, and less interaction with administrators. My policy-level findings regarding COVID-19 relief are a critical contribution I make to the literature because scholars have not focused on using qualitative methods to study the challenges faced by researchers as a result of the pandemic.

Complexity of the PI role

The PI role is complex and requires leaders to manage several aspects of the project. This includes developing an idea, envisioning the aims of the project, recruiting the right personnel, taking lead during the application process, managing the budget, leading meetings, integrating and facilitating communication between subgroups,

mentoring students and junior faculty, and ensuring the team is meetings deadlines. To better understand and structure the findings, I classified the IDR role into three themes: managing intellectual direction (or taking on the role of an intellectual leader), interpersonal interactions (or people leader), and project management (enlisting the role of a project manager).

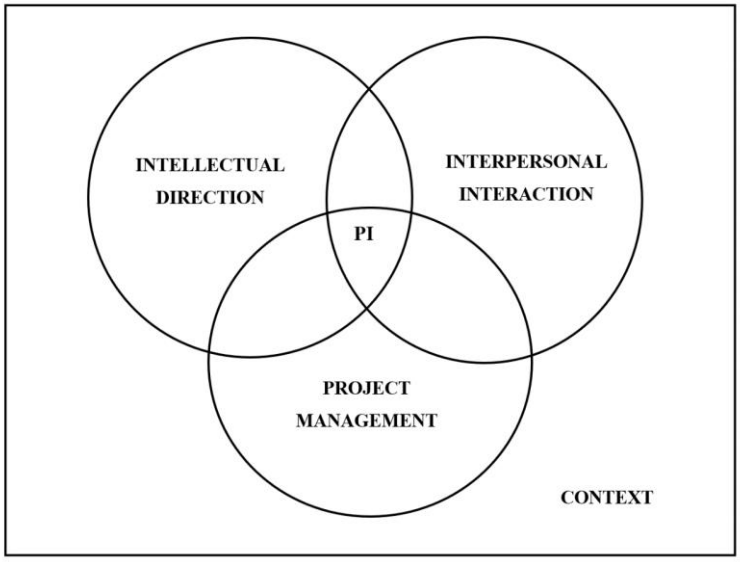

Figure 2. Relationships among themes associated with the PI role

Scholars have classified the role and responsibilities of a leader in many ways. For example, Zaccaro and colleagues (2001) discuss how leaders influence four team-related processes: cognitive, motivational, affective, and coordination. Gray (2008) groups a leader's tasks into three categories: cognitive, structural, and processual. Yukl (2012) classifies leadership activities into four areas: task-oriented activities, relations-oriented activities, change-oriented activities, and external activities. Benoliel and Somech (2015) categorize leadership activities into external activities (acquiring

resources and monitoring the external environment) and internal activities (managing processes occurring within the team).

König and colleagues (2013) conceptualized four dimensions of IDR leadership: i) facilitating an ID culture; ii) creating an open system; iii) managing research outputs; and iv) monitoring internal processes. Facilitating an ID culture involves mentoring team members and engaging in open dialogues around knowledge-sharing and communication (König et al., 2013). To nurture an open system, leaders are required to take on the role of innovators and brokers. When managing the research output dimension, an ID leader wears the hats of producer and director, guiding and monitoring research outputs. Tracking internal processes requires a leader to be a project manager and coordinator (König et al., 2013).

Managing Intellectual Direction: Envisioning and Strategizing

In addition to envisioning the objectives of their respective X-Grant teams, all respondents in my sample developed short- and long-term goals. Some participants saw themselves establishing a research center or institute five to ten years down the road, while others aspired to obtain "proof of concept" by applying for patents.

While I perceive vision and strategy as task activities to guide the intellectual direction of the team, some scholars believe envisioning is an integrative behavior (Salazar et al., 2012; Zaccaro et al., 2001) that helps a leader clarify project goals and identify strategies for communication and exchange of knowledge (Salazar et al. 2012; Zaccaro et al. 2001). An effective IDR leader must establish "a clear direction and vision for the team" (Nancarrow et al., 2013). Lanier and colleagues (2018) note that ID

leadership must also be abreast of the overall progress of teams, picturing not just the objectives, but also how team members may or may not work together. Besides envisioning research objectives and milestones, participants commented extensively about thinking ahead or looking into the future in regard to external grant applications.

The most recurring theme in my dataset was "tracking external grant opportunities", a theme that emerged in the data more than 40 times. All PIs believed that tracking and applying for external grant opportunities is an integral part of their role. The reason behind this code occurring at a high frequency could lie in the emphasis P&T guidelines place on obtaining external funding. A critical parameter when assessing applicants' research contributions are external grants secured from funding agencies. Furthermore, many PIs perceived the X-Grants as a pilot project or a launch pad to apply for external grants.

Although scholars have discussed the significance of vision, my findings indicate that this practice goes beyond simply picturing the aims of the project. Vision is a multidimensional concept that involves envisioning the objectives of the project, determining how subteams might integrate their findings, and, finally, "looking ahead" into potential external grant opportunities, centers, institutes, and/or patents.

Managing Intellectual Direction: Recruiting Team Members

After envisioning the idea for an X-Grant, participants proceeded to recruit personnel who possessed the right expertise to fill a knowledge gap in the team. Recruitment of team members occurred before the PIs applied for their grants, as they were required to indicate the names of collaborators in their application. Some

participants reached out to their existing professional networks, while others contacted academic acquaintances. One participant even cold-called/emailed scholars who demonstrated expertise and skills in a particular research area to close a knowledge gap in the team.

One participant expressed that TAMU is exceptional in its scope because "on one end of the campus, you've got a world-class veterinary school, and on the other end of campus, you've got a nuclear reactor." This range of expertise could present an opportunity to the PIs to invite and select a wide variety of experts. However, some participants indicated that they nevertheless found the recruitment process challenging.

Scholars acknowledge the importance of hiring the right personnel for a research team. Makris and colleagues (2018) cite the example of business leaders who admit that hiring talented people for the wrong roles was one of the biggest mistakes they had made. Distinguishing between the business and academic worlds, the authors posit that aligning team members' strengths with their roles increases individual satisfaction and reduces attrition (Makris et al., 2018). While Makris and colleagues (2018) suggest that PIs conduct interviews and elicit letters of recommendation, none of the participants mentioned using these types of formal processes.

In sum, although scholars stress the importance of PIs finding the right team members to work with, exactly how the PIs should recruit in an academic setting was not explored anywhere, making this topic worth investigating in future studies.

Managing Intellectual Direction: Conducting research

Because the PI role has many moving parts, it is easy to forget that PIs are as much team members as they are leaders. In addition to managing the many components of their X-Grant teams, an important part of their responsibilities involves conducting research. Some PIs recalled leading the research of subteams, thereby contributing to the overall research and knowledge of the team. This facet of the PI role has been woefully underexplored in the literature and needs investigation.

Project Manager: Managing Administrative tasks

A vital part of the PI role is wearing the cap of a project manager, whose responsibilities include tracking milestones, leading and managing meetings, planning, coordinating and facilitating communication among team members. Although some PIs indicated taking on the role of the project manager themselves, two PIs delegated the role to graduate students and postdoctoral scholars.

Even though several scholars acknowledge that being a project manager is a key task of PIs (Gray, 2008; Halvorsen et al., 2016; Carne et al., 2012; König et al., 2013), only Makris and colleagues (2018) recommend delegating the role to a project manager or research assistant as he/she may be able to help the PI with paperwork and delegation of tasks. A research associate, on the other hand, can help with research activities, data collection and analysis (Makris et al., 2018). As PIs must balance and juggle many responsibilities, Makris and colleagues' (2018) suggestions could prove beneficial for leaders.

Besides managing the administrative and technical direction of the team, respondents believed their role also involves managing the fiscal or financial aspects of a grant. Managing a grant involves making decisions around finances and allocation of resources and salaries, which only König and colleagues (2013) discuss.

Stedman and Adams-Pope (2019) note that a PI of an interdisciplinary team has to act as a manager and/or administrator. Halvorsen and colleagues (2016) concur, adding that an effective IDR leader is required to clarify tasks set deadlines for deliverables (Halvorsen et al., 2016). Similarly, Gray (2008) notes that the structural tasks of a leader include creating a system of accountability with regard to deadlines and deliverables, defining objectives, and recruiting team members. IDR leaders must recognize the challenges of IDR and, accordingly, work with their teams to identify responsibilities for each team member. In addition, the leaders must actively manage the team so that systems are developed and maintained throughout the life of the grant (Gray, 2008).

People Manager

An integral part of nurturing team members involved mentoring and supporting them. Mentorship at the IDR team level involves mentoring three sets of individuals: graduate students, postdoctoral scholars, and junior faculty. Considering the size of each team, mentoring the three groups can be enervating. However, leaders must continually adjust to their support based on team members' needs.

Every respondent mentioned mentoring junior members of the team. Having systematic one-on-one meetings with team members presents an opportunity to build and

nurture professional relationships, discuss project-related tasks, and mentor individuals (Makris et al., 2018). In line with Makris and colleagues' suggestions, several interviewees indicated having regular one-on-one meetings with students in an attempt to check on the progress of team publications and mentor them.

When meeting with junior faculty, leaders sought to determine how the project could best help young faculty professionally. When providing support to team members and facilitating their growth, Makris et al. (2018) suggest that leaders align personal and team success along with organizational priorities. Participants mentioned meeting with junior faculty, often reviewing junior members' professional goals, and ensuring that their contributions are valued and in line with promotion and tenure guidelines.

Organizing one-on-one meetings with team members also enabled PIs to align team member's personal goals with those of the X-Grant project. Similar to Makris and colleagues' (2018) recommendation, leaders of X-Grant teams took an active interest in ensuring that team members met their personal and professional goals during their engagement with the project. Identifying and revisiting team member goals will enable the PI to boost individual and team member morale and motivation (Makris et al., 2018).

In their study of graduate students and faculty members, Soltano and colleagues (2016) found students benefiting from their mentors. Students reported learning how to conduct basic and applied research, collaborate, and build relationships with fellow students and professors. König and colleagues (2013) determined that mentorship involves three duties: paying attention to the needs of the team, building commitment among members, and maintaining morale. Although the abovementioned studies

explored briefly the benefits and facets of mentorship, future studies could focus on mentorship in IDR teams in a higher education setting and could uncover the nuances of, benefits, and barriers to mentorship in interdisciplinary teams.

Using Theory to Understand and Explain Interrelationships

The themes described in the prior section do not exist as silos. The findings are part of a larger context, in which factors influence each other in a complex and dynamic environment. To understand the interplay among different factors highlighted in my findings, I turned to theory, as theory explains the phenomena in a logical, ordered, and interconnected manner (Goodson, 2010).

Explaining Interplay Among Factors: Social Ecological Model & Complex Systems

According to the tenets of the social ecological model (SEM), behavior is perceived to be both affected by and affecting multiple levels of influence (McLeroy et al., 1988). Per the core tenet of SEM, challenges or barriers in a single level do not exist in isolation. Instead, occurrences and phenomena at one level are dynamically being shaped by factors from other levels. In other words, challenges in one level may dynamically interact with and affect each other *within* and *across* levels, often changing and evolving over time. In summary, as McLeroy and colleagues (1988, p. 354) note, the SEM perspective "implies reciprocal causation" between the individual and the environment or different factors influencing a phenomenon.

In addition to the SEM perspective, I use the complex dynamic systems (CDS) perspective to better understand how different elements interact with each other. "A complex system is a system with a large number of elements, building blocks or agents

capable of interacting with each other and with the environment" (Amaral & Ottino 2004, p.148). Complexity theory facilitates the study of complex systems, focusing on the interactions among different components in the system (Jorm & Roberts, 2017).

Complex systems have five dimensions: diversity, nesting, self-organizing (Jorm & Roberts, 2017), emergence, and adaptability (Tani, Papaluca, & Sasso, 2018). According to Jorm and Roberts (2017), diversity represents the number of different interconnected elements; nesting refers to large complex systems surrounding the initial system; self-organizing describes the ability of "interconnected system components to spontaneously arrange themselves in a purposeful way" (Jorm & Roberts, 2017, p. 2). Emergence refers to the birth of new paths and behaviors from systematic interactions (Tani, Papaluca, & Sasso, 2018). Adaptability is defined as a system's ability to change and adapt in response to feedback and stimuli (Tani et al., 2018).

The elements of complex systems are dependent on each other and are organized in a hierarchical system. Hierarchical systems are a set of interrelated systems, with each subsystem being a part of another subsystem "until we reach some lowest level of elementary subsystem" (Simon, 1962, p. 468). Nested subsystems allow the mapping of interdependencies between elements (Zhou, 2013).

A small caveat is in order before proceeding. Viewing IDR under a complex systems perspective might reveal emerging and non-linear interactions among factors. However, the introduction of this perspective could also give rise to multiple possibilities and uncertainties (Moore et al., 2019). As Moore and colleagues (2019) point out, it is neither practical nor necessary to explore all interactions among factors.

Using a complex systems perspective is likely to provide a framework with which to view IDR teams and inform decision making.

A Competing Values Framework to Understand the PI Role

Even though using a social ecological model framework and complex systems perspective are beneficial, a competing values framework (CVF) may shed light on the complexity of the PI role. Quinn and Rohrbaugh (1981) characterized organization effectiveness by two paradoxical, or competing, values: i) the need for adaptability and flexibility versus stability and control; and ii) internal and external orientation. While Quinn and Rohrbaugh developed this framework to study factors contributing to organizational effectiveness, CVF also serves as a guide for leaders regarding which roles they are expected to fulfill (Cameron, 2007).

As noted in chapter IV, leaders of IDR teams are required to juggle several roles, which include managing the team's intellectual direction, interpersonal elements, and logistics. The first dimension of the CVF captures the push and pull between adaptability and stability. The role of an IDR leader calls for working with ambiguity, complexity, and flexibility so as to generate innovative solutions to problems. Simultaneously, leaders must rely on structure by managing logistics, meetings, and deadlines. A key challenge for the PI, then, is to balance this flexibility and structure—a task that inevitably involves many moving parts.

The CVF's second dimension distinguishes between internal orientation integration and external orientation, differentiation, and rivalry. Cameroon (2007, p. 7) elucidates this difference, noting that "some organizations are effective because they

have harmonious internal characteristics, whereas others are effective because they focus on interacting or competing with others outside their boundaries." Leaders of IDR teams have to pay attention to both internal and external environments. Internally, participants mentioned nurturing team members by mentoring them and opening the channels of dialogue and communication, with the goal of ensuring that the team is harmonious. Externally, leaders had to work with administrators, seek out and apply for external funding, and operate within the bounds of the traditional academic structure.

König and colleagues (2013) assert that the CVF is a useful tool that guides leaders in managing the needs of IDR teams, where leaders are required to fulfill many roles at different levels. While IDR teams operate as flexible systems interested in maximizing output, they also need structure to help achieve their goals.

Interpreting Interplay Among Factors in Two Layers

I describe the interrelationships among themes in two layers. First, I present connections between sub-themes that emerged when exploring a research question. For example, I describe how challenges at the individual level influence challenges at the team level (as they relate to my research question about barriers). I also describe how the IDR project management role overlaps with intellectual direction (as it is concerned with my second research question about the PI role). When examining the second layer—an interesting and complex one—I underscore possible relationships between barriers and challenges that X-Grant leaders encounter and how they perceive their PI role, two seemingly unrelated phenomena.

Layer 1: Connections Among Sub-themes

Challenges in one level can influence barriers within and across levels. I illustrate my points using two examples. First, let us take the issue of the community-level barrier "journal guidelines." Respondents acknowledged that journal guidelines are not favorable to interdisciplinarity because they are organized rigidly along disciplinary lines. This community-level barrier influences faculty members' career trajectories and decisions, which is another community-level challenge.

For assistant and associate professors on the tenure track, it is important to demonstrate "publication in high-quality, peer-reviewed journals (e.g., the best in the candidate's field) as measured by metrics such as Scimago Journal Rank and as judged by experts in the candidate's field" (School of Public Health, 2018). To demonstrate being rooted in their fields, then, faculty members must publish in high-impact journals in their respective disciplines. Publishing in their own fields enables researchers' contributions to be valued when making hiring decisions and/or tenure and promotion. Researchers concerned that ID publications do not count towards their P&T review may therefore disengage from IDR altogether (Hein et al., 2018; Rafols et al., 2012; Rijnsoever and Hessels, 2011). On the other hand, if P&T reviews are favorable to IDR, there is a possibility of more participation in IDR projects.

The desire of faculty members to publish in their own field could also contribute to team-level challenges, including disagreements regarding data ownership. If a chemistry subteam chooses to publish in a chemistry journal, they are likely to adhere to authorship guidelines outlined by their professional communities. This could potentially

lead to conflicts regarding authorship order and data ownership within the larger team. As discussed earlier, the recommended order of authorship varies across disciplines. In social sciences, the first author is typically the corresponding author. Conversely, in chemistry, the last author is often the corresponding author. Furthermore, issues related to data ownership could emerge. If the chemistry subteam uses its data to publish in a journal of its choice, who owns the data: the subteam or the team-at-large?

Several PI roles also feed off each other. Envisioning the goals of their research project and developing strategies to achieve team goals is an integral part of managing the team's intellectual direction. A project management task of leading and managing meetings both influences and is influenced by the overall intellectual direction of the team. A key part of managing meetings involves deciding on the agenda of each meeting. In my interviews, PIs mentioned dedicating a few meetings solely to strategize how to move forward with the team's research direction. Although an essential part of project management involves tracking milestones and progress, several PIs indicated using meetings as a tool to strategize and move closer to their goals, which influences and overlaps with managing the team's intellectual direction.

Layer 2: Connections between Barriers and PI Role

When I finalized my research questions, I expected to study challenges to IDR teams and the role of a PI independently; I did not anticipate any relationship between these two phenomena. After viewing the two phenomena from the SEM and complex dynamics systems perspectives, I am now of the opinion that the way in which a PI perceives a role has a reciprocal influence on the challenges he/she discusses. For

example, if a PI did not consider recruitment to be a part of his/her role, he/she would not have discussed recruitment as a challenge.

It is noteworthy that PIs are neither trained to take on this role, nor do they have guidelines for how to lead an IDR team. As a result, each person interprets their role differently and shapes the role in their own unique way. In my interview notes, I observed that some PIs adopt a hands-on approach when leading, often noticing problems and nipping them in the bud. For instance, one PI mentioned facing challenges with students. Upon identifying this problem, the PI worked with co-PIs on the team to cross-train students and assign them to their peers in another discipline in an attempt to facilitate learning. Other PIs, however, are a bit more hands-off in their approach. For example, one PI said, "I took a mostly hands-off approach because everyone's busy, and so we didn't really sit down as a group very often."

The functional leadership approach provides additional insights into the relationship between a leader's role and barriers encountered when leading. According to this approach, "leaders are called upon to prevent any potential problems that could impede the team's ability to identify and implement appropriate solutions (Benoliel & Somech, 2015, p. 86). The functional leadership approach also emphasizes that a team's ability to accomplish its goals is largely shaped by the team itself and its organizational context (Benoliel & Somech, 2015).

Because the two phenomena—barriers in an IDR team and the PI role—influence each other, I propose a nested system (see figure 3) to provide theoretical insights into interdisciplinary research teams, similar to Golden and colleagues' conceptualization. I

draw five concentric circles, which are connected to each other—"to distinguish embedded systems and forces that mutually influence each other" (Golden et al., 2015, p., 9S).

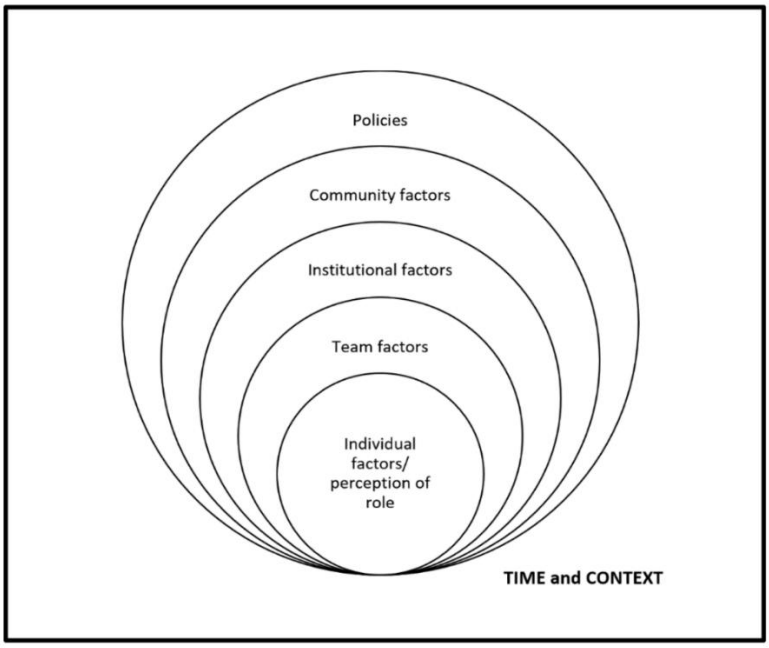

Figure 3. Nested Systems Framework

A nested social ecological system is an "integrated system of ecosystems and human society with reciprocal feedbacks and interdependence" (Folke et al., 2010, p. 20). Recognizing organizational networks as nested systems allows us to "consider how the levels within a system of nested networks relate to each other" (Moliterno & Mahoney, 2011, p. 447). A significant part of the framework is that it explains how relationships in a nested system change over time due to changes in other levels or subsystems (Moliterno & Mahoney, 2011).

Although the nested systems framework offers insight into how one can view IDR teams, nested systems may run the risk of not demonstrating (all) the interplay between different elements and subsystems. It is important to note that interactions occur not only between subsystems, but also with the surrounding or external environment (Oughton, Usher, Tyler, & Hall, 2018).

Implications for Theory

> *It is important to use theory to "attempt to tell the story of why phenomena occur the way they do" (Goodson, 2010, p. 8).*

Along with the proposed nested systems frameworks, the themes identified in the study add to the emerging conversation in the literature. Literature found prior to and during the data collection and analysis did not use a social ecological model perspective or a nested systems framework to understand the interplay between elements in IDR teams and settings.

While human resource development (HRD) is considered a large field of practice, Swanson and Holton (2009) contend that it is a young academic discipline (Swanson & Holton, 2009). It is commonly agreed that HRD is interdisciplinary in nature (Weinberger, 1998; Chalofsky, 2007; Swanson & Holton, 2009) and is the culmination of three core theory domains: psychological theory, economic theory, and system theory (Swanson & Holton, 2009). While HRD draws on theories from other disciplines, it has not developed any of its own overarching theories (Swanson & Holton, 2009) and is therefore said to be experiencing "theory application deficit disorder" (Swanson, 1997).

By seeking to add to the existing conversation and explain the role and barriers of PIs in IDR teams—using social ecological model and a complex dynamic systems perspective—I provide a unique lens with which to view the phenomena. A social ecological model perspective reveals that interaction exists both within and among levels, with influences from the context or setting. A CDS of interaction explains that factors dynamically influence each other over time. This means that the way in which a PI perceives his/her role can influence the barriers he/she is encountering, and vice versa. We need to pursue and develop theoretical frameworks and systems of explanations about topics concerning HRD so that we can begin to learn, explain, and understand relationships among phenomena of study. Swanson (2001) posits that theory building is critical for all academic areas and this is especially true in HRD.

Implications for Practice

McLagan defined HRD as the "integrated use of training and development, career development, and organization development to improve individual and organizational performance" (p. 7). My dissertation has profound implications to each of the three HRD sub-fields, namely career development (CD), organization development (OD), and training and development (T&D).

My findings revealed concerns among participants regarding career development for early-career scientists and researchers. Because IDR is not evaluated or valued at par with monodisciplinary research, individuals on the tenure track might choose not to engage in IDR. Additionally, students who seek employment in academia may fear the perception of not being grounded in their discipline because of their engagement in IDR

and publishing in ID journals and conferences. Researchers generally perceive IDR to be less rewarding than monodisciplinary research in terms of recognition, career advancement, and publications (Hein et al., 2018; Rijnsoever & Hessels, 2011). Because monodisciplinary pursuits are rewarded and incentivized (Hein et al., 2018; Rijnsoever & Hessels, 2011), early-career scientists typically have a higher number of monodisciplinary research outputs (Carayol & Thi, 2005; Hein et al., 2018; Rijnsoever & Hessels, 2011) and see their participation in IDR as a career risk.

OD centers on "long-term change efforts focused on improving interpersonal relationships of employees" (Rothwell, Park, Anderson, Corn, & Haynes, 2015, p. 5). OD professionals are called upon to diagnose, collect, and analyze organizational data in an effort to design the appropriate intervention (Rothwell et al., 2017). Because an important part of an OD professional's role involves designing interventions, it is critical for practitioners to understand the complex interplay of influences on an IDR team. If an OD professional is sought because of low motivation among team members, this study provides a framework to view the issue of low motivation as one element in a complex system. This means that OD practitioners should not design interventions with the sole intent of improving and boosting motivation. Instead, they must view the issue in light of other influences, mapping factors and elements that might be contributing to low motivation.

In a survey of 588 participants, 94% agreed or strongly agreed that there is a need for IDR-relevant training at academic institutions (Hein et al., 2018), especially in the areas of communication and team skills. T&D practitioners can better tailor their

training to suit the needs of IDR teams by learning more about the barriers and challenges revealed in this study. Instructing students and faculty members on teamwork and developing interventions to address some common IDR team challenges should become an integral part of graduate and postgraduate training (Hein et al., 2018).

This research project gives HRD practitioners and organization leaders pertinent information about the barriers and challenges that PIs of IDR teams face. Understanding multilevel challenges and barriers in IDR teams presents an opportunity for HRD practitioners to anticipate some of these challenges and to develop appropriate interventions. HRD practitioners and organization leaders will consider the findings of this study beneficial, especially as they connect to CD, OD, and T&D. By developing a better understanding of these issues holistically, HRD practitioners are likely to develop interventions which address different aspects of a problem. Though this study was conducted at Texas A&M University, practitioners and funding agencies may find the study useful not only to address barriers to IDR teams, but also provide leadership training to make the complexity of PI role manageable.

Conclusion

The grand challenges we face in society today are multi-faceted, ambiguous, and complex. To tackle these complex problems, researchers from multiple disciplines must come together to engage in cross-disciplinary (multi, inter, or transdisciplinary) research. Recognizing the importance of interdisciplinary research (IDR), several universities and funding agencies have instituted programs and grant opportunities to promote IDR (Leahey et al., 2019).

Although opportunities to participate in IDR initiatives are burgeoning, IDR teams continue to face a wide range of multilevel challenges at the individual, team, organizational, community, and policy levels. Using a social ecological model (SEM) and complex dynamic systems (CDS) perspective to interpret my results revealed that these challenges do not exist in silos; they often influence and sometimes, exacerbate barriers within and across levels. In addition to tackling multilevel challenges, PIs reported having to take on the role of a thought leader, people leader, and project manager.

This study has theoretical and practical implications. By seeking to add to the existing conversation from the lens of SEM and a CDS perspectives and explain the role and barriers of PIs on IDR teams, I provide a unique lens with which to view the phenomena, thereby making a theoretical contribution. A SEM framework reveals interactions within and among levels, with contextual influences. A CDS perspective interaction explains that factors dynamically influence each other over time. How a PI perceives his/her role can influence the barriers he/she is encountering and vice versa.

In practice, my dissertation has profound implications to all three sub-fields of HRD, namely career development, organization development, and training and development. By developing a better understanding of how factors in an IDR team interact with and influence each other, practitioners are likely to develop holistic interventions addressing different aspects of a problem and not solutions that merely scratch the surface of an issue.

Though this study was conducted at Texas A&M University, practitioners and funding agencies may find the findings of my research useful not only to anticipate and address certain barriers to IDR, but also to provide leaders with training and support to clarify their own roles and to make the complexity of the PI role more manageable.

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APPENDIX A

RECRUITMENT EMAIL

Good morning Dr. <Insert Name>,

Our team has been funded by the Office of the Vice President for Research at TAMU to study the T3 and X-Grant initiative. As part of our research, we are conducting interviews of PIs and administrators involved with the initiative, such as yourself, to capture your valuable experiences. I am reaching out to you because you are a PI of a funded X-Grant project.

We would like to schedule an interview with you in the next few weeks for approximately 30-45 minutes to learn about your experience with the initiative.

Our team plans to conduct your interview using the method you most prefer: Google Meet/Skype/ Zoom/ phone. If you are willing to participate in an interview, please fill out this doodle poll to indicate what time works best for you. I look forward to hearing from you about your decision to participate (or not) in this interview opportunity. A summary of the interview results is presented to the VPR each year to aid in guiding the design and implementation of the Initiative.

If you have questions about the evaluation, please contact our Principal Investigator, Dr. Michael Beyerlein, by email at beyerlein@tamu.edu or by phone at (979) 845-2716.

Sincerely,
Sarayu Sankar
Ph.D. Student
Human Resource Development
Texas A&M University

TAMU IRB#2019-0021M
Approved on 08/15/2019

APPENDIX B

INFORMED CONSENT

Title of Research Study: Comprehensive Evaluation of the T3 and X-Grants at Texas A&M University.
Investigator: Michael Beyerlein, Ph.D.
Funded/Supported By: This research is funded/supported by the TAMU Office of Research.
Why are you being invited to take part in a research study?
You are being asked to participate because of your experience with the T3 and/or X-Grant initiative.
What should you know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Who can I talk to?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at:
Michael Beyerlein
EAHR Department, College of Education & Human Development
(979) 862- 2183
beyerlein@tamu.edu (email preferred)

This research has been reviewed and approved by the Texas A&M Institutional Review Board (IRB). You may talk to them at 1-979-458-4067, toll free at 1-855-795-8636, or by email at irb@tamu.edu if

- You cannot reach the research team.
- Your questions, concerns, or complaints are not being answered by the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Why is this research being done?
To evaluate the effectiveness of the T3 and X-Grants Initiative on campus and to improve our understanding of interdisciplinary and transdisciplinary research and use of seed grants for supporting it.

How long will the research last?

We expect that the amount of time that you will be in this research study varies based on your involvement with the T3 and/or X-Grant programs. The entirety of the study will last three years.

How many people will be studied?
All faculty at TAMU (about 4,000) that are eligible to apply for T3 and X-Grants will be invited to participate in surveys or interviews. This consent form focuses on faculty members who have been involved in that Initiative with plans to interview about 30 each year.

What happens if I say "Yes, I want to be in this research"?
You will be interviewed either virtually such as a phone call or Zoom link for approximately 30 to 60 minutes. With specific permission to do so, the interview(s) will be audio recorded.

What happens if I do not want to be in this research?
You can leave the research at any time and it will not be held against you.

What happens if I say "Yes", but I change my mind later?
You can leave the research at any time and it will not be held against you.

Is there any way being in this study could be bad for me?
Risks incurred in this study are not greater than routine daily risks academics face, related to their work. It may be possible to identify some interview respondents whose information is included in either reports or publications. However, to both protect respondents and to assure the accuracy of interview data you will have the opportunity to review your transcribed interview.

Will being in this study help me in any way?
There are no immediate benefits to the individual participant.

What happens to the information collected for the research?
Efforts will be made to limit the use and disclosure of your personal information, including research study and other records, to people who have a need to review this information. We cannot promise complete privacy. Organizations that may inspect and copy your information include the TAMU HRPP/IRB and other representatives of this institution.

Can I be removed from the research without giving my OK?
The person in charge of the research study or the sponsor can remove you from the research study without your approval. Possible reasons for removal include your termination of employment with the College Station TAMU campus.
We will tell you about any new information that may affect your health, welfare, or choice to stay in the research.

What else do I need to know?
The interim and final results of this research will be provided to the Texas A&M Office of Research at least annually and at the conclusion of the three year study.

Optional Elements:
The following research activities are optional, meaning that you do not have to agree to them in order to participate in the research study. Please indicate your willingness to participate in these optional activities by placing your initials next to each activity.

I agree	I disagree	
_____	_____	The researcher may audio record me to aid with data analysis. The researcher will not share these recordings with anyone outside of the immediate study team.
_____	_____	The researcher may audio record me for use in scholarly presentations or publications. My identity may be shared as part of this activity, although the researcher will attempt to limit such identification. I understand the risks associated with such identification.
_____	_____	The researcher may use portions of this interview as direct quotations in scholarly presentations or publications anonymously.

If you agree, please respond to this email by writing the statement "I agree to be interviewed", and then your full name and UIN.

IRB Approval Number: 002019-0021
IRB Approval Date: 12/04/2020

APPENDIX C

INTERVIEW GUIDES

- Tell us a little bit about your project.
    - Has your project changed or evolved since it was funded?
- Tell us about your role in the project.
    - What are your responsibilities as a PI? (e.g: managing meetings/ deadlines/ team member performance, etc.).
    - How do you view your experience as a PI?
- What motivates you to do ID research?
    - Has your motivation changed?
- What are some of the challenges you have faced?
    - Functioning (e.g. communication, collaboration, team meetings)
    - Experience in keeping the team together
    - Relationship with team members
    - Managing barriers
- Resources/ support from IRB, dept. heads, deans, VPR's office?
    - What else do you need?
- Now that you have been involved in the T-3/ X-Grants, if you had to point to one good thing that came out of this, what would it be?
    - If yes, can you elaborate?
- What comes next?
    - Plans for dissemination/ external funding/ developing networks
- What should I be asking you that I have not?

APPENDIX D

LIST OF SRQR ITEMS

Standards for Reporting Qualitative Research (SRQR)[a]

No.	Topic	Item
	Title and abstract	
S1	Title	Concise description of the nature and topic of the study Identifying the study as qualitative or indicating the approach (e.g., ethnography, grounded theory) or data collection methods (e.g., interview, focus group) is recommended
S2	Abstract	Summary of key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results, and conclusions
	Introduction	
S3	Problem formulation	Description and significance of the problem/phenomenon studied; review of relevant theory and empirical work; problem statement
S4	Purpose or research question	Purpose of the study and specific objectives or questions
	Methods	
S5	Qualitative approach and research paradigm	Qualitative approach (e.g., ethnography, grounded theory, case study, phenomenology, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g., postpositivist, constructivist/ interpretivist) is also recommended; rationale[b]
S6	Researcher characteristics and reflexivity	Researchers' characteristics that may influence the research, including personal attributes, qualifications/experience, relationship with participants, assumptions, and/or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results, and/or transferability
S7	Context	Setting/site and salient contextual factors; rationale[b]
S8	Sampling strategy	How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g., sampling saturation); rationale[b]
S9	Ethical issues pertaining to human subjects	Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues
S10	Data collection methods	Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources/methods, and modification of procedures in response to evolving study findings; rationale[b]
S11	Data collection instruments and technologies	Description of instruments (e.g., interview guides, questionnaires) and devices (e.g., audio recorders) used for data collection; if/how the instrument(s) changed over the course of the study
S12	Units of study	Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)
S13	Data processing	Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymization/deidentification of excerpts
S14	Data analysis	Process by which inferences, themes, etc., were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale [b]
S15	Techniques to enhance trustworthiness	Techniques to enhance trustworthiness and credibility of data analysis (e.g., member checking, audit trail, triangulation); rationale[b]
	Results/findings	
S16	Synthesis and interpretation	Main findings (e.g., interpretations, inferences, and themes); might include development of a theory or model, or integration with prior research or theory
S17	Links to empirical data	Evidence (e.g., quotes, field notes, text excerpts, photographs) to substantiate analytic findings
	Discussion	
S18	Integration with prior work, implications, transferability, and contribution(s) to the field	Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application/ generalizability; identification of unique contribution(s) to scholarship in a discipline or field
S19	Limitations	Trustworthiness and limitations of findings
	Other	
S20	Conflicts of interest	Potential sources of influence or perceived influence on study conduct and conclusions; how these were managed
S21	Funding	Sources of funding and other support; role of funders in data collection, interpretation, and reporting

APPENDIX E

CODEBOOK

Code	Definition
ADMIN SUPPORT: Extension due to COVID	Participant notes that his/her project has received an extension from the VPR's office due to COVID-19, enabling him/her to finish the project at a later date.
ADMIN SUPPORT: Need support	Participants note that they need some type of support from the administration. This could be related to resources, equipment, labs, etc.
ADMIN: Positive beliefs about administration	Participants share their positive beliefs about the administration (specifically VPR's office).
BARRIER: A lack of a systems view	Participant explains that a lack of a systems view in team members is a barrier for the team.
BARRIER: Authorship and authorship order	Participant discusses challenges around authorship "rules" and expectations, which are different across disciplines.
BARRIER: Budgeting-related	Participant recounts barriers/ challenges related to budgeting/ managing finances relating to the grant.
BARRIER: Competition	Participant shares that team members being competitive is a barrier/ challenge.
BARRIER: COVID-related (changes in ops)	Participant notes that his/her team had to change how they operated due to COVID. Example: change from in-person meetings to virtual meetings.
BARRIER: COVID-related (delays)	Participant share that COVID 19 has caused delays in the project. This could include delays in timeline, publications, accomplishing goals.
BARRIER: COVID-related (have not seen any members in person)	Participant notes that he/she hasn't seen his/her team members in person due to the pandemic and that this is a barrier to working with the team.
BARRIER: COVID-related (methods)	Respondents recounted changing how they applied their methodologies as a result of COVID. For instance, some teams tweaked

	their data collection efforts to allow for virtual interviews.
Barrier: COVID-related (TRAVEL)	Participant notes that COVID-19 restrictions have led to difficulties in traveling, which has slowed down team progress and/or affected other aspects of their project work.
BARRIER: COVID-related barriers (no access to labs/ equipment)	As a result of the pandemic, participant expressed not having access to labs/certain types of equipment because of shelter-in-place restrictions.
BARRIER: COVID-related: uncertainty	Participant notes that COVID has led to uncertainty with regard to team management, project direction, timeline, for example.
BARRIER: Crediting team members	Participant notes that fairly crediting team members for their contribution in an ID project is a challenge due to differing P&T guidelines, authorship order, etc.
BARRIER: Data ownership	Participant notes data ownership in an ID team is challenging.
BARRIER: Deciding on boundaries/ scope	Deciding on the scope or the boundaries of the IDR project is challenging because teams can explore many different directions.
BARRIER: Delegation	Delegating responsibilities/ tasks to team members is challenging because several fields and members can use the same equipment, for instance.
BARRIER: Distance between disciplines	Participant notes that distance between disciplines is a barrier. Multiple languages, paradigms, theories, and methods across different disciplines might contribute to this factor.
BARRIER: Finding a meeting time	Finding a common meeting time is a challenge due to busy faculty schedules.
BARRIER: Geographical distance	Integrating team member efforts, especially when they are in different cities—is challenging.
BARRIER: Hierarchy	The pecking order (hierarchy) and seniority in rank/ titles is a barrier for members to voice their opinions/ questions.
BARRIER: ID work takes time	ID work takes time because agreeing on research methods/ developing new

	technologies from scratch can be time consuming.
BARRIER: Individual motivation	Sustaining individual team members' motivation is challenging.
BARRIER: Integrating	Integrating knowledge from different team members, who represent multiple fields is a challenge participants pointed to.
BARRIER: involving team members	Respondents commented that, as part of their role, they see it as their duty to keep the team informed and communicate with them.
BARRIER: Monodisciplinary journals	Journals organized along disciplinary lines is a problem/ issue in IDR projects. For example, this makes it difficult for teams to publish in ID journals.
BARRIER: My role as junior faculty	Junior faculty (associate/ assistant professors) note that their role as junior faculty is a barrier. For example, it prevents some members from speaking up in meetings/ interrupting senior faculty
BARRIER: Promotion and Tenure processes	P&T processes do not evaluate IDR contributions at par with monodisciplinary work and this is an obstacle for IDR leaders.
BARRIER: Quantifying contribution to team science	How can leaders and P&T reviewers fairly quantify IDR work, so team members are credited and evaluated fairly?
BARRIER: Recruiting	Participants mentioned struggling to recruit the right faculty/ students for their team.
BARRIER: Resources	Resources such as not having access to the right equipment/software was a barrier.
BARRIER: Role definition/ overlap	Defining team member roles and delegating tasks was a challenge as a PI.
BARRIER: Student-related	PIs acknowledged facing some challenges when dealing with students. Examples: not knowing how to mentor fellow students.
BARRIER: The phenomenon of a quick expert	This idea that individuals are able to spend a few hours/ days/ weeks and become "experts" is a hurdle because this causes conflicts/frustration among team members.
BARRIER: Time	Participants note that a lack of time to engage in their ID projects is a barrier.

BARRIER: None	Participant expressed no significant barriers were encountered.
COVID-related change: Change in focus	Due to COVID, participants had to change the focus of their X-Grant project.
COVID-related change: Positive/ silver lining	Participants discussed a few silver linings because of COVID. Example: Time to work on publications, conference proceedings, grants,
COVID-related: Less interaction with Admin	Due of COVID, participant mentioned that he/she did not interact much with administrators (which he/she was able to do before COVID).
COVID: Made us nimble	As a result of COVID, participant noted, the team became nimble/flexible, finding ways to collect and analyze data even with restrictions in place.
COVID: No impact on the team's research	COVID did not have any impact on the team. The team was able to carry on with its research.
GRAD STUDENTS: As links in the team	Graduate students are crucial links in the team because they interact with different subteams.
GRAD STUDENTS: Co-advised	Some graduate students are co-advised (in their theses/ dissertation studies) because one PI does not have the knowledge to mentor a student on different fields.
GRAD STUDENTS: Importance of grad students	Participant notes that students are critical and important in their teams.
GRAD STUDENTS: Role	Participants explained/ discussed the role of graduate students. Example: assisting PIs, conducting experiments, etc.
LEADERSHIP STYLE: Takes this seriously	This is my observation. Participant indicates to me that he/she takes this role seriously.
LEADERSHIP STYLE Wants accountability	Observation: Participant wants accountability in the X-Grants process. He/she may indicate wanting to submit annual reports/ progress updates to the funders.
LEADERSHIP STYLE: adaptable/ agile	Participants exhibited agility/ flexibility, especially in relation to COVID-19.
LEADERSHIP STYLE: Collaborate on a need basis	All team members may not work together all the time. Participants indicated collaborating with members on an as-needed basis.

LEADERSHIP STYLE: Collaborative	Participants mentioned valuing collaborations with other members on the team.
LEADERSHIP STYLE: Hands-off approach	Observation/ quote: Participants had an hands-off approach/ leadership style in the team. Participants can indicate things like: "I let people do their thing"
LEADERSHIP STYLE: Hands-on approach	Participants take their role seriously and are proactive in how the lead their teams. Example: observing conflict and addressing it before it becomes a problem.
LEADERSHIP STYLE: Learning from team members	Participants mentioned how he/she learns from team members.
LEADERSHIP STYLE: Mindful about imposing	Speaking to their leadership style, participants mentioned that they were very mindful about imposing their views or ideas on the team.
LEADERSHIP STYLE: Patient	Participant indicated being patient or needing patience to deal with some of the challenges in IDR/ leadership in general.
LEADERSHIP STYLE: People driven	Participant indicates putting people first.
LEADERSHIP STYLE: Self-development	Participant values self-development. May mentioned reading leadership books, introspecting about their leadership, etc.
LEADERSHIP STYLE: Selfless?	Example: One participant gave away her funding to support graduate students.
LEADERSHIP STYLE: Structured/ details driven	Participant was detail oriented and systematic in how they approached their leadership role. Example: detailed agendas, minutes, etc.
MANAGING BARRIER: Communication	Participants discussed strategies they used to overcome barriers related to communication.
MANAGING BARRIER: Journals	Participants discussed how they overcame the issue of journals being organized along disciplinary lines. Example: letting subteams publish in their fields.
MANAGING BARRIER: Zoom meetings	Participants managed some challenges using virtual platforms like Zoom
MANAGING BARRIERS: COVID-related (focused on other areas of research)	When teams could not focus on conducting experiments, for example, the teams shifted focus to concentrate on other aspects of the project.
MANAGING BARRIERS: Distance between disciplines	Participants commented on how they overcame the issue of distance between

	disciplines. Example: communication, cross-training, etc.
MANAGING BARRIERS: Integrating	Participants explained how they managed barriers related to integration of knowledge/ methods among disciplines
MANAGING BARRIERS: Resources	When they encountered challenges like having access to resources, participant managed their barriers using these strategies.
MANAGING BARRIERS: Students' attitudes	Participants mentioned cross-training/ mentoring students (these are just a few examples) to surmount the issues they faced because of students' attitudes.
MANAGING BARRIERS: Organization	Participants referred to changes in how the team had to change how it operated/ organized tasks due to COVID and how they managed this challenge.
MANAGING BARRIERS: Working with each other	This code refers to strategies participants used to handle/ manage hurdles they faced when working with each other. Strategies related to working across disciplines, languages, etc.
MANAGING STUDENTS: Partnering	Participants partnered students with each other in an effort to cross-train them.
MENTORING: Team members are mentors	When participants are junior faculty, team members who have higher ranks, mentored them about grant applications, for instance.
MENTORING: Undergrads mentored by postdocs	Participant notes that in his/her team, postdoctoral students mentor the undergrad students.
PI EXPERIENCE: Self-reflection	Participant reflects on his/her experience as a PI, his/her learnings.
PI ROLE: Bridging gaps between disciplines	Participants note a key part of their role is bridging the gap between disciplines.
PI ROLE: Bringing disciplines/ people together	Participants note bringing team members and disciplines together to work on a common problem. Example: meetings where team members map/ brainstorm.
PI ROLE: Communication	PI talks about communicating internally (within the team) or externally (with stakeholders). Internally could be among sub-groups, communicating with team members. Externally means stakeholders/ partners.

PI ROLE: Conducting research	In addition to other roles, PIs mention conducting their own research in their X-Grant teams.
PI ROLE: Coordination	Interviewee refers to coordinating and communicating with the team.
PI ROLE: Delegate work	PIs are in charge of delegating work/ divvying up the research project for team members.
PI ROLE: Enabling members to achieve their professional goals	Participants mention being mindful about each member's P&T requirements when working with them to help members meet their professional goals, as well.
PI ROLE: Financial decisions/ managing funding	Participants mention managing funding as part of their role.
PI Role: Generate and maintain networks	As a PI, participants discuss generating and maintaining professional networks.
PI ROLE: Integrating efforts	As a PI, participants noted a key role of theirs was to integrate knowledge that subteams or groups generated.
PI ROLE: Leading and managing meetings	Participants said they lead and manage meetings.
PI ROLE: Leveraging team members' networks	As part of their recruiting efforts, PIs leverage their team members' networks.
PI ROLE: Mentoring Grad students/ postdocs	PIs commented on how they mentored students - both graduate students and postdoctoral scholars.
PI ROLE: Mentoring junior faculty	PIs mentored junior faculty in their teams and departments/ colleges.
PI ROLE: Operating within the bounds of the college	PIs discussed that they had to operate within the bounds of their college norms.
PI ROLE: Planning	Participants are in charge of planning ahead/ looking into the future of the project.
PI ROLE: Procuring permission for access to technology	Participants mention being a key player in the IRB process/ taking care of new purchases relating to software, for instance.
PI ROLE: Project Management	A key part of the PI role is project management - scheduling, leading, and managing meetings, taking care of the GANTT chart/timeline, etc.
PI ROLE: Recruiting team	Participant discusses how he/she brought the team together.

PI ROLE: Recruiting/working with members on a need basis	Participant discusses how he/she works with the team members on an as needed basis. Not all team members are involved in all meetings/ discussions.
PI ROLE: Recruitment (to fill in gaps)	Recruiting members based on "the types of questions you are answering can help you pick you needs to be in the team."
PI Role: Reflection – Humble	Participant notes that engaging in ID has made him/her humbler.
PI ROLE: Seeing how pieces fit together/ big picture	Participant discusses how he/she sees the different disciplinary pieces/disciplines fitting together in the IDR project.
PI ROLE: Strategy	Participant notes how they strategize/ plan the next steps for/ with the team.
PI ROLE: Providing support	PIs mention supporting members as a role.
PI ROLE: Team climate	Ensuring a conducive and positive team climate and environment is a PI role.
PI ROLE: Thought leader	This refers to participants being an intellectual leader of the team - often, leading discussions about the research direction, scope, etc.
PI ROLE: Tracking current and future grants/ publications	This refers to participant tracking the progress and status of grants the team has applied for and planning future grant submissions/ proposals.
PI ROLE: Vision	Participant describes the vision they have for the project. For example: future publication ideas, vision for a center a few years down the lane. In other words, any short, mid, or long-term goals or ideas.
PI: BELIEFS about ID	Perceptions and beliefs about ID.
PI: Beliefs about ID: advantages/ benefits	Perceptions and beliefs about the benefits/ advantages of IDR.
PI: BELIEFS on the benefits of networks	Perceptions and beliefs on the advantages/ benefits of networks.
PI: Bringing people together is fun	Participant notes that she enjoys bringing people together and work in a team.
PI: Cross training	Interviewees discuss how they engage in cross training their team members.

PI: Encourages other faculty/ students to engage in ID	Respondents share how they encourage other faculty, especially, junior faculty to engage in IDR projects such as X-Grants.
PI: Enjoys leading/ experience	Participant shared enjoying the X-Grant experience, especially leading the team.
PI: Assumption about understanding each other's language	Participants state that one generally expects to have trouble understanding each other's languages in an IDR project.
PI: Motivation for ID	PIs discuss their motivation for engaging in ID
PI: Perception on X-Grants	Participants refer to their perceptions of X-Grants.
PI: Prior experience with ID	Participant highlights his/her own previous involvement in ID projects.
PI: Project has many moving parts	PI notes that his/her team project has many moving parts.
PI: Value other kinds of knowledge	Participant notes that she/she values disciplines other than the one he/she is trained in.
PI: X-Grant as Pilot project	Participant refers to X-Grants as pilot project. In other words, they note that they use X-Grants as a "stepping stone" to acquire external funding.
PIs need to protect themselves	Participant mentioned that PIs could be selfless and need to think about themselves and protect their interest as well.
PIs need training	Respondent comments that PIs need training on how to handle the different components of an X-Grant.
PROJECT: Description	Participant explains his/her team's project idea.
PROJECT: Objective	Participant explains the his/her team's objects they hope to accomplish using X-Grant funding.
PI: Nature of ID	Participant discusses the nature of interdisciplinary research. For example, they share ID work takes time, or that it is high risk, high reward, etc.
RESOURCES: Haven't used many	PI notes that he/she hasn't used many of the available resources.
RESOURCES: People at TAMU	Participants note that people at TAMU (students, faculty) are great resources.

RESOURCES: Talking with other PIs	When talking about resources, participant notes that talking with other X-Grant PIs has been resourceful.
TEAM: Meetings	Participant explains how meetings in his/her team are organized, how often they meet, who is present in the meetings, etc.
TEAM: Part-time	Participant mentions that the team works part-time on the project.
TEAM Structure: Co-PIs take lead on external grants	Participant highlights that in his/her team, not everyone works together all the time. Depending on the project, or grant proposal, any member of the team can take the lead and collaborate with other members of the team.
TEAM Structure: Working in subgroups	Participant highlights that his/her team works in subgroups and how the subgroups collaborate with each other.
TEAM: Building	Participant discusses how he/she built the team from the ground up.
TEAM: Change in team size and composition	Participant discusses a change in the team size or composition compares to year 1. For example, the PI may have recruited new members to the team. Some members of the team might no longer be a part.
TEAM: Positive beliefs about team	Participant mentions positive characteristics of the team.
TEAM: Prior work with each other	When talking about recruitment and/or network, participant notes that certain members of the team have worked (or not) with each other previously. Even if participants mention team members haven't worked with each other, this code is applicable.
TEAM: Shared leadership	Participants describe a shared leadership framework being employed in the team. Participants could note that they share their leadership responsibilities with the other PIs, for example.
TEAM: Size/ Composition	Participant talks about the number of team members in his/her team and its composition.