ORGANIZING AND MANAGING SCIENTIFIC RESEARCH COLLABORATIONS

by

HEATHER NICOLE RIMES

(Under the Direction of Hal G. Rainey)

ABSTRACT

This dissertation presents three independent but complementary manuscripts that offer theoretical and empirical perspectives on the organization and management of scientific research collaboration in selected science, technology, engineering, and mathematics (STEM) fields. The first manuscript, Chapter 2, proposes a typology of collaboration structures. The chapter categorizes collaborations based on two key organizing features: centralization of decision making and role specialization. It utilizes survey data to explore connections between the characteristics of individual scientists and varying combinations of these two features. Findings indicate that career length, field of study, and collaboration origin variables are significantly related to the methods which scientists use to structure their collaborative work. Also related to collaboration organization, Chapter 3 explores four collaboration characteristics: division of administrative authority, division of scientific authority, role specialization, and formalization. It employs an expanded definition of collaboration, allowing researchers to identify collaborators and describe collaborative work beyond the bounds of a single co-authored publication, and it utilizes interview data to gain a rich description of individuals' collaboration experiences. The chapter identifies patterns across these experiences and highlights linkages between organizational features and the contextual characteristics of collaboration, including collaboration size and institutional environment. It concludes with a discussion of the ways in which contingency theory approaches can contribute to understanding the structural organizing elements of collaborations. Next, Chapter 4 turns attention to research collaboration management strategies and challenges. It reviews the scholarly literature related to collaboration management and develops an organizing scheme for considering common collaboration management challenges. It then applies the organizing scheme and expands it based on findings from semi-structured interviews, suggesting five overarching categories of management challenges: 1) excessive coordination costs, 2) managing interpersonal issues, 3) contribution and crediting dilemmas, 4) leadership issues, and 5) managing external influences. The dissertation concludes with a discussion of how the findings in each chapter intersect as well as their implications for policy and practice.

INDEX WORDS: research collaboration, scientific collaboration, science policy, research management, collaboration management

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DEDICATION

First, for my husband, Josh Rimes, my partner in every adventure.

Also for my parents, Billy and Ruth Symon, whose faith and pride are two constants for which I am always grateful.

And for my late grandmothers, Ruth Symon and Velma Phillips, who were not able to see me complete this milestone, but who I know would have been proud.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Research collaboration is a standard approach to tackling complex scientific problems. Collaborative projects range from small, informal efforts comprising as few as two researchers within a single academic department to large, long-term projects spanning multiple institutions, disciplines and even nations. Although they may take many shapes, scientific collaborations are, fundamentally, organizational forms through which participants structure and coordinate their knowledge production efforts (B. Bozeman, Fay, & Slade, 2013). Since the World War II era, scientific collaboration in the United States has attracted a great deal of attention, particularly from actors in the public sector. Government interest is rooted in efforts to stimulate economic growth as well as to develop solutions to pressing social problems, and numerous actors including policymakers, government agencies, and university administrators participate in developing and implementing policies, programs, and structures to promote collaborative work.

The centerpiece of many of these efforts is harnessing or enhancing the potential of the academic scientist. For example, the federal government is the largest funder of scientific research within U.S. universities. In its 2014 Science and Engineering Indicators Report, the National Science Foundation documents that U.S. colleges and universities spent $65.8 billion on research and development in 2012. Federal funds account for approximately sixty percent ($40 billion) of those expenditures, a proportion that has been relatively stable for over three decades. The report also indicates that state and local government funding represents another five and half percent ($3.4 billion) of total expenditures, bringing the government funding share to over sixty-five percent (National Science Board, 2014). Academic scientists in science, technology, engineering, and mathematics (STEM) fields receive the bulk (93%) of the funding (Hourihan, 2014). Federal agencies providing the majority of this funding include the Department of Health and Human Services (HHS), the National Science Foundation (NSF), National Institutes of Health (NIH), the Department of Energy (DOE), the Department of Defense (DOD), and the National Aeronautics and Space Administration (NASA) (National Science Board, 2014).

These agencies' funding stipulations increasingly favor collaborative research, and some funding streams expressly require projects to have multiple principle investigators (Clark, 2011). For instance, one such program is the Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE). INSPIRE awards target, "some of the most complicated and pressing scientific problems that lie at the intersection of traditional disciplines" ("Integrated NSF Support Promoting Interdisciplinray Research and Education (INSPIRE)," 2014). In addition to programs like INSPIRE, aimed at promoting inter-academia collaboration, a variety of federal initiatives also seek to stimulate cross-sector collaboration. For example, the Bayh-Dole Act (1980) encourages university researchers to collaborate with industry by participating in technology transfer activities. Also along these lines, the Small Business Technology Transfer Program (STTR) provides funding to facilitate collaborative research and development projects between small businesses and non-profit research institutions (typically a university or a federally funded research and development center)[1].

Universities and government entities also encourage research collaboration through the use of institutional forms such as university research centers. These centers are formed outside of

[1] See http://www.sbir.gov/about/about-sttr

traditional academic departments to bring together teams of scientists, often multi-disciplinary teams, to investigate specific problems or areas of inquiry. Scholars have defined a university research center as a “formal organizational entity within a university that exists chiefly to serve a research mission, is set apart from the departmental organization, and includes researchers from more than one department’’ (B. Bozeman & Boardman, 2003, p. 17). This institutional form began to flourish in the 1980s, and today there are multitudes of university research centers (B. Bozeman and Boardman, 2003). Some are sponsored by government agencies and play vital roles in areas of national or state interest[2] while others operate solely under the auspices of their parent universities[3].

Ultimately, policies and programs that promote the varying permutations of scientific collaboration are only as successful as the collaborative projects that they encourage. Thus, gaining a better understanding of the elements that contribute to effective collaboration is vital. Developing this understanding benefits not only the individual scientists participating in collaborative projects but also the policymakers and university administrators crafting programs and institutions to support collaborative scientific work. Therefore, research collaboration and its various aspects have been the focus of a number of studies and evaluations. Bozeman, Fay and Slade (2013) offer a comprehensive state-of-the-art review of current work on research collaboration. Additional reviews include those by Melin and Persson (1966), Katz and Martin (1997), and Melin (2000). Specific areas of scholarly attention have included analyzing and suggesting means to improve interdisciplinary (Cummings & Kiesler, 2005; Porter & Rafols,

[2] For examples see http://www.arl.army.mil/www/default.cfm?page=510, http://www.nasa.gov/offices/education/programs/national/urc/home/ and http://www.mississippi.edu/urc/
[3] For examples see http://www.ovpr.uga.edu/centers-institutes/, http://www.stanford.edu/research/centers.html

2009; van Rijnsoever & Hessels), cross-sector (Etzkowitz & Leydesdorff, 2000; Gray, 2011; Turpin & Fernández-Esquinas, 2011; Turpin, Garrett-Jones, & Woolley, 2011), and international research collaboration efforts (Lemarchand, 2012; Luukkonen, Persson, & Sivertsen, 1992). The National Research Council recently emphasized the importance of working to synthesize lessons from studies of research collaboration across various disciplines (Committee on the Science of Team Science, 2015), and their forthcoming book cites advancing scholarly work and understanding regarding collaboration processes and effectiveness as a crucial current need.

The three manuscripts presented in Chapters 2 through 4 of this dissertation explore several aspects of organizing and managing academic research collaboration. Chapter 2 defines collaboration as co-authorship and proposes a typology for categorizing collaborations based on two key organizing features: role specialization and centralization of decision making. It explores connections between the characteristics of individual researchers and their choices regarding collaboration structure. Next, Chapter 3 employs an expanded definition of collaboration, and it utilizes interview data to gain a rich description of individual collaboration experiences. It then identifies patterns across these experiences and discusses linkages between organizational features and the contextual characteristics of collaboration. It concludes by arguing that contingency theory approaches can contribute to understanding collaboration structures. Chapter 4 turns attention to research collaboration management strategies and challenges. It reviews the scholarly literature related to collaboration management and develops an organizing scheme for considering common management challenges. It then applies the organizing scheme and expands it based on findings from semi-structured interviews. The dissertation concludes in Chapter 5 with a discussion of how the findings from each of the previous chapters intersect as well as their practical and public policy implications.

CHAPTER 2

SCIENTIFIC RESEARCH COLLABORATION: A TYPOLOGY OF ORGANIZATIONAL PATTERNS [4]

[4] Rimes, H. To be submitted to *Research Policy*.

Abstract

This manuscript examines relationships between the individual level characteristics of academic scientists such as career, demographic, and field of study variables and their choices regarding how to structure and organize their collaborative work. Using survey data from the 2012 National Study of Research Collaboration (NSF Award # SES-1026231, principal investigator Barry Bozeman), research collaborations are classified into four categories according to varying patterns of role specialization and centralization of decision making. These categories are labeled 1) assembled, 2) cooperative, 3) integrated, and 4) directed. Then, a multinomial logistic regression model estimates the log-odds of these outcome variables. Findings indicate that the integrated structure is the most common style utilized across research collaborations in all fields of study. In particular, biologists and physicists have the highest predicted probability of choosing an integrated collaboration style. Additionally, other individual level characteristics of scientists influence their choices regarding collaboration structures. As scientists career lengths increase, they are more likely to choose other patterns of collaboration organization beyond integrated structures. This may be associated with the growth of their professional networks and increasing number of contacts for potential collaborative relationships, thus increasing their ability to participate in collaborations with more varied structures. The study argues that a better understanding of these collaboration types and the factors that influence the selection of particular organizing characteristics can help to promote strategic decisions regarding collaboration management.

Introduction

Although scientific research collaboration is not a new phenomenon (Beaver & Rosen, 1978), its prevalence and scale among academic scientists in the United States has dramatically increased in the last century, and movement towards more collaborative work continues, evidenced by long-term trends of increased co-authorship across many disciplines (e.g. Braun, Glänzel, & Schubert, 2001; Cronin, Shaw, & La Barre, 2003; Melin & Persson, 1996; Wagner-Döbler, 2001) as well as larger collaborative team sizes (Adams, Black, Clemmons, & Stephan, 2005). Additionally, a recent National Science Foundation publication reports growth between 2003 and 2012 in the number of research grants awarded to projects with multiple principle investigators (National Science Foundation, 2014). Ponds, Van Oort, and Frenken (2007) offer four reasons to expect the persistent formation and growth of research collaborations throughout a wide variety of scientific fields: 1) increasing specialization in many fields as well as interest in multi-disciplinary work creates the need for researchers to combine their skills and knowledge to produce results; 2) costs for research facilities and equipment in some fields have become prohibitive to individual work; 3) instrumentation is also becoming more expensive and complex, requiring scientists with specific skills sets to operate it; and 4) funding is being tied to collaboration. Technological advances, especially in information and communication technologies, create another dynamic that facilitates collaborative efforts by making geographic proximity less important and giving researchers the capacity to gather, share, and analyze data more quickly than in the past (Cummings & Kiesler, 2007).

Individual level incentives and expectations may also drive scientists to collaborate. For instance, credit and reputation are key elements of academic reward structures (Dasgupta & David, 1994), and researchers have found evidence that collaborative journal articles may be more highly cited (Presser, 1980; Sauer, 1988). A key assumption regarding collaboration is that it has the potential to increase scientific productivity (Lee & Bozeman, 2005; Subramanyam, 1983), and although the magnitude of the increase that can be claimed depends largely upon how productivity is conceptualized and measured, empirical studies that have tested this assumption generally find positive correlations between collaboration and productivity[5] (Abramo, D'Angelo, & Di Costa, 2009; Hollis, 2001; Lee & Bozeman, 2005). Individual researchers may also be drawn to collaborations because of an opportunity to build their professional network by working with a prestigious researcher, increase social capital by being associated with a highly reputed department or research center, or gain access to funds and equipment by participating in a well-funded project (Adams et al., 2005; Melin, 2000). Furthermore, many researchers simply enjoy the intellectual stimulation and growth that can be a part of the collaboration process (Katz & Martin, 1997).

These individual level motivations are a reminder that scientists[6] form the core of any collaborative research effort. The act of combining their unique bundles of knowledge, skills, abilities, and social capital fuels the direction and productivity of the group as a whole. Although academic research collaborations take place within, and are thus influenced by, pre-existing institutions (e.g. universities) and organizational structures (e.g. academic departments, labs, and research centers), meaning that the degree of individual autonomy in academia is far from absolute (Krimsky, 2006), participating scientists typically have a relatively high degree of freedom in terms of selecting collaborative partners and organizing their own teamwork. Melin

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[5] These studies focus on collaboration in developed nations; other recent studies provide evidence that this positive collaboration-productivity relationship does not necessarily hold in developing nations where resource constraints can be significant barriers. See Ynalvez and Shrum (2011).

[6] The dissertation is concerned with collaboration in science, technology, engineering, and mathematics (STEM) fields. Throughout the dissertation these researchers are referred to broadly as scientists.

(2000 p.39) characterizes scientists' descriptions of their decisions to collaborate by saying that, "there seems to be a strong pragmatism at work together with a high degree of self-organization." Further, he finds that scientists tend to resent policies that dictate how collaborative work must be organized and also prescribes ways in which funding agencies and policymakers can encourage collaboration without dictating its direction. While defining what constitutes an appropriate level of outside direction falls outside the purview of this study, the following chapter does assert that scientists themselves are generally the most proficient actors for finding others whose particular skills and expertise are best suited for joining in a collaborative project. Scientists are well-positioned for self-organization because their expert subject matter knowledge is central to decisions about what combinations of personnel, skills, techniques, instrumentation, and facilities are needed for addressing a specified scientific problem. However, little is known about how scientists' individual level attributes contribute to their methods for organizing collaborative work. As Bozeman and colleagues (2013 p.14) argue, "there is a large hole in the literature addressing the personal and social attributes of the individual scientists that influence collaboration."

This study takes a step towards filling this gap by investigating the ways in which career, demographic, collaboration origin, and field of study characteristics of tenure-track scientists in STEM fields influence how they organize their collaborative research efforts. It proposes a typology that differentiates collaborations along two key dimensions: centralization of decision making and role specialization. Utilizing cross sectional data from the 2012 National Study of Research Collaboration (NSRC), a project funded by the National Science Foundation (NSF Award # SES-1026231, principal investigator Barry Bozeman), collaborations are classified according to varying patterns of these characteristics. Results suggest that, in general, collaborative structures with low levels of centralized decision making are popular in all STEM fields, although patterns do vary across fields of study in terms of the frequency with which higher degrees of centralization are adopted. Additionally, personal characteristics and contextual elements, particularly career length and collaboration origin variables, are related to how scientists organize their collaborative work.

Literature Review

Scientific research collaboration has received a good deal of scholarly attention (see Bozeman, Fay, & Slade, 2013 for a recent review). Within this voluminous body of research there is a stream of work that takes a structural approach, examining organizational elements of the collaboration process and the organizational and institutional structures within which collaborations operate. For instance, these types of studies explore the mechanisms and activities for organizing multi-disciplinary collaborations (Cummings & Kiesler, 2005, 2007), the processes of institutionalizing research organizations (Corley, Boardman, & Bozeman, 2006), the influences of organizational structures on scientific creativity (Heinze, Shapira, Rogers, & Senker, 2009), the organization of university research centers (Boardman & Corley, 2008), and the application of network approaches to understanding international collaboration (Wagner & Leydesdorff, 2005). Alternatively, another stream of scholarly work investigates characteristics of the individuals involved in scientific collaboration. Studies in this vein provide insights into who collaborates and why by examining collaboration patterns and how they are related to variables such as career lengths and trajectories (Lee & Bozeman, 2005; B. L. Ponomariov & Boardman, 2010; van Rijnsoever & Hessels, 2011), gender (B. Bozeman & Corley, 2004; B. Bozeman & Gaughan, 2011) and social networks (B. Bozeman & Corley, 2004; Dietz & Bozeman, 2005; Goel & Grimpe, 2013; Maglaughlin & Sonnenwald, 2005; Martinelli, Meyer, &

von Tunzelmann, 2008; Newman, 2001, 2004; B. Ponomariov & Boardman, 2008). However, as referenced above, a gap exists in the literature regarding the link between the attributes of collaborating scientists and the elements of the collaboration process, particularly in relation to how collaborations are structured and how collaborators organize their work processes.

Connecting Individual Researcher Characteristics and Collaboration Structures

Two subsets of research within the larger research streams discussed above provide a basis for linking characteristics of individual researchers to these structural organizing characteristics. First, within the stream of work that explores the characteristics of individual collaborators, there are a number of studies that investigate researchers' motivations for collaboration along with individuals' collaboration styles. In particular, Melin (2000) explores these topics using both survey and interview data. He highlights evidence from both types of data regarding a variety of individual motivations for collaboration, suggesting that collaborations work best when they are voluntary and self-organized and when scientists are allowed to choose their own structures for collaborative work. In later work, Bozeman and colleagues (B. Bozeman & Corley, 2004; B. Bozeman & Gaughan, 2011; Lee & Bozeman, 2005) identify and explore the implications of various patterns of self-organization. In particular, Bozeman and Corley (2004) label six collaboration strategies of individuals: the taskmaster, the nationalist, the mentor, the follower, the buddy, and the tactician. Each of these tactics can been seen as an individual scientist's strategy for how roles should be structured and organized within a collaboration.

The second stream of research linking collaborator characteristics to collaboration organization consists of work that classifies collaborations according to patterns of organizational features (Chompalov, Genuth, & Shrum, 2002; Hara, Solomon, Seung-Lye, & Sonnenwald, 2003; Landry & Amara, 1998; Shrum, Genuth, & Chompalov, 2007). The earliest work in this stream (Landry & Amara, 1998) examines various institutional structures for collaboration. This study describes research teams, research institutes/centers, and structures outside of formal institutions as the range of institutional structures available for collaborative work. Notably, the authors emphasize that the type of institutional structure employed depends on the choices of the participating scientists.

In a more recent study, Hara and colleagues (2003) draw attention to the importance of individual researcher characteristics when they classify collaborations along a continuum from complementary to integrative. They propose that, at one extreme, complementary collaborations are comprised of researchers with congruent but distinct skills sets who tend to work relatively independently; whereas, integrative collaborations involve researchers with overlapping roles and skills sets who interact more closely with each other. Characteristics of individual scientists such as work style, management style, and writing style have differing levels of importance depending on where along the complementary-integrative continuum the collaboration falls. In this way, the fit between individual collaborator skills is assumed to affect how the collaborative work is organized and conducted.

In two related pieces of work, Chompalov, Genuth, and Shrum (2002) and Shrum, Genuth and Chompalov (2007) propose a typology of collaboration organizational structures. Drawing on Weberian characteristics of traditional bureaucracy, they distinguish four dimensions of multi-institutional collaboration organization (hierarchy, role specialization, formalization, and scientific leadership systems) and then use cluster analysis to create a typology of multi-institutional collaborations based on varying combinations of these four features. Using data from a large number of interviews collected over multiple years, they propose that four distinct types of multi-institutional collaborations exist. First, bureaucratic collaborations are the most like traditional bureaucratic organizations. They have high levels of hierarchy, formalized roles and rules, and participating institutions each have highly specialized roles. They also tend to have clearly designated leaders or decision making committees. Next, the scholars apply the label leaderless to a second type of collaboration. These groups are characterized by specialized roles but no hierarchical structure for decision making (i.e. no designated scientific leaders). Chompalov and colleagues note that leaderless collaborations generally use formal processes to differentiate roles and prevent any one set of interests from controlling the collaboration. Conversely, the third collaboration type, non-specialized collaboration, has a set decision making hierarchy but no specialized roles. “Whereas leaderless collaboration is bureaucratic in formalization and differentiation, non-specialized is bureaucratic in hierarchical management and leadership structure (Shrum et al., 2007, p. 103). The final type of collaboration management structure is labeled participatory. These collaborations are organizationally the opposite of bureaucratic collaborations in that they lack any of the traditional bureaucratic features. Instead, they employ participatory decision making processes and tend to avoid formal contractual agreements. Participants in these collaborations do tend to have designated roles; however, the collaboration culture is one that promotes idea sharing and intellectual critique across roles.

Developing a Typology of Collaboration Organizational Patterns

Although Shrum and colleagues examine multi-institutional collaborations and thus, identify and explore variables and structural dimensions at the organizational level, their approach provides a useful starting point for thinking about how individual scientists might also structure their work. In a similar manner to their application of the characteristics of Weberian bureaucracy, this study looks to scholarly work on the organization and structure of work in a team setting. Specifically, Johnson and colleagues (2006) discuss two key dimensions of team structure: centralization and role specialization. They describe these as follows (p. 104):

> In a highly centralized team, the team leader retains control of most (or all) decisions regarding the team and its work. In a highly decentralized team, team members have extensive autonomy in making decisions affecting their individual work, and they often must reach consensus decisions on issues affecting the team as a whole. Second, departmentation reflects the horizontal aspect of structure (i.e., the degree to which the organization members' formal roles are specialized). In highly functional team structures, each team member is a specialist or has expertise that the other team members do not share. In highly divisional team structures, team members are undifferentiated generalists, and they share expertise.

These attributes are also discussed by other team scholars. For instance, Johnson and colleague's definition of role specialization is similar to the definition that Stewart and Barrick (2000 p.137) offer for team interdependence: "the extent to which members cooperate and work interactively to complete tasks." Mathieu and colleagues (2008) also assert that the degree of interdependence is a central element of team studies and that it is a key consideration for studies aimed at furthering knowledge of team processes. Similarly, other team scholars have studied leadership and decision making within teams. Recent work explores the implications of shared (i.e. decentralized) leadership versus having a single (i.e. centralized) team leader (Carson, Tesluk, & Marrone, 2007; Mathieu, Maynard, Rapp, & Gilson, 2008). Drawing on this work, this essay proposes a typology of collaboration structures at the level of the collaborative group or team. The typology can be summarized using a two-by-two grid (Shown in Figure 2.1) representing the two key dimensions of team structure discussed above (i.e. centralization of decision making and role specialization).

First, the bottom left quadrant represents collaborative groups that employ both low levels of role specialization and low levels of centralization. These collaborations are labeled 'integrated'. In integrated collaborations researchers utilize participative decision making procedures, meaning that scientific decision making authority does not reside in any single collaborator. As such, there is no collaboration leader who controls the scientific direction of the work. Instead, collaborators pool their expertise to address questions or problems of interest. It is routine and expected for participants to work closely together, communicating often, and task roles generally overlap.

Next, the top left quadrant represents ‘directed’ collaborations. These collaborations utilize a high degree of centralization but have low levels of role specialization. In this way, directed collaborations have a designated leader who guides the work and makes decisions about the scientific direction of the project. However, as with integrated collaborations, participants are expected to work closely together on overlapping tasks.

In the top right quadrant collaborations possess high levels of both centralization and role specialization and can be called ‘assembled’. In these types of groups, a leader guides overall scientific direction and compiles the contributions of the collaboration’s constituents, assembling them like pieces of a puzzle. Because roles are highly specialized and related to areas of expertise, collaborators have autonomy over their own tasks, but decision making regarding group processes is centralized.

Finally, the bottom right quadrant represents collaborations with low levels of centralization but high levels of role specialization, and collaborations in this quadrant are designated ‘cooperative’. This description corresponds to the most traditional representation of scientific collaboration (Hagstrom, 1964). Here, collaborators bring differing sets of expertise to the collaboration and work relatively autonomously. Decision making procedures are participative and no one group member has authority over any of the others in terms of scientific work.

Hypotheses

This chapter proposes four sets of hypotheses linking individual level collaborator characteristics to the four types of collaboration structures represented in the above typology.

Career Characteristics

The first set of hypotheses address career related variables. Studies have shown that career trajectory variables are associated with scientists' publication and patenting productivity (Dietz & Bozeman, 2005). Additionally, findings suggest that younger scientists accrue more benefits from research collaboration than do those who are farther along in their careers (Lee & Bozeman, 2005). To date, no findings directly address the association between career variables and collaboration structures. However, on the basis of the above findings which indicate that younger researchers receive more benefit from collaborations and also the fact that younger researchers are under more pressure to produce publications to achieve tenure and promotion, a set of hypotheses is proposed.

First, during the early stages of their careers, scientists must track and report their research contributions for the purposes of tenure and promotion. Therefore, they may be drawn to collaborations where roles are clearly delineated and credit for an activity is easily attributable to one person. Assembled and cooperative collaborations have higher levels of role specialization.

Hypothesis 1a: Early career scientists will be more likely to be involved in assembled collaborations.

Hypothesis 1b: Early career scientists will be more likely to be involved in cooperative collaborations.

On the other hand, late career scientists have more latitude to pursue collaborations in which their contributions are not strictly defined. Additionally, scientists who are more advanced in their careers may have more opportunities to mentor students. In these cases, researcher roles may intentionally overlap to facilitate student learning.

Hypothesis 1c: Late career scientists will be more likely to be involved in directed collaborations.

Hypothesis 1d: Late career scientists will be more likely to be involved in integrated collaborations.

Collaboration Origins

A second set of hypotheses is informed by the theory of scientific and technical human capital (S&THC) (B. Bozeman, Dietz, & Gaughan, 2001; Dietz & Bozeman, 2005). This work highlights the importance of researchers' social capital as well as the knowledge, skills and abilities that make up their store of human capital. Dietz and Bozeman (2005) find that S&THC factors affect scientists' career patterns and productivity levels, and other discussions have suggested that these factors may also affect the collaboration's internal organizational structure (B. Bozeman, Fay, & Slade, 2013, p. 17). While data availability precludes testing the links between overall S&THC and collaboration organization in the current study, some aspects of scientists' S&THC are examined. Specifically, survey questions ask respondents to report how they met their current collaborators. Different types of collaboration origins may influence the choices that collaborators make regarding how to organize their research efforts. For instance, a collaboration emerging from a relationship between a single professor in a mentor role and one or more students may have a higher degree of centralization than a collaboration originating from professional relationships among equally situated peers. The following hypotheses link various permutations of collaboration origins to collaboration structures.

First, in collaborations with equally situated peers, decision making might be more participative or consensual, indicating a decreased degree of centralization. Collaboration structures with low degrees of centralization include cooperative and integrated collaborations, and origin variables that indicate that collaborators are potentially same status peers include collaborators who meet at conferences, those who meet through mutual colleagues, and those who meet in graduate school.

Hypothesis 2a: Collaborators who meet at conferences will be more likely to form cooperative or integrated collaborations.

Hypothesis 2b: Collaborators who meet through mutual colleagues will be more likely to form cooperative or integrated collaborations.

Hypothesis 2c: Collaborators who meet in graduate school will be more likely to form cooperative or integrated collaborations.

Alternatively, in collaborations with unequally situated members, high degrees of centralization might be more common. Both assembled and directed forms utilize high degrees of centralization. Because collaborators who indicate that they are working with current or former students as well as those working with former advisors can be considered to have an unequal status collaboration, two additional hypotheses propose that collaborators in these types of groups are likely to choose more centralized structures for organizing their work.

Hypothesis 2d: Collaborations between professors and current or former students will be more likely to be assembled or directed.

Hypothesis 2e: Collaborators who collaborate with their former thesis advisor will be more likely to form assembled or directed collaborations.

Other individual level characteristics may also affect the level of role specialization that collaborators choose to employ. For instance, if researchers from different departments are collaborating with each other, it is likely they have chosen to work together so that they can benefit from their divergent areas of expertise. In these cases, researchers may be likely work on parts of the project related to their specific knowledge areas rather than having overlapping roles. Collaboration structures with high levels of role specialization include the cooperative and assembled forms.

Hypothesis 2f: Collaborations including researchers from different academic departments will be more likely to be cooperative or assembled.

Finally, instances may also occur where collaborators' skills are substitutes rather than complements. In these situations their mutual expertise may allow them to work closely together on the same elements of a project, integrating their work and sharing overlapping roles. Collaboration organizational forms with low role specialization include integrated and directed structures.

Hypothesis 2g: Collaborations including collaborators from the same academic department will be more likely to be integrated or directed.

Field of Study

Another characteristic that potentially influences the structures of research collaborations is the academic department of the participating scientists. Field of study may serve as a proxy for various contextual elements of the collaboration. For example, Chompalov and colleagues (2002) argue that high energy particle physics is associated with a participatory style of collaboration organization due to research facility size and data sharing norms in the field. Additionally, in some fields such as biomedical sciences large collaborations and their attendant complexity are standard (Cronin, 2001). Although NSRC data does not allow for the examination each of these contextual elements separately, they can be approximated through field of study. Because there is only scant evidence for how various fields of study and features of collaboration may be linked, this study proposes a general hypothesis rather than treating each field of study separately.

Hypothesis 3: A scientist's field of study will be significantly related to choice of collaboration structure.

Collaboration Size

In addition to the individual characteristics of collaborators, organization theory describes ways in which the contextual characteristics of an organization might affect its internal organizational structure. Size is a particularly important variable; larger organizations are often linked to bureaucratic organizational features (Child & Mansfield, 1972; Grinyer & Yasai-Ardekani, 1981; Hinings & Lee, 1971; Pugh, Hickson, Hinings, & Turner, 1969). This study argues that increasing size likely also introduces increased complexity for research collaborations. In particular, high degrees of centralization may provide researchers in large collaborations with a mechanism for smoothing decision making processes and diminishing coordination costs. Both assembled and directed structures are characterized by high levels of centralization.

Hypothesis 4a: Large collaborations will be more likely to be assembled or directed.

The converse is hypothesized to be true for smaller collaborations; they should exhibit lower levels of centralization and therefore should be associated with cooperative or integrated collaboration structures.

Hypothesis 4b: Smaller collaborations will be more likely to be cooperative or integrated.

Data

In order to examine these four sets of hypotheses, this study employs data from the 2012 National Study of Research Collaboration (NSRC), a project funded by the National Science Foundation (NSF Award # SES-1026231, principal investigator Barry Bozeman). Its investigators conducted surveys that queried scientists about their most recent research collaboration experience, its outcomes, and their general perceptions about past collaboration experiences more broadly. The sampling frame for the survey included researchers in tenure-track academic positions and a subsample of postdocs from fourteen targeted disciplines employed at universities classified by the Carnegie Foundation for the Advancement of Teaching[7] as having very high research activity[8]. Questionnaires were sent to 1700 respondents, and a total of 654 surveys were completed (initial response rate=38.5%). Since the purpose of this study is to examine research collaboration, respondents who reported never collaborating were eliminated from the final data set. This resulted in 641 observations (final response rate 37.7%). Two additional adjustments were made to the data. First, NSRC questionnaires collected data from respondents in economics fields. Economics is not traditionally considered a STEM field. In the NSRC economists were included in the sample in order to incorporate experiences

[7] Responsibility for the classifications have now been transferred to Indiana University Bloomington's Center for Post-Secondary Research. See http://carnegieclassifications.iu.edu/

[8] Selected Disciplines: Biology, Computer Science, Mathematics, Physics, Earth and Atmospheric Science, Chemistry, Economics, Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, Materials Engineering/Materials Science, Industrial/Manufacturing Engineering, Biomedical Engineering

from social scientists into the survey. Because this chapter focuses specifically on STEM fields the economists are excluded from the data set (62 observations). Finally, the subsample of postdocs (17 observations) is also removed from the analysis to maintain the focus on collaborations among tenure-track faculty. Therefore, the total number of observations included in the analysis is 581. Table 2.1 displays descriptive statistics for the data set.

Due to the structure of the questionnaire, which asks scientists to relate information about their most recent publication, co-authorship is used as a measure of collaboration. This practice is a standard and accepted method for estimating collaborative activity (Katz & Martin, 1997; Melin & Persson, 1996), and it has several advantages, "including verifiability, stability over time, data availability, and ease of measurement" (B. Bozeman et al., 2013, p. 2). Many studies that examine collaboration as co-authorship use bibliometric techniques to analyze collaboration patterns (Katz & Martin, 1997). The questionnaire data employed here mitigates one major criticism levied at these studies of collaboration as co-authorship because survey responses allow for exploration of elements of the collaboration process beyond a list of author names and affiliations. However, it should be noted that other shortcomings still remain, chiefly that publications are only one possible outcome of collaborative work and that collaboration is likely more complex and multi-faceted than is captured by examining any single publication (B. Bozeman et al., 2013).

Key Variables and Measures

The following subsections describe the key variables and measures that the study uses to analyze collaboration structures. A summary of this discussion including key concepts, definitions, variables, and measures is provided in Table 2.2.

Dependent Variable

The key dependent variable in this study is the type of collaboration structure chosen by collaborating scientists: assembled, directed, integrated or cooperative. In order to create these categories, the study first operationalizes centralization and role specialization using two sets of survey questions. Table 2.3 provides the specifications of these survey items. The first set of questions collects information related to the level of centralization within a collaboration. These questions inquire about the decision making practices collaborators use to determine co-authorship order. This portion of the questionnaire asks scientists to indicate whether they had an explicit discussion about co-authorship order either before, during, or after their collaboration experience. If they specify that they did not discuss co-authorship order, a follow-up question asks if co-authorship order was assumed based on a previous collaboration or if one person made the co-authorship decision. The assumptions is that in a highly centralized group one person or entity has final decision-making authority. Therefore, when scientists report that one person made the authorship order decision, their collaborations are coded as having a high degree of centralization. Alternatively, collaborations are coded as having low centralization if scientists indicate that authorship order decisions were a result of group discussion or mutual understanding.

A second set of questions probes the level of role specialization within the collaboration by asking about the division of labor among participating scientists. Respondents are presented with a list of eight common research roles and are asked to indicate whether the lead author, another co-author, the scientist responding to the survey (if not the lead author), or someone not included as a co-author fulfilled that role in the collaboration. The eight activities include generating the research question, collecting data, analyzing data, reviewing literature, writing part of the published article, providing funding, and administering the laboratory or center. Because this chapter uses co-authorship to indicate collaboration, responses about roles played by individuals not included as co-authors are disregarded[9]. In order to maintain focus on roles directly related to the product of the collaboration, questions about funding and administration roles are also not included in the final analysis. Furthermore, even in collaborations with very specialized roles several of the co-authors might participate in writing and reporting their respective portions of the project therefore the question about writing part of the published article is also excluded. The remaining four questions provide insight into whether the collaboration has a high or low level of role specialization. Scientists are able to check as many boxes as apply to indicate who worked on that part of the project. In order to create the role specialization variable, the boxes are counted with the expectation that collaborations with very specialized roles only have four checked boxes. In other words, the scientist indicates that one person is responsible for each task. Alternatively, scientists participating in collaborations with low levels of role specialization are expected to check boxes in such a way as to indicate that collaborators have overlapping roles for the core collaborative tasks.

After gathering this information, two dichotomous variables are created, one to indicate whether a specific collaboration has a high or low level of centralization and another that reports whether there is a high or low level of role specialization. Then, these two variables are used to create a categorical variable with categories corresponding to the aforementioned types of collaboration structures: assembled, directed, integrated, or cooperative. Table 2.4 summarizes data frequencies for each type of research collaboration.

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[9] Very few respondents indicated that a non-author had a role in these substantive research activities: developing the research question (2%), collecting data, (6%) analyzing data (2%), and reviewing the literature (1%).

<u>Key Independent Variables</u>

Previous research indicates that researchers' demographic and career characteristics are associated with outputs and outcomes of collaborations (B. Bozeman et al., 2013). The current analysis includes two career stage variables, a series of dummy variables indicating types of collaboration origins, two demographic variables, a set of dummy variables representing respondents' home academic departments, and a variable capturing collaboration size. Each is discussed briefly in turn below, and Table 2.1 displays summary statistics.

Career Stage

The NSRC survey provides two variables that offer a snapshot of each respondent's career stage. The first is a dichotomous variable measuring whether or not the scientist has tenure at his or her institution. In addition, respondents are asked to indicate the year that they received their PhD. This response is used to calculate the current length of the respondent's career in years, represented by a continuous variable.

Collaboration Origins

The second set of independent variables includes a series of dummy variables indicating the social relationships that form the basis for the collaborative relationship. The survey instrument asks the respondent to choose the best option to describe his or her relationship to the collaborator(s) within his or her most recent collaboration. Respondents were instructed to check all that apply, meaning that these categories are not mutually exclusive. Options include the following: met in graduate school, met at an academic conference, work in the same academic department, work at the same institution but in different departments, met through a mutual colleague, my thesis advisor was my co-author, my co-author was my current or former student and other. A series of dummy variables is constructed to represent each origin category.

Demographic Characteristics

Demographic variables included as controls in the model are gender and race. Both are dichotomous variables. Gender is coded 1 for male and 0 otherwise, and race is coded 1 for non-white and 0 otherwise. In particular gender has been a central focus of various studies of research collaboration (B. Bozeman & Corley, 2004; B. Bozeman & Gaughan, 2011; Gaughan & Corley, 2010; van Rijnsoever & Hessels, 2011). However, these studies tend to examine male/female differences in research productivity rates or number of collaborators. They do not offer much insight into whether gender differences play a key role in choices of collaboration structures. Therefore, no specific hypotheses are offered for the influences of gender or race on the structures of research collaborations.

Home Department

With the exception of high energy particle physics, which Chompalov and associates (2002) indicate should be expected to engender more participatory collaborations; little is known regarding whether specific fields are more or less aligned with certain organizational strategies. When completing the NSRC survey, scientists indicate their affiliation with an academic department. These responses are grouped into eight categories: Earth and Atmospheric Sciences, Chemistry, Physics, Computer Science, Engineering, Math, and Biology, and a dichotomous variable is created for each category. Departmental affiliations are expected to be associated with choices of organizational structures, but no specific associations are hypothesized.

Size

Collaboration size can be conceptualized in a variety of ways including in terms of magnitude of funding, number of disciplines involved, and number and size of partnering institutions, among others. However, because this chapter employs the definition of collaboration as co-authorship and examines collaborations among individual scientists, the size of the collaboration is equated to the number of co-authors on the publication. The survey asked respondents to report the number of co-authors from their most recent collaboration. This number is reported as a continuous variable representing the size of the collaboration.

Method

In order to investigate the above hypotheses, the study employs multinomial logistic regression which is appropriate for modeling the relationship between researcher characteristics and type of collaboration structure because of the inherently unordered nature of the categories of the dependent variable[10] (i.e. assembled, directed, integrated, and cooperative). Multinomial logit models fit the log-odds of membership in each category of the nominal variable of interest with one of the outcomes of the variable which is specified as a base or comparison category. The general multinomial logit model[11] is specified as

$$\ln \frac{\Pr(Y = m \mid x)}{\Pr(Y = b \mid x)} = x\beta_{m \mid b} \qquad \text{for m=1 to J}$$

The left hand side of the equation represents the natural log of the odds of choosing a particular outcome. The letter *b* represents the base category and the letter *m* represents the other categories of the dependent variable. On the right hand side $\beta_{m|b}$ is a vector of regression coefficients, and x represents a vector of independent variables.

[10] The multinomial logit model assumes the independence of irrelevant alternatives (IIA), meaning that the odds of choosing one alternative do not depend on the odds of other available alternatives. A Small-Hsiao was conducted to check for IIA violations. The test provided conflicting evidence of whether there were violations of the assumption. This is not unusual (Long & Freese, 2006).

[11] See Long and Freese 2006 p. 227

The following equations show the multinomial logit model that was fitted for this study[12]. The largest outcome category, integrated, is used as the base category[13]. Table 2.4 shows the distribution of collaborations among outcome categories. Independent variables in the model, as discussed above, include a series of dummy variables for respondents' fields of study (variables 1-6), variables representing different types of collaboration origins (7-14), number of co-authors in the collaboration (15), demographic information about the respondent (16-17), and career related variables (18-19). The equations for the multinomial model are displayed below.

$$\ln \frac{\Pr(y=Assembled)}{\Pr(y=Integrated)} = \beta_{0,A|I} + \beta_{1,A|I}(\text{EAS}) + \beta_{2,A|I}(\text{Engineering}) + \beta_{3,A|I}(\text{Biology}) +$$
$$\beta_{4,A|I}(\text{Chemistry}) + \beta_{5,A|I}(\text{Physics}) + \beta_{6,A|I}(\text{ComputerScience}) +$$
$$\beta_{7,A|I}(\text{MetSameUnivDiffDepartments}) + \beta_{8,A|I}(\text{MetStudents}) + \beta_{9,A|I}(\text{MetConference}) +$$
$$\beta_{10,A|I}(\text{MetSameDepartment}) + \beta_{11,A|I}(\text{MetGradSchool}) + \beta_{12,A|I}(\text{MetAdvisor}) +$$
$$\beta_{13,A|I}(\text{MetMutualColleague}) + \beta_{14,A|I}(\text{MetOther}) + \beta_{15,A|I}(\text{Number Coauthors}) +$$
$$\beta_{16,A|I}(\text{Male}) + \beta_{17,A|I}(\text{Nonwhite}) + \beta_{18,A|I}(\text{Tenured}) + \beta_{19,A|I}(\text{CareerLength})$$

$$\ln \frac{\Pr(y=Cooperative)}{\Pr(y=Integrated)} = \beta_{0,C|I} + \beta_{1,C|I}(\text{EAS}) + \beta_{2,C|I}(\text{Engineering}) + \beta_{3,C|I}(\text{Biology}) +$$
$$\beta_{4,C|I}(\text{Chemistry}) + \beta_{5,C|I}(\text{Physics}) + \beta_{6,C|I}(\text{ComputerScience}) +$$
$$\beta_{7,C|I}(\text{MetSameUnivDiffDepartments}) + \beta_{8,C|I}(\text{MetStudents}) + \beta_{9,C|I}(\text{MetConference}) +$$
$$\beta_{10,C|I}(\text{MetSameDepartment}) + \beta_{11,C|I}(\text{MetGradSchool}) + \beta_{12,C|I}(\text{MetAdvisor}) +$$

[12] For sensitivity analysis binary logits of each of the outcome variables were performed as well. Results were very similar and corroborated the multinomial logit results.

[13] On the right hand side of the equations the letters A, I, C, and D represent the outcome categories assembled, integrated, cooperative, and directed, respectively. The base category (Integrated) is the category with the largest number of outcomes.

$\beta_{13,C|I}$(MetMutualColleague) + $\beta_{14,C|I}$(MetOther) + $\beta_{15,C|I}$(Number Coauthors) + $\beta_{16,C|I}$(Male) + $\beta_{17,C|I}$(Nonwhite) + $\beta_{18,C|I}$(Tenured) + $\beta_{19,C|I}$(CareerLength)

$$\ln \frac{\Pr(y=Directed)}{\Pr(y=Integrated)} = \beta_{0,D|I} + \beta_{1,D|I}(\text{EAS}) + \beta_{2,D|I}(\text{Engineering}) + \beta_{3,D|I}(\text{Biology}) + \beta_{4,D|I}(\text{Chemistry}) + \beta_{5,D|I}(\text{Physics}) + \beta_{6,D|I}(\text{ComputerScience}) + \beta_{7,D|I}(\text{MetSameUnivDiffDepartments}) + \beta_{8,D|I}(\text{MetStudents}) + \beta_{9,D|I}(\text{MetConference}) + \beta_{10,D|I}(\text{MetSameDepartment}) + \beta_{11,D|I}(\text{MetGradSchool}) + \beta_{12,D|I}(\text{MetAdvisor}) + \beta_{13,D|I}(\text{MetMutualColleague}) + \beta_{14,D|I}(\text{MetOther})\ \beta_{15,D|I}(\text{Number Coauthors}) + \beta_{16,D|I}(\text{Male}) + \beta_{17,D|I}(\text{Nonwhite}) + \beta_{18,D|I}(\text{Tenured}) + \beta_{19,D|I}(\text{CareerLength})$$

Results

Tables 2.5 – 2.7 display the results of the multinomial logistic model and subsequent analyses. Overall, the findings indicate that the integrated collaboration structure is overwhelmingly the most popular among individual scientists, with assembled and directed collaborative structures representing relatively rare events.

Hypothesis 1

Of the characteristics of individual researchers, career related variables have the most consistent influence across collaboration structures. However, the results indicate a reversal of the direction of Hypotheses 1a-1d which propose that early stage scientists are more likely to be involved in assembled and cooperative collaborations and late stage scientists are more likely to be involved in directed and integrated collaborations. On the contrary, evidence indicates that increases in career length are associated with increased likelihoods of choosing assembled and cooperative structures over integrated structures. Findings also show that tenured scientists are less likely to choose to be involved in directed collaborations than integrated ones. This may be associated with the larger professional networks of later career scientists which imply increasing numbers of contacts for potential collaborative relationships and thus, opportunities to participate in collaborations with more varied structures. Further, the finding could reflect pressures for younger scientists to collaborate with similarly situated peers and establish evidence of their own reputation in a field of study rather than being involved in centralized collaborations in which they may have lower status or position. Additionally, younger scientists are also less likely to have developed a reputation for having a specific set of skills or expertise. Therefore, they may be less likely to be invited into a collaboration on the basis of fulfilling a highly specialized role. Similarly, later stage scientists may find collaborations that offer some form of autonomy attractive, either in terms of independence in their own tasks or in terms of filling a leadership role for a collaborative group.

In addition to the regression coefficients, average marginal effects, reported in Table 2.6, further describe the characteristics that drive collaboration structural choices by indicating the magnitude of the effect of each variable. Only statistically significant effects are reported in the table which shows that although the marginal effect of career length is statistically significant for all structural choices except directed, the effects are very small. For example, a one year increase in career length is only associated with a .01% increase in the probability that a researcher chooses an assembled structure for his or her collaborations.

Hypothesis 2

The second set of hypotheses proposes that various collaboration origins facilitate certain types of collaboration structures. Results offer some support for this premise, although typically not in the hypothesized direction. One notable exception is Hypothesis 2e which receives partial support. This hypothesis states that collaborators who are involved in a collaboration that includes their former thesis advisor will be more likely to have assembled or directed structures. The results indicate that respondents who reported collaborating with their past advisor are more likely ($p<.1$) to choose assembled structures. Marginal effects indicate that when collaborating with an advisor a researcher is 4% more likely to report an assembled collaboration.

Although not in the hypothesized direction, two other origin variables are also significant in the model. Researchers who indicate that they met their collaborators in a different department at their own university and those who met collaborators through a mutual colleague are less likely to adopt cooperative collaboration organizational structures than integrated ones. This may be indicative that social ties between collaborators facilitate an environment in which tasks can be shared and different perspectives more easily melded allowing them to integrate their work rather than working separately and then fitting the pieces together.

Hypothesis 3

In addition to personal characteristics, departmental affiliation also has a significant effect on researchers' choices of collaboration structures. This supports Hypothesis 3 which indicates that field of study characteristics should have an effect on collaboration organization. While Table 2.4 displays overall percentages for each outcome variable (integrated 72%, assembled 2%, directed 7%, cooperative 19%), Table 2.7 below adds detail to this picture by presenting the predicted probabilities for each collaboration structure based on the respondent's academic department while holding all other variables constant at their means. The predicted probabilities show that the integrated collaboration style is predicted to be, by far, the most popular choice in every field of study (> 70% predicted probability in all fields), followed by cooperative style collaborations (.05-.18). Chemists (.92), physicists (.83), and biologists (.85) have higher predicted probabilities than scientists in other fields for choosing the integrated style of collaboration organization, and chemists, in particular, have a zero predicted probability of choosing to organize using the assembled structure.

Hypothesis 4

The final set of hypotheses proposed that research collaboration size would have an effect on the whether participating scientists utilize centralized decision making procedures. The findings do not indicate a significant effect of size on collaboration structure. Thus, Hypothesis 4 is not supported. However, this result should be viewed with some caution. Although there are a few very large collaborations included in the data set, the majority report less than twenty collaborators. The mean number of collaborators is approximately ten, and seventy-five percent of collaborations have seven or fewer co-authors. Data therefore may not fully capture typical organizational structures of very large research collaborations. Additionally, collaboration is defined here as co-authorship; as collaborations become very large it is likely that subsets of scientists will co-author papers rather than the entire list of collaboration participants.

Discussion

This findings relayed in this chapter suggest several practical implications for organizing and managing scientific research collaborations and also offer lessons for science policy makers and public managers such as university administrators. First, the study provides empirical evidence that research collaboration structures are affected by the individual characteristics of their organizers. A better understanding of collaboration structures and the factors influencing their selection and use can help to promote strategic choices regarding collaboration management strategies. These strategies can include a variety of activities such as processes for resolving conflict among collaborators, making decisions about co-authorship and contribution, assigning roles, and dividing resources, among others. If scientists understand which types of management strategies best support the type of organizational structure they have chosen, this can help to smooth the workflow throughout the collaborative project and mitigate potential problem situations. For example, if a group of scientists is intentional about organizing in an integrated manner, they can plan meetings for key decision points in the project to ensure that all collaborators have a voice in decision making processes so that all perspectives may be truly integrated into the work. In this way, understanding organizational structures helps participating researchers to build appropriate expectations for collaborative work.

Another key implication for scientists relates to differences in organizational norms across various fields of study. As cross-disciplinary collaboration continues to increase in popularity, researchers should not assume that organizational strategies typically employed in their own fields of study are familiar to all collaborators. Early and deliberate discussions about how to blend organizational preferences for researchers in different fields may help sensitize researchers to differing norms and facilitate future problem-solving.

Policy makers and administrators can also benefit from recognizing patterns in how scientists organize the processes of collaborative work. For example, evidence in this study indicates that the most popular structures for collaboration among individual scientists are those that have low degrees of centralized decision making. Both public sector actors and university administrators are involved in the creation and maintenance of university research centers as an institutional form for encouraging collaborative research. However, research centers often involve administrative apparatuses that may create pressures to organize collaborations more bureaucratically. Garrett-Jones and colleagues (2010) found that scientists sometimes express dissatisfaction with research center work because they expect research centers to be collegial rather than hierarchical. Research center administrators or government sponsors of university centers may be able to mitigate this strain by developing more participatory procedures for how scientists interact within the center, or alternatively, providing more extensive orientation for scientists when they choose to affiliate with the center.

Limitations and Future Directions

It is important to note some of the limitations of the study as well as the directions that these limitations indicate for future research. First, the measures used here are broad gauge measures of centralized decision making and role specialization; both concepts are more nuanced than is allowed by their current dichotomous operationalization. Both role specialization and centralization might be better envisioned as spectrums rather than dichotomous variables. Additionally, the current measures of both of these variables do not fully capture all of their dimensions. For instance, role specialization or lack thereof, among the co-authors, outside of the lead author and responding scientist, is not fully encapsulated in the current variable. Similarly, decision making processes, beyond those used for the co-authorship decisions are not presently considered. However, as Bozeman, Fay, and Slade (2013) challenge their audience, studies of research collaboration should begin to address the linkages between researcher characteristics and decision making processes within collaborations. The measures employed here offer a small step toward this goal by exploring how variations in organizing variables are driven by the characteristics of individual researchers.

A second limitation of the study is the scarce number of observations in some of the categories of the dependent variable. The integrated category captures 72% of all research collaborations reported in the study, and the assembled (2%) and directed categories (7%)

comprise relatively rare events. Therefore, it is not possible to discuss the typical collaboration in either of these categories. It also raises questions about what contextual elements not identified here might be the impetus for scientists to choose to utilize assembled or directed structures.

The analysis is also limited by the fact that only one member of a collaboration reports on the collaboration structure. It would be beneficial to triangulate perceptions from all study members in relation to the organizational elements of the collaboration. For example, it is interesting that respondents are significantly more likely to claim that their collaborations are assembled rather than integrated if their co-authors include their former thesis advisor while, on the other hand, this relationship does not hold true for collaborations that include current or former students as co-authors.

Other areas for future research suggested by the line of reasoning in this study include understanding how collaboration structures may be linked to collaboration outputs and outcomes. Little is known about whether some structures facilitate outputs such as publications, patents, company start-ups, or new technology development more readily than others or whether certain structures are more appropriate for specific types of scientific endeavors, questions, or contexts than others. Questions also remain regarding the longitudinal development of research collaborations. Collaborations can terminate after one project, experience periods of dormancy followed by additional activity at a later date, operate continuously across years and a variety of projects, or potentially develop and become institutionalized as a research center or academic department. With the current cross-sectional data, it is not possible to develop an understanding how structures evolve and change over the life span of the collaboration, but this is another area that may have important implications for scientists, policymakers, and administrators alike.

Table 2.1: Descriptive Statistics

Variable Name	N	Mean	sd	Min	Max
Home Department					
EAS	581	.10	.30	0	1
Physics	581	.10	.30	0	1
Engineering	581	.43	.50	0	1
Biology	581	.10	.31	0	1
Comp. Science	581	.09	.29	0	1
Chemistry	581	.10	.30	0	1
Math	581	.08	.27	0	1
Collaboration Origins					
Met Grad School	581	.12	.33	0	1
Met at Conference	581	.24	.43	0	1
Met Same Dept.	581	.28	.45	0	1
Met Same Univ. Diff. Dept.	581	.25	.43	0	1
Met Mutual Colleague	581	.21	.41	0	1
Met Past Advisor	581	.06	.23	0	1
Met My Student	581	.43	.50	0	1
Met Other	581	.07		0	1
Researcher Characteristics					
Career Length	567	20.89	11.47	3	56
Tenured	568	.71	.46	0	1
Male	562	.47	.50	0	1
Non-White	581	.22	.41	0	1
Collaboration Size					
Number of Coauthors	567	9.90	86.02	1	2000

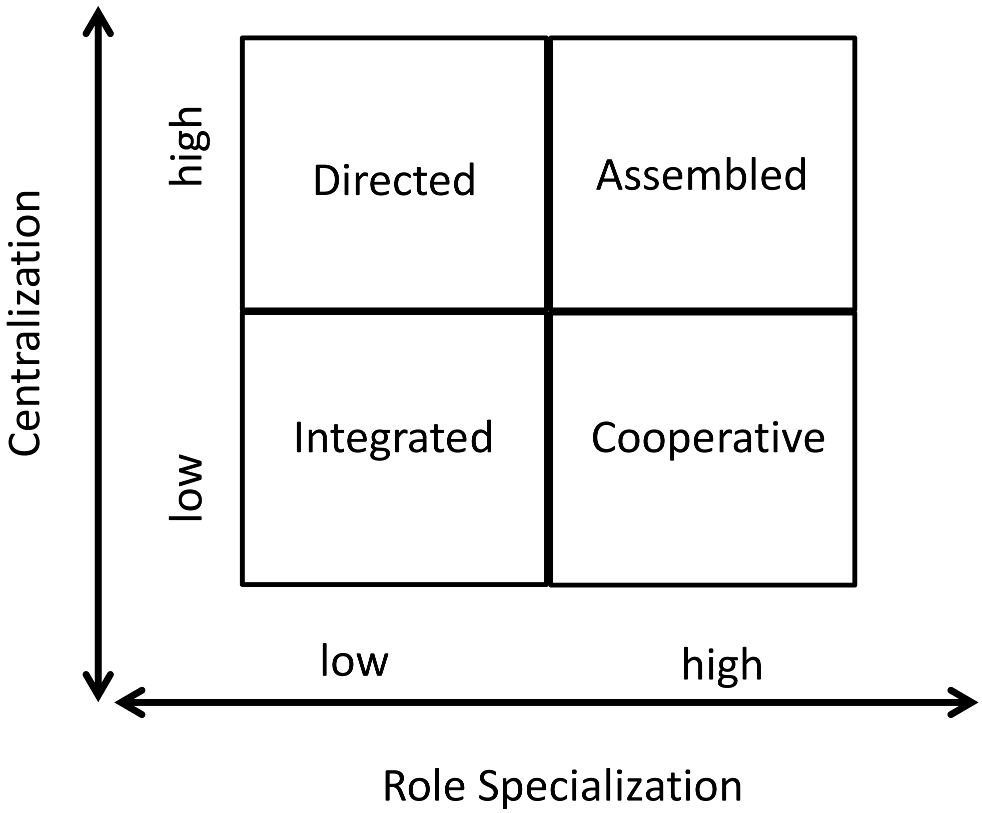

Figure 2.1: Typology of Collaboration Structures

Table 2.2 Summary of Key Concepts, Definitions, Variables, and Measures

Key Concept	**Definition**
Research Collaboration	Defined narrowly as co-authorship for a peer reviewed journal publication.
Classifier Variables	**Measure**
Role Specialization	Dichotomous (0/1) variable representing the degree to which collaborators' tasks overlap. When tasks overlap variable is coded 0 (low). When tasks do not overlap variable is coded 1 (high).
Centralization of Decision Making	Dichotomous (0/1) variable representing the degree to which decision making is centralized within a collaboration. When collaborators indicate discussion or mutual understanding about co-authorship the variable is coded 0 (low). When collaborators indicate that one person made the co-authorship decision the variable is coded 1 (high).
Dependent Variables	**Measure**
Integrated Collaboration	Dichotomous (0/1) variable representing a combination of role specialization and centralization variables. When Role specialization = 0 (low) and Centralization = 0 (low), then a collaboration is classified as integrated.
Assembled Collaboration	Dichotomous (0/1) variable representing a combination of role specialization and centralization variables. When Role specialization = 1 (high) and Centralization = 1 (high), then a collaboration is classified as assembled.
Directed Collaboration	Dichotomous (0/1) variable representing a combination of role specialization and centralization variables. When Role specialization = 0 (low) and Centralization = 1 (high), then a collaboration is classified as directed.
Cooperative Collaboration	Dichotomous (0/1) variable representing a combination of role specialization and centralization variables. When Role specialization = 1 (high) and Centralization = 0 (low), then a collaboration is classified as cooperative.

Independent Variables	Measure
Career Length	Continuous variable measuring the number of years since the respondent received his or her PhD.
Tenure Status	Dichotomous variable coded 0 (not tenured) and 1 (tenured).
Gender	Dichotomous variable coded 0 (female) and 1 (male).
Race	Dichotomous variable coded 0 (non-white) and 1 (white)
Home Department	Series of dummy variables coded 0/1 for each of the following departmental affiliations: Earth and Atmospheric Sciences, Physics, Engineering, Biology, Computer Science, and Chemistry.
Collaboration Origins	Series of dummy variables coded 0/1 for each of the following types of collaborations origins: met in grad school, met at a conference, met working in the same department, met through a mutual colleague, met working at the same university in different departments, collaborator is a past advisor, collaborator is a past student, and other
Collaboration Size	Continuous variable that indicates the number of co-authors in the collaboration

Table 2.3: Survey Items Used for Development of Dependent Variables

Variable	Survey Item
Decision Making: explicit discussion indicates *decentralized* decision making	Q: Did you and your co-author(s) ever have explicit discussions about co-authoring credit (e.g. who should or should not be listed as a co-author, author order)? R1. We had an explicit discussion R2. We had no explicit discussion, these issues were more or less assumed
Decision Making: one person made the decision (R2-R4) indicates single locus of decision making authority and *centralized* decision making. Other reasons for not having a discussion (R1, R5, R6) are coded as *decentralized*. Responses that fell into the other category (R7) were coded low or high on a case by case basis.	*If "we had no explicit discussion, these issues were more or less assumed" is selected.* Q: Since there was no explicit discussion of co-authorship, how was the decision made about whom to include and not include as a co-author? Please check all that apply. R1. We followed practice from previous collaborations R2. One person made the decision R3. The person making the decision was first author R4. The person making the decision was the most senior person in the collaboration R5. Author order seemed obvious because of the nature or amount of work that each collaborator performed R6. It was clear to us that one or more persons had greater need because of career status (e.g. job-seeking, tenure) R7. Other
Role Specialization: overlapping roles indicates *low role specialization;* separate roles indicates *high role specialization* (note: not all activities included on the questionnaire are shown here since expectations are that for some activities such as writing, several collaborators will share the role even in collaborations with high role specialization)	Q: Below is a list of activities that could be part of any research collaboration. Referring again to the same most recent co-authored publication, please indicate below whether co-authors were engaged in the respective activities. Activities: 1. Initially Developing the Research Question 2. Providing or Collecting Data 3. Conducting Data Analysis or Testing 4. Reviewing Literature Performed by: 1. Myself 2. Lead Author 3. Other co-author 4. Person not listed as co-author

Table 2.4: Collaboration Structures

Collaboration Type	N	Mean	sd	Min	Max
Assembled	581	.02	.14	0	1
Cooperative	581	.19	.39	0	1
Directed	581	.07	.25	0	1
Integrated	581	.72	.45	0	1

Table 2.5: Multinomial logit estimates for the probability of choosing collaboration structure, base category: integrated

Independent Variables	Assembled vs. Integrated	Cooperative vs. Integrated	Directed vs. Integrated
EAS	-1.523	-1.828*	0.556
	(1.283)	(0.528)	(1.166)
Engineering	-1.791+	-1.494**	0.641
	(1.006)	(0.408)	(1.076)
Biology	-1.405	-2.925**	0.591
	(1.121)	(0.638)	(1.148)
Chemistry	-15.340	-2.957**	-0.341
	(750.526)	(0.642)	(1.274)
Physics	-1.984	-2.452**	0.698
	(1.358)	(0.598)	(1.198)
Comp. Science	-0.369	-1.459**	0.684
	(1.153)	(0.530)	(1.227)
Met Grad School	0.129	-0.675	-0.220
	(0.880)	(0.442)	(0.540)
Met Conference	-0.005	-0.021	-0.688
	(0.724)	0.305	(0.518)
Met Same Dept.	-0.181	0.403	0.088
	(0.731)	(0.273)	(0.393)
Met Diff Dept.	-0.725	-1.069**	-0.122
	(0.848)	(0.366)	(0.418)
Met Mutual Colleague	0.019	-0.862*	0.322
	(0.750)	(0.364)	(0.410)
Met Past Advisor	1.799+	-0.964	-0.052
	(0.961)	(0.782)	(0.685)
Met My Student	0.211	0.053	0.230
	(0.692)	(0.282)	(0.389)
Met Other	0.147	-0.431	0.551
	(1.277)	(0.572)	(0.778)
# of Coauthors	-0.002	-0.000	-0.010
	(0.018)	(0.002)	(0.022)
Male	0.198	0.299	-0.155
	(0.704)	(0.268)	(0.403)
Tenured	-1.307	-0.595	-1.071*
	(0.848)	(0.366)	(0.480)
Non-White	0.517	0.806**	-0.225
	(0.770)	(0.298)	(0.491)
Career Length	0.077*	0.046**	0.016
	(0.032)	(0.014)	(0.022)
Constant	-3.159**	-0.267	-2.416*
	(1.127)	(0.507)	(1.118)
N	548		
$\chi2$	117.76**	+p<.10; *p<.05; **p<.01	
Pseudo R^2 .13			

Table 2.6: Selected Statistically Significant Marginal Effects

	Assembled	Cooperative	Directed	Integrated
EAS		-.23**		.20**
Engineering		-.19**		.16**
Physics		-.31**		.26**
Biology		-.37**		.31**
Comp. Sci.		-.19**		
Met Different Dept.		-.13**		.13**
Met Mutual Colleague		-.11*		
Met Past Advisor	.04+			
Tenured			-.06*	.14*
Career Length	.001+	.005**		-.007**
Non-White		.10**		-.09+

Note: Average marginal effects reported where significant.
+p<.10, *p<.05, **p<.01

Table 2.7: Predicted Probabilities of Collaboration Structure by Field of Study

	Assembled	Cooperative	Directed	Integrated
EAS	.02	.14	.07	.78
Engineering	.01	.18	.07	.74
Biology	.02	.05	.07	.85
Chemistry	.00	.05	.03	.92
Physics	.01	.08	.08	.83
Computer Science	.05	.18	.07	.70

Note: Predicted from the multinomial logit results presented in Table 4, while holding all other variables in the model constant at their means.

CHAPTER 3

ORGANIZATIONAL CHARACTERISTICS OF SCIENTIFIC RESEARCH COLLABORATIONS[14]

[14] Rimes, H. To be submitted to *Social Studies of Science*.

Abstract

The manuscript presented in this chapter utilizes semi-structured interview data to investigate four organizing characteristics of scientific research collaborations: administrative authority, scientific authority, role specialization, and formalized rules and procedures. The goal of the study is to depict collaborators' reported experiences structuring and organizing collaborative work and to identify patterns across collaboration experiences. Findings indicate that research collaborations exhibit a broad range of variation in regard to internal processes and structures. At one extreme collaborations adopt characteristics often associated with formal organization including elements such as complex administrative apparatuses, written rules and procedures, and designated decision making hierarchies. At the other end of the spectrum collaborations possess traits such as ad hoc structuring, consensual decision making, and informal norms for interaction. Larger collaborations tend to utilize more formalized structures and processes than smaller ones. Relatively high levels of role specialization are common across the majority of collaborations, and authority structures can be divided into two spheres: administrative and scientific. Administrative authority is closely linked to funding structures and processes, whereas, bases of scientific authority are more varied, deriving from relationships, expertise, seniority, and formal procedures. The study concludes with a discussion of both the practical and theoretical implications of variations in approaches to collaboration organization.

Introduction

Collaboration organization refers to how roles and responsibilities within research collaborations are structured, delegated, and coordinated. Because scientific collaboration is an intentional, goal-driven social process (B. Bozeman, Fay, & Slade, 2013) requiring the coordinated efforts of participants, scientists must answer, either deliberately or by default, a variety of questions about how to organize their joint efforts. For instance, how will decisions be made and relayed to members? Which person or group is responsible for which tasks? What should the group's authority structure look like? Which, if any, interactions should be governed by codified rules and procedures? The answers create a blueprint for the internal organizational structures and processes of the collaboration. These types of questions have received a great deal of analysis in the general organization (Daft, 2007) and teamwork literatures (Stewart, 2006) as well as more limited attention in studies of other types of scientific structures such as labs (Carayol & Matt, 2004; Crow & Bozeman, 1998) and research centers (Garrett-Jones, Turpin, & Diment, 2010; Gray, 2008). However, scholarly work in the research collaboration literature, with some notable exceptions (Hara et al. 2003; Shrum, Genuth, & Chompalov, 2007), has largely focused on other aspects of scientific collaboration such as exploring factors that motivate individual scientists to collaborate, collaborator attributes, and the linkages between collaboration and scientific productivity (See B. Bozeman, Fay, and Slade, 2013 for a recent review of the state-of-the-art of research collaboration literature).

This chapter asserts that organizational processes link the skills, abilities, and human capital (i.e. inputs) of collaboration participants to the knowledge, technology, or intellectual property (i.e. outputs) generated by collaborations. As such, "the social and organizational features of work are critical influences on research performance" (McNeely & Schintler, 2010, p.

2). The study takes a step toward expanding understanding of collaboration organization by utilizing semi-structured interview data to investigate four structural organizing characteristics of scientific research collaborations: administrative authority, scientific authority, role specialization, and formalized rules and procedures. The goal of the study is to depict collaborators' reported experiences structuring and organizing collaborative work and to identify patterns across collaboration experiences.

Findings indicate that research collaborations exhibit a broad range of variation in regard to internal processes and structures. At one extreme collaborations adopt characteristics often associated with formal organization including elements such as complex administrative apparatuses, written rules and procedures, and designated decision making hierarchies. At the other end of the spectrum collaborations possess traits such as ad hoc structuring, consensual decision making, and informal norms for interaction. Not unexpectedly, interviewees participating in larger collaborations, especially those affiliated with research centers or operating under the auspices of targeted federal programs, tend to report that they organize using more formalized structures and processes than interviewees who relate experiences from smaller collaborations stemming from relationships built through professional or social networks. Relatively high levels of role specialization are common across the majority of collaborations, and interviewees describe a variety of methods, linked to collaboration context, for dividing authority among participants. The study concludes with a discussion of both the practical and theoretical implications of collaboration organization.

Background and Literature Review

Because collaborations can be conceptualized in a variety of different ways it is first necessary to describe the boundaries of collaboration for the purposes of this study. Researchers who use bibliometric techniques to study scientific collaboration often view the peer-reviewed journal publication as the representation of collaborative work and restrict the definition of collaboration to those individuals whose names are listed as co-authors (Melin & Persson, 1996). While this measure is useful in many ways, collaborations can be conceived as being much broader (Katz & Martin, 1997). For instance, collaborations may involve technicians who are not listed as co-authors on the final publication, or, in the case of very large collaborations, smaller segments of the collaborative group may author articles together that do not include the entire list of collaboration participants. Therefore, this essay adopts a broader definition of collaboration proposed by Bozeman, Fay, and Slade (2013); collaborations are defined as "social processes whereby human beings pool their human capital for the objective of producing knowledge" (p.3). As Bozeman and colleagues explain, this definition recognizes collaborations that have outputs other than publications as well as the possibility of having collaborators who are not listed as co-authors; further, it excludes entities whose sole purpose is to provide funding as they do not contribute human or intellectual capital to the collaborative effort. Defining collaboration this way paints a fuller, more realistic picture of collaboration process than the more narrow co-authorship definition, and it is particularly appropriate for a study that utilizes interview data because interviewees are able to give rich descriptions of collaboration participants and their roles.

Features of Collaboration Organization

Collaborations occupy a somewhat unique organizational space. They are not typically considered formal organizations due to the temporary nature of their goals as well as the fact that they are embedded within (and across) larger, superordinate organizational structures. Neither are they project teams in the traditional sense because of the level of autonomy that collaborators have in setting goals, making decisions, and managing human, technical, and pecuniary resources. However, as structured social processes they do exhibit a variety of organizational mechanisms and characteristics.

Previous studies offer several methods for classifying collaborations based on their organizational features. For example, Landry and Amara (1998) identify classes of institutional structures within which collaborations operate including research centers, teams, and arrangements outside of formal structures. They find that researchers in engineering, natural, and health sciences are more likely to collaborate in institutes rather than teams, although they find no significant difference between the two institutional structures in terms of coordination costs or ability to appropriate additional funding. Additionally, Hara and colleagues (2003) differentiate between collaborations based on how labor is divided, asserting that collaborations fall along a spectrum from complementary to fully integrated roles. They describe four key factors that affect a collaboration's division of labor: work style of researchers, work connections between researchers, incentives, and socio-technical infrastructure. In two related studies, Chompalov and co-authors (2002, 2007) develop a collaboration typology utilizing concepts rooted in traditional bureaucratic theories of organization. They identify four key dimensions of multi-institutional collaboration organization: hierarchy, division of labor, formalization, and scientific leadership systems and classify collaborations according to differing patterns along these dimensions.

Because of their more comprehensive approach, the work of Chompalov and colleagues (2002, 2007) provides a foundation for examining the internal organizational structures and processes of research collaborations. However, their study focuses on multi-institutional collaborations, meaning that some modifications are needed in order to investigate the dimensions among collaborations more generally. Importantly, many collaborations take place among individual scientists rather than institutions. In these cases, which can be as small as two scientists, formal hierarchy may be less likely to be adopted as an authority structure and to govern decision making procedures. Therefore, rather than a single hierarchy dimension, this study proposes a more general concept: division of authority which can be subdivided into administrative and scientific authority structures. Consequently, following these adaptations, the structural organizing characteristics that are the focus of this study are as follows: 1) division of administrative authority, 2) division of scientific authority, 4) role specialization, and 3) formalization. The following sub-sections describe these characteristics and, in the context of collaboration organization, provide an overview of the current state of research on each aspect.

Division of Authority

Division of authority refers to how power to direct, control, and make decisions is apportioned among members of a collaboration. Within collaborations there are two key spheres of authority: administrative and scientific (Shrum, Genuth, and Chompalov, 2007). With respect to collaborations among individual scientists, administrative authority encompasses elements such as coordinating among collaborative team members, directing distribution of resources, and reporting to funding agencies, universities, or other external parties. On the other hand, scientific authority comprises control of areas such as the scientific direction of research, technology utilization, and the presentation and dissemination of research results.

In an early study, Kraut, Galegher, and Egido (1987) analyze a number of pairwise collaborations among peer-level scientists. They find that leadership and project monitoring is typically shared relatively evenly and that it is somewhat rare for one member of the pair to take on a project manager role. Notably, this research does not conjecture how this arrangement may change within larger collaboration structures. Alternatively, Shrum, Genuth, and Chompalov (2007) examine the distribution of authority among institutional actors in multi-institutional collaborations finding a range of variation in how institutions share scientific and administrative leadership including, among other permutations, collaborations with scientific but not administrative leadership, collaborations with various scientific leaders, and collaborations that assign project managers to deal with both scientific and administrative issues. Other studies have touched on the division of authority concept by examining leadership or management styles of individual collaborators (B. Bozeman & Corley, 2004; B. Bozeman & Gaughan, 2011; Lee & Bozeman, 2005); this perspective focuses on the methods and preferences of single individuals rather than patterns for the entire collaborative group. Therefore, most of the current work on division of authority focuses either at the level of the individual researcher or on collaboration at the extremes, those that are very small and those that are very large.

Role Specialization

Duties must be divided among participating researchers during the course of a collaborative project. A short list of general tasks might include the following: developing a research question, applying for funding, coordinating among collaborators, performing measurements, providing access to resources or equipment, analyzing and interpreting data, managing and storing data, reviewing literature, administering a research group, and writing a summary of results for dissemination or reporting[15]. Each of these tasks can be further divided into subparts, and moreover, tasks unique to a specific project might be added to the list. Role specialization refers to the degree of independence or integration of responsibilities among

[15] This list of tasks is not exhaustive. For example, if the collaboration is more property-focused additional tasks may be included such as filing patents or establishing a spin-off company.

collaborators (Pugh, Hickson, Hinings, & Turner, 1968); in other words, it describes the extent to which responsibilities for tasks are shared. This has also been referred to as the level of task interdependence in a collaboration (Walsh & Maloney, 2007).

Many studies note the importance of division of labor to successful and productive research collaboration (Beaver, 2001; Lee & Bozeman, 2005; Melin, 2000), and some empirical work specifically examines this aspect of collaboration structure. For example, Hara and colleagues (2003) classify collaborations based on a role specialization spectrum. They describe collaborations at the high end of the spectrum as having researchers with complementary yet independent roles; each researcher or research group is assigned specific functions with no overlap between their activities and those of the other participants. Alternatively, collaborations may also have low levels of role specialization. In these cases, work is more fully integrated, and researchers or research groups share responsibilities and overlapping tasks, often interacting and working closely with each other. Scholars report similar findings in a case study of InterMed, a large collaboration among five medical informatics research laboratories; researchers describe "a continuum from loosely coupled cooperative efforts to highly integrated joint initiatives. In any sustained coordinated group endeavor such as InterMed, activities and tasks will fall somewhere on the continuum between highly integrated and loosely coupled" (Shortliffe, Patel, Cimino, Barnett, & Greenes, 1998, p. 105). Additionally, Shrum, Genuth, and Chompalov (2007) present corroborating evidence for multi-institutional collaborations. They find that the most commonly adopted arrangement is highly specialized teams although a minority of collaborations have teams that perform similar functions and then aggregate their efforts.

Formalization

Formalization refers to the idea that "policies, procedures and rules are written and explicitly articulated" (Carpenter, Bauer, & Erdogan, 2009). There are a variety of ways that formalization may be present in a collaboration. For example, collaborators commonly formalize funding and resource distribution arrangements through contractual agreements. Lab procedures might also be formalized to ensure a standardized and transparent process of transferring samples or materials from one research group to another. Further, data management plans may codify data collection and sharing procedures that apply to the whole collaboration. In some instances, collaborations may even establish by-laws that outline general rules for the collaborative process.

As with role specialization, formalization can be conceptualized as a continuum. Shrum, Genuth and Chompalov (2007) find that all of the multi-institutional collaborations in their study exhibit some degree of formalization, but the extent to which it is employed varies greatly. For example, one collaboration in their study strategically embraces above-average levels of formalization as a means to manage competing institutional interests. By creating a completely separate corporation to govern collaboration infrastructure and interactions among participating institutions, the collaborating universities create a scaffolding that assures that one set of interests will not be served above others. In contrast, some of the least formalized collaborations in the study describe their only formal arrangements as those between individual institutions and funding agencies.

Data and Method

To investigate the organizational features described above, the current study employs data from semi-structured telephone interviews with thirty academic scientists. A qualitative, interview-based approach is appropriate for these research questions because the variables of interest are difficult to measure quantitatively and the issues being explored are complex and detailed (Creswell, 2012); the focus is on identifying patterns and describing variations in these aspects of the organization of collaborative research.

To identify potential interviewees, the researcher received permission to contact scientists who had previously participated in the 2012 National Study of Research Collaboration (NSF Award # SES-1026231, principal investigator Barry Bozeman). This group included researchers from STEM fields in tenure-track academic positions at universities classified by the Carnegie Foundation for the Advancement of Teaching[16] as having very high research activity[17]. Estimating about a 10% response rate, 400 scientists (approximately 60%) of the prior NSRC survey respondents were randomly selected to receive interview invitations. The invitations were sent in two stages; during the first stage, selected individuals received an initial email that briefly outlined the study, explained how they were selected to receive an invitation to participate, and informed them that they would receive a second email later in the week with more information as well as a link to an interview scheduling tool. Next, any email addresses that were not working were eliminated from the list, and a second set of emails with further description of the study and an invitation to schedule an interview were then sent to the addresses that had not been eliminated. In total, scheduling invitations were sent to 344 potential interviewees, thirty of whom scheduled an interview (response rate=8.7%). Interviews took place between October 2014 and January 2015. The interviewer asked each interviewee for permission to conduct the telephone conversation by speaker phone and record the conversation using a digital recording

[16] Responsibility for the classifications have now been transferred to Indiana University Bloomington's Center for Post-Secondary Research. See http://carnegieclassifications.iu.edu/

[17] Selected Disciplines: Biology, Computer Science, Mathematics, Physics, Earth and Atmospheric Science, Chemistry, Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, Materials Engineering/Materials Science, Industrial/Manufacturing Engineering, Biomedical Engineering

device. All thirty interviewees gave permission for their conversations to be recorded, and recordings were later transcribed verbatim for textual analysis. On average, interview duration was approximately thirty-five minutes, totaling nineteen hours and sixteen minutes of recorded interview data.

Interviewees' demographic characteristics (summarized in Table 3.1) include a mix of perspectives across gender, scientific discipline, and career stage. Geographically, interviewees represent universities in Alabama, Arizona, Arkansas, California, Georgia, Florida, Illinois, Iowa, Louisiana, Michigan, Mississippi, Missouri, New Jersey, New Mexico, New York, Pennsylvania, South Carolina, Tennessee, Washington, and Washington D.C. Their collaborations also include scientists from other locations throughout the U.S. as well as internationally.

The focus of each interview is gaining a rich description of a single collaboration experience. Interviewees were instructed to describe their most recent collaboration, either ongoing or recently complete. Their collaborations exhibit a range of variation (see Table 3.2 for a summary) in terms of the duration of the collaboration, number and type of participants, and affiliation with special programs or research centers. This variation across interviewee and collaboration perspectives allows for generalizability consistent with the goals of qualitative research in that "the aim is to make logical generalizations to a theoretical understanding of a similar class of phenomena rather than probabilistic generalizations to a population" (Popay, Rogers, & Williams, 1998, p. 348)[18].

[18] See also Donmoyer (2008) for a discussion generalizability in qualitative research

Weston and colleagues (2001) discuss qualitative research when a priori theory plays an important role. They explain their approach to using interview data to study improvements in teaching:

> First, existing theories helped to frame our research questions, influenced the structure of data collection, and influenced our coding system….This corresponds with suggestions that researchers develop tentative theories of what is happening with the phenomenon being studied and why (e.g., Maxwell, 1996). (Weston et al., 2001, p. 384)

The current study adopted a similar approach following the key steps that are outlined in the description above. First, pre-existing theories and evidence in the scholarly literature, discussed above, motivated the research question and informed the interview protocol. Following the example of previous work that has utilized broader definitions of collaboration (B. Bozeman & Corley, 2004; B. Bozeman & Gaughan, 2011), this study did not impose collaboration boundaries on interviewees but rather asked them to describe their collaboration and identify collaborators. More than half of the interviewees (57%) participating in the study described their collaborations as being wider, both in terms of collaborators and collaboration products, than the bounds of a publication. The interview protocol (see Appendix A for the complete protocol) included background questions about interviewees' typical collaboration patterns as well as a focal set of questions that asked interviewees to choose a recent collaboration and share details about that collaboration's organizational features and decision making processes. After several close readings of the interview transcriptions, coding schemes informed by previous research were developed, and the coder was also watchful for emerging themes.

Findings

All interviewees, based on the structure of the interview protocol, shared information about the division of administrative and scientific authority, role specialization, and formalization of their most recent collaboration experience. The following subsections discuss interviewee response patterns within each of these overarching categories.

Division of Administrative Authority

Interviews included a series of questions related to authority structures and centralization of leadership within the collaboration. First, interviewees indicated whether there were designated (either formally or de facto) scientific and administrative leaders of the collaboration. Then, follow-up questions investigated what the interviewee perceived as the basis or source of authority for these leaders. Notably, the discussion below focuses on how interviewees described the division of authority among PhD level scientists rather than authority structures within the research groups or labs of individual scientists (see Beaver (2001) for a description of the typical organization of research groups), although the interviewer utilized probes to explore cases where it seemed evident that a student or technician held a position of authority relevant to the collaboration as a whole.

Interviewee responses link administrative authority structures to collaboration funding configurations, size, and institutional context. Table 3.3 provides a summary of interviewee responses about division of administrative authority. Foreseeably, the bulk of administrative tasks are related to obtaining and managing project funding, meaning that division of administrative authority is tightly coupled to funding structures. Although exact funding guidelines differ by funding agency, in general, when a single agency funds a collaborative project for a group of individual scientists the award is structured one of two ways: 1) as a single award with sub-awards/sub-contracts administered by the lead awardee or 2) as multiple awards flowing directly to each participant[19]. As such, in the majority of cases (83%), administrative authority is conferred by principal investigator (PI) or lead PI status, and PIs work with and through university offices of research administration or equivalent offices to manage funding arrangements and ensure compliance with any grant or contract requirements. In the words of one interviewee, “the person that brings the money…the PI…basically dictates the administration.” Similarly, in the case of collaborations with multiple-PIs, each leader typically has responsibility for the administrative tasks at his or her institution. Interviewees describe the administrative authority in these types of relationships as tending to be piecemeal, divided along funding lines. For example, an interviewee states, “I would say we're, we are not a particularly hierarchical organization [in terms of administration]…this reflects the fact that funding for various aspects of this project are coming from so many different sources.”

Unsurprisingly, interviewees also indicate that special funding arrangements (e.g. cooperative agreements) or collaborative work in institutional contexts outside of traditional academic departments (e.g. funded research centers) usually adds administrative complexity and a more formal administrative hierarchy (10%). For example, one interviewee describes administration in a collaboration that took place as part of a targeted federal program,

> [There was a] pretty strong structural leadership associated with them [the federal agency] and the leadership does a very good job of making sure that these stay on track…So their oversight and guidance…and their regular reviews and also keeping tabs of who’s doing what was something that was much more organized than maybe other collaborations I’ve been in.

[19] For examples see the NSF Grant Proposal Guidelines for collaborative projects (Chapter 2 Section D.5) http://www.nsf.gov/pubs/policydocs/pappguide/nsf15001/gpg_print.pdf or the NIH Application Guide for collaborating with other organizations (section 9.2.1) http://grants.nih.gov/grants/funding/424/SF424_RR_Guide_General_VerC.pdf

Another outlines the structure of administrative authority in a research center context,

> There is a lead for the entire thing, a lead Principal Investigator, then informing him are two bodies, three bodies actually. There's an Executive Council made up of five people who are with the overall team. There is an additional executive advisory board of outside academic and industrial researchers and that number is, I think, four if I remember correctly, four or five, and then NSF program officers also provide guidance.

Although rare in STEM fields, some collaborations proceed without funding. Two interviewees describe work done through unfunded collaborations. In one instance, the collaborators did not pursue funding because they were working on a theoretical paper, and in the other funding was difficult to attain because one collaborator works at a primarily undergraduate institution with low research activity. Both were small collaborations (2-3 PhD level researchers) and interviewees felt that the collaborative work had no real administrative requirements to address and therefore no need for anyone to have administrative authority.

Division of Scientific Authority

Previous work suggests that collaborations have spheres of both scientific and administrative authority (Shrum et al., 2007), implying that the structure of authority in one sphere does not necessarily mirror the other. Findings in this study corroborate this perspective. Interviewee responses related to division of scientific authority indicate four approaches to dividing authority: functional (47%), diffuse (33%), procedural (10%), seniority (10%). Table 3.4 displays frequencies for the number of collaborations in each category.

The largest category comprises approximately forty-seven percent of interviewee responses and is labeled ‘functional’. This type of division refers to collaborations where scientific authority is derived from expertise in a specific area or field. This can be either a formal or informal arrangement where collaborators take leadership roles and have authority over the rest of the collaborative group in matters related to their own areas of expertise. One interviewee in a small, three member collaboration describes an informal functional division of authority in the following way: “We take the position of the guy that knows better… I mean who are you to judge his field?” Similarly, another interviewee depicts a more formal functional division of authority in a larger collaboration. He states, “We are divided up into disciplinary, more or less, disciplinary teams… each of those folks has…a team leader.” Both large and small collaborations employ functional divisions of authority, and this type of division is closely linked to role specialization. All interviewees involved in collaborations with functional divisions of authority indicate an expectation for relatively high degrees of role specialization. In these collaborations, participants tend to work on separate parts of the project and then combine the work of individuals or task-based groups in latter project stages.

After functional division of authority, the method for dividing authority that has the greatest frequency (approximately 33%) among interviewees is labeled ‘diffuse’. This label describes a division of authority in which there are no clear scientific leaders in the group. Collaborators tend to share ideas, deciding jointly on scientific direction or the best approaches for tackling problems. One interviewee expresses, “It’s very collegial. I mean we know each other very well and get along very well, and so it doesn’t require any kind of formality.” In general, collaborations with diffuse divisions of authority tend to be small (70% have fewer than five PhD level collaborators), serial collaborations (the average duration of the collaborative relationship is 11.4 years). Eighty-two percent have one or both of the following characteristics: collaborators work in the same field of study or the interviewee expresses that he or she has a particularly close relationship with the other collaborator(s).

One interviewee reports a diffuse collaboration that is strikingly different from other collaborations in this category. This collaboration is very large (>100 collaborators). It appears that the collaboration is able to adopt a diffuse authority structure because it has evolved from an initial project with ten collaborators to resemble what would now be called a sub-discipline. Current collaborators are loosely connected by a shared phenomenon of study, choose their own projects, and are supported individually by a variety of funding streams. Coordination and meetings of the entire collaborative group happen annually in a conference setting where recent work is presented.

In addition to diffuse and functional divisions of authority, approximately ten percent of interviewees indicate that the basis for scientific authority in their collaboration is procedural. All three of these collaborations are large (20-100 members), have hierarchical administrative structures, and are either associated with a university research center or a special program aimed at bringing together large groups of scientists for collaborative work. Scientific authority is not vested in any single individual or group but rather in a set of formal collaborative decision making procedures. For example, one interviewee describes,

> There is a team lead that rotates amongst different students. There is a student lead and…there are multiple faculty members assigned as advisors, so, usually two to three whose research is intimately tied with that team….Students and post-docs write proposals with the guidance of professors that go through then this massive eighty person team for review. And on the basis of those reviews some proposals are rejected and some are put… through for the next year's work.

Another shares that,

> In terms of the science…every PI sends in a project description and a report on what they did that year, you know in the previous time period, and then we have the rest of us evaluate it and that's what decides what your funding is for the following year and…we use that mechanism to give people feedback on their projects.

The final type of division of scientific authority reported by interviewees (10%) is authority based on seniority. The three interviewees that report this type of division describe small collaborations, between two and six PhD level collaborators. In each case the collaboration contains one investigator who is at a significantly different career stage than all of the other participants. For instance, one of the collaborations is between a full professor and a post-doc, the second between an emeritus professor and two younger faculty members, and the final between senior scientists at a government lab, a young assistant professor on fellowship for the summer, and two post-docs. In two cases the senior member of the collaboration was the interviewee. One describes his reasoning for assuming scientific authority:

> You know I'm sort of the guy that's done a lot of research over the years. My former collaborator is the youngest guy. He's about 20 years maybe 30 years younger than I am…and then the third guy is a guy in the philosophy of science that really does not have…any professional background in my field.

The second senior interviewee explains that her expectation for a pattern of authority based on seniority derives from her training.

> I went to... [a university] which is very European in this way, with the very strict professors and the low ranking system, you know you are an undergrad, then you're a grad, then you're a postdoc, then you're tenure track, and then you are a professor. It's very ranked…and very clear who is who. And that's what I grew up with.

In the third case the young assistant professor describes her summer fellowship with the senior scientists as being a mentoring situation in which "it was clear who the two senior PIs were…but…the way they acted was not because they wanted to…use their authority on us but they…steered the research."

Role Specialization

Interview questions explore the level of role specialization within research collaborations by asking respondents to explain how tasks were divided among collaborators and to describe the degree to which researchers or subgroups work together on the same task. Interviewee responses are ranked relative to each other in terms of the degree of overlap or independence in collaborator roles, with similar collaborations receiving the same ranking. This ranking system results in five distinct levels of role specialization ranging from high to low. Table 3.5 displays the frequencies for the various levels of role specialization.

To be classified as having a high degree of role specialization, an interviewee must indicate that the collaborators tend to work independently on various aspects of the work, usually only combining their work after each individual or project group has completed their portion. Collaborations with medium-high role specialization also tend to follow this pattern, except the interviewee indicates that there is some overlap in the work that collaborators do. Some interviewees answer that there is both overlap and differentiation in the work of collaboration participants. These collaborations are categorized as having medium levels of role specialization. Further, medium-low role specialization refers to those collaborations in which collaborator's duties are fairly integrated. Finally, low role specialization indicates complete integration of collaborator tasks and overlap of duties. The following quotes from interviewees are illustrative of the varying degrees of role specialization.

High role specialization:

- We have so many different aspects of the science taking place and people with different expertise that there's very few people stepping on anybody else's toes…In some sense it's compartmentalized with some very specific tasks for each working group and people's roles within those tasks pretty well defined, and then what happens is once those tasks are completed or there's progress reports that's where we will talk as a…big collaboration and hear what people are doing and try to incorporate what…team X did into the work that I'm doing.

- Each of the four primary faculty involved in this have their own unique set of expertise…we create teams where there's a core of common interests…the actual solution is like a puzzle, and you're trying to fit these pieces together so at the end of it the puzzle is complete and the problem is solved.

Medium-high role specialization:

- In the beginning when we were designing the experiments we would have sort of weekly, biweekly meetings…then when we were actually doing experiments and collecting data we didn't meet that frequently. And then, like for the last year, [we've been] pretty much doing data analysis, and we've been meeting without the kinesiology [collaborator]. It's sort of a half-split project such that the psychologist's and my work are kind of along one line and then the kinesiology person…is sort of on a different line of the work.

- You had the, the software developers, you had what was called a cyber-security group, you had the visualization group which was myself and, you know, there was a little bit of cross-collaboration between all of those because of course I was working with the software developers and…with the visualizations, but…there were a couple of other groups as well. So it's like we had one main contact and we all just kind of reported up to him, but then we kind of had our own little silos with a little bit of interplay between different groups.

Medium role specialization:

- Every team has at least half of their work if not more, like two-thirds, overlapping with other teams' interests; so they're not truly separate.

- For example, a student is working on a project that might be primarily in one investigator's laboratory but…there's input from other people in the group as to, you know, what specifically they're looking at, interpretation of data, discussion of…what's going on, things like that. Especially because we have a large component of computational chemistry and physics so a lot of the questions are addressed from both experimental and theoretical points of view, and so there's a lot of talk back and forth.

Medium-low role specialization:

- Generally what we do, I'm a little old-fashioned…, is we exchange the file that is doing the computations. So one of us works on the file, does computations, it's all mathematics, so we don't have experimental data. So we're doing computations, we outline our plan of how we think we can prove something, often at the very initial meeting and then we start trying. Each week we'll form out the pieces of the proof, and each of us is working on the pieces separately. And we'll swap the file and say look I got stuck here and you got stuck there so let's switch who is working on what, and we go back and forth like that.

- Well there's always some overlap in terms of expertise. I tend to want to know everything, so that's just the way I am. I'm curious. So if my collaborator has an expertise that differs from mine I'll want to try to learn as much as I can about it to the point that maybe I could do it too….So it becomes a learning experience. I've had collaborations where the other person is off completely in their own field and they do a piece and they deliver it and I staple it together. But that doesn't happen for me as often.

Only one interviewee indicated that her collaboration had a low degree of role specialization where collaborator roles overlapped a great deal. This was a collaboration between six scientists and engineers who were working with the specific purpose of developing a software tool, and the interviewee described the project as being unique and outside of the usual range of work for the collaborators. She explained that, "roles would overlap because…for this particular project…I cannot really use my technical knowledge…It's more coming up with some creative ideas."

Overall, interviewees' responses indicate that it is common for collaborations to employ relatively high degrees of role specialization (83% have medium to high levels). This is particularly true for collaborations that include cross or multi-disciplinary collaborators (85% of multi-disciplinary collaborations), but can also be employed in single discipline collaborations when collaborators have expertise in different methods or techniques. In one instance, an interviewee indicated that an extremely high degree of role specialization became a problem because the collaborators, "were working…probably too separately. It was hard to identify papers that…we could write collaboratively and when we went for renewal of the grant for the second year that was actually one of things that the NSF program manager mentioned as a negative was that there weren't as many co-authored papers as she would have expected."

Formalization

In contrast to the general pattern of medium to high levels of role specialization, interviewees report that their collaborations typically exhibit lower degrees of formalization (87% range from low to medium). Table 3.6 summarizes levels of formalization reported by interviewees who responded to a series of questions including whether the collaboration has codified rules, data collection and sharing guidelines, a formal authority structure, formal evaluation procedures, and whether there were any contractual agreements as part of the collaborative work. Affirmative answers were tallied along with any other formalized elements that interviewees described, collaborations were then categorized comparatively based on the number of formalized elements utilized. Those indicating zero to one formalized elements were classified as having low levels of formalization, two to three as medium, and four or more as highly formalized.

Collaboration size is closely connected to the adoption of formalized elements. The majority of interviewees in small collaborations (82% of those with fewer than 5 PhD level researchers) report low levels of formalization. In these collaborations, the most common element of formalization is the use of formal evaluation procedures for the purpose of generating reports for funding agencies.

Collaborations with medium levels of formalization range in size from two to twenty-five PhD level scientists. The interviewees typically describe the formal elements they utilize as being imposed by external funding agency requirements or university level institutional processes. These include formal evaluations of collaboration progress, data management plans, and sub-contracts for resource distribution. Additionally, several of these collaborations include industry partners, and some interviewees also report formal arrangements with those partners such as non-disclosure agreements.

The four collaborations in the highly formalized category all have more than twenty PhD level researchers, and in general these collaborations take place either in independent institutional structures such as research centers or, alternatively, are supported by programs targeted to support large collaborative efforts. Interviewees in these larger collaborations are more likely to report that their collaboration had a combination of both internal and external motivations for adopting formalized elements. In addition to the elements adopted by collaborations in the low and medium categories, highly formalized collaborations also typically include either codified scientific and administrative authority structures or written rules guiding the collaborative process (or both).

Discussion and Conclusion: A Contingent Perspective on Collaboration Organization

Like other forms of social organization, scientific research collaborations do not take place in isolation but rather are organized within systems that include a variety of contextual and environmental factors. Contingency theory and contingency based approaches (see Donaldson, 2001 and Van de Ven, Ganco and Hinings, 2013 for discussions on the history, development and continued applicability of contingency theories of organizations and Poole and Hollingshead 2004 for an overview of contingency approaches in small group research) pay particular attention to these factors. The basic contention of contingency theory is that performance is affected by the degree of fit between an organization or group's characteristics and the contingencies the organization faces. Contingencies have been defined as "any variable that moderates the effect of an organizational characteristic on organizational performance" (Donaldson, 2001, p. 7) and "can be envisioned as a set of overlapping elements that shape an organization's structure and work processes" (Daft, 2012, p. 17). The overarching idea is that contextual and situational variables should factor into organizational decisions, and these factors help to determine the appropriate response to organizational problems. As such, contingency-based approaches reject one-best-way assertions regarding various organizational issues. This reasoning has been successfully employed in a variety of areas including decision-making (Fredrickson, 1984; Vroom & Yetton, 1973), leadership (Fiedler, 1967; House, 1971), job design (Hackman & Oldham, 1976), reward structures (Beersma et al., 2009), managing human resources (Delery & Doty, 1996), and structuring organizations (Burns & Stalker, 1961; Hage & Aiken, 1969). In depth reviews of studies that explore the relationships between contingencies and organizational structures can be found in Donaldson (2001) and Pennings (2013).

Interviewee descriptions of collaboration organizational structures reflect that there are numerous factors upon which collaboration organizational structures are contingent. Overall, these descriptions suggest linkages between five key areas (i.e. categories of contingencies) and collaboration organizational choices: 1) collaboration size, 2) collaboration composition, 3) institutional environment, 4) academic context, and 5) collaboration goals[20]. Briefly, collaboration size refers to the magnitude of the collaboration. Collaboration composition encompasses the amalgamation of characteristics of individual collaborators. The institutional environment comprises the overarching structures within which collaborations operate. Additionally, academic context denotes the elements that form the intellectual backdrop of the collaboration, and collaboration goals refer to the desired results of the collaborative effort, either individual or corporate. Each of these areas represents numerous contributing variables. Figure 3.1 adapts a diagram from Daft (2012 p.17) to illustrate how these contingency factors affect structural characteristics within the research collaboration context. As Daft explains, contingencies and structural characteristics are depicted as overlapping because, “these features

[20] Examples of the types of variables in each category include the following:
Size: Number of collaborators, number of disciplines, level of funding
Institutional Environment: Funding sources, Research center/university/department affiliations and norms
Collaboration Composition: Collaborator demographics, Collaboration origins, Career status of collaborators, Disciplinary affiliation of collaborators
Goals: Scientific goals, Technology/Property focused goals, Individual collaborator goals, Estimated length of collaboration, Student development goals, Political/Strategic goals
Academic Environment: Norms of fields of study, technology and infrastructure needs

of organization design interact with one another and can be adjusted to accomplish the [organization's] purposes" (Daft, 2012, p. 17).

While it is beyond the scope of this study to explore the numerous possible linkages between variables that fall within each contingency category and the structural characteristics of collaboration, reports from interviewees do suggest some general conclusions. For instance, as collaborations increase in size and operate in independent institutional structures they tend to become more formalized and more administratively complex. Further, the pre-collaboration relationships between individual collaborators affect choices of organizational structures. Collaborations comprised mainly of individuals who have previously established trusting relationships tend to report less formalized collaborations and often adopt diffuse divisions of scientific authority. Additionally, degree of role specialization is linked to collaboration composition, with multi-disciplinary collaborations typically exhibiting higher degrees of role specialization.

Implications and Future Directions

These findings have both theoretical and practical implications. From a theoretical standpoint, the contingency perspective can contribute to understanding, evaluating, and strategically molding the organizational structures of research collaborations. Examples of the types of questions that this lens can help to answer include the following:

- What role do environmental factors such as funding sources and requirements play in the structural arrangements of collaborative work?
- How does the environmental instability of the research collaboration environment interact with trends toward increasing centralization and large scale projects?
- What are the triggers for creating multi-institutional collaborations?
- What role does multi-discipline participation play in determining collaboration structure?
- How does the individual nature of scientific reward structures affect collaborative organizational structures?

- How can the fit or misfit of a collaboration and its contingencies be judged, and what are the implications in terms of collaboration outputs and outcomes?
- Unlike many organizations, research collaborations do not always have their own survival as a chief goal. How does this affect organizational structures?

In terms of practical implications, collaborators should seek to strategically design collaborations so that their internal organizational structures support their strategies and goals while still enabling them to operate within existing contextual constraints. Interviews reveal that in some collaborations, participants are aware of how strategically designing organizational structures may facilitate collaboration objectives. For example, one participant describes how they deliberately organized a large collaboration using a network type structure to encourage inter-disciplinary interaction as well as enhance participation:

> So each network in and of itself is interdisciplinary, and the idea is…it's right sized as it were. So… [If] you have like ten PIs in a network then the PIs and their students can all fit around a U-shaped table, and nobody's hanging back at meetings. And so literally everybody has a seat at the table. And student opinions and post doc opinions and faculty opinions are all given a chance to add to the conversation.

On the other hand, many collaborations as they develop organically default to functional divisions with collaborators working 'separately together' as each participant assumes responsibility for things falling within his or her area of expertise. While this type of structure is likely appropriate in many cases, intentional pre-collaboration conversations connecting organizational processes to collaboration goals may help collaborators to better leverage collaborative efforts, not only for answering their proposed research questions but for promoting other long-term objectives such as enhancing student development, pursuing additional collaborative funding, or making industry connections. Particularly in an era when collaborative team sizes are continually increasing (Adams, Black, Clemmons, & Stephan, 2005) and funding of larger, multi-disciplinary projects continues to grow (Clark, 2011), this type of intentionality in designing and structuring the collaborative process may contribute to more competitive project proposals and ultimately may be linked to improved research performance.

Table 3.1 Descriptive Statistics for Interviewees

	count	mean	sd	min	max
Gender					
Male	19	0.63	0.49	0	1
Female	11	0.37	0.49	0	1
Rank					
Assistant Prof.	3	0.10	0.31	0	1
Associate Prof.	8	0.27	0.45	0	1
Full Prof.	16	0.53	0.51	0	1
Emeritus	3	0.10	0.31	0	1
Interviewee Field of Study					
Biology	3	0.10	0.31	0	1
Chemistry	5	0.17	0.38	0	1
Engineering	10	0.33	0.48	0	1
Geosciences	1	0.03	0.18	0	1
Math/Computer Science	6	0.20	0.41	0	1
Neuroscience	1	0.03	0.18	0	1
Physics	4	0.13	0.35	0	1
N 30					

Table 3.2 Descriptive Statistics for Collaborations

	mean	sd	min	max
Number of PhD Level Scientists	11.67	19.82	2	100
Total Number of Participants	18.10	27.04	2	100
Time Scale (years)	5.73	4.68	1	20
Cross/Multi-Disciplinary	.70	.47	0	1
Number of Disciplines	2.59	2.01	1	10
Includes Industry Collaborators	.13	.35	0	1
Includes Government Collaborators	.23	.43	0	1
Research Center/Special Program	.27	.45	0	1
N 30				

Table 3.3 Division of Administrative Authority

Category	Number of Collaborations
No Administrative Authority	2
Formal Hierarchy	3
Funding Driven--Principal Investigators	25

Table 3.4 Division of Scientific Authority

Category	Number of Collaborations
Procedural	3
Seniority	3
Functional	14
Diffuse	10

Table 3.5 Role Specialization

Category	Number of Collaborations
High	12
Medium High	7
Medium	6
Medium Low	4
Low	1

Table 3.6 Formalization

Category	Number of Collaborations
High	4
Medium	10
Low	16

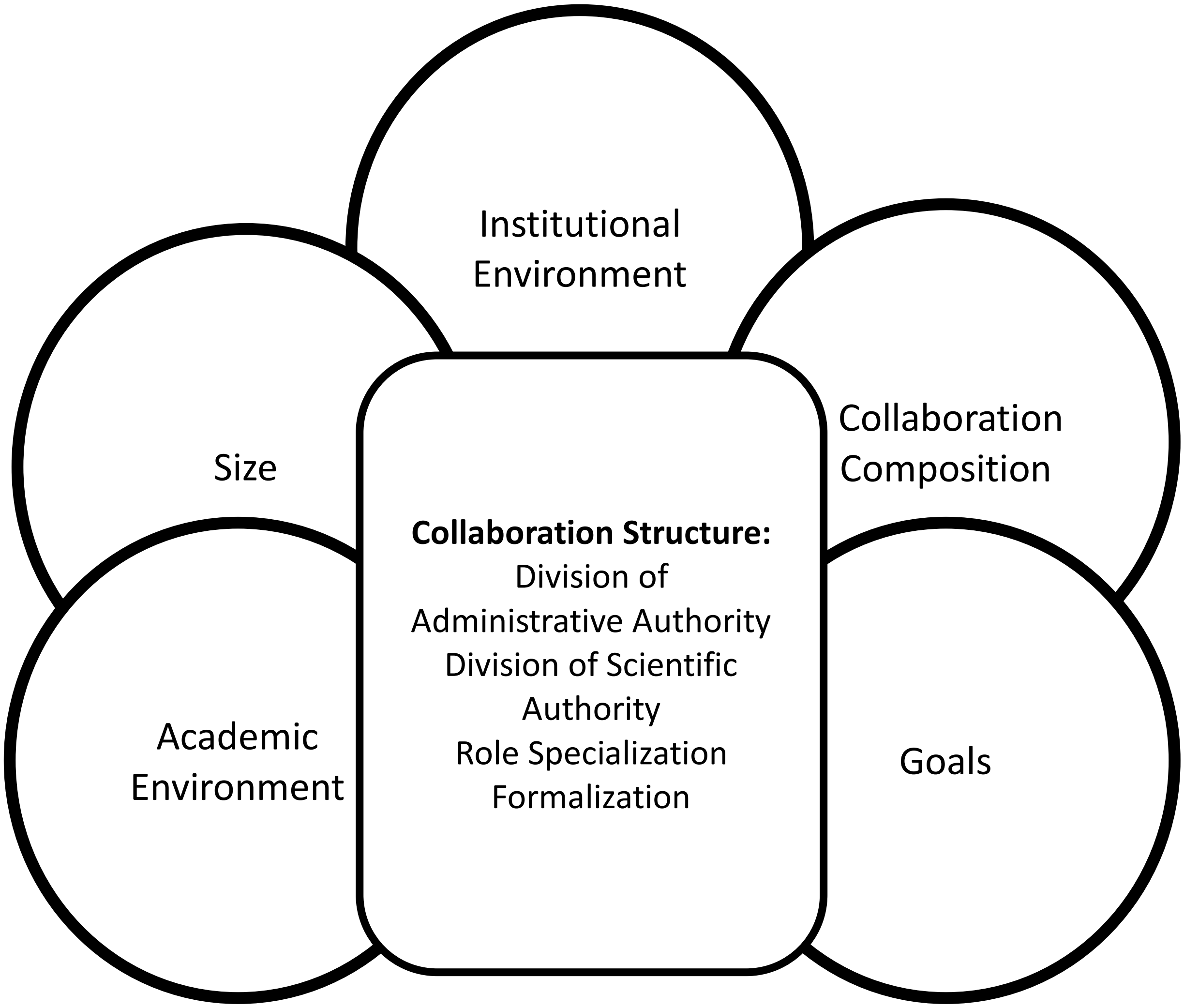

Figure 3.1: Collaboration Structure and Contingencies[21]

[21] Examples of variables in each contingency category
Size: Number of collaborators, number of disciplines, level of funding
Institutional Environment: Funding sources, Research center/university/department affiliations and norms
Collaboration Composition: Collaborator demographics, Collaboration origins, Career status of collaborators, Disciplinary affiliation of collaborators
Goals: Scientific goals, Technology/Property focused goals, Individual collaborator goals, Estimated length of collaboration, Student development goals, Political/Strategic goals
Academic Environment: Norms of fields of study, technology and infrastructure needs

CHAPTER 4

MANAGING SCIENTIFIC RESEARCH COLLABORATIONS: EXPLORING COMMON CHALLENGES[22]

[22] Rimes, H. To be submitted to *Science and Public Policy*.

Abstract

This manuscript examines common challenges that occur during the research collaboration management process. It reviews the scholarly literature related to research collaboration management and proposes an organizing scheme consisting of four overarching categories of common collaboration management challenges: 1) excessive coordination costs, 2) contribution/crediting dilemmas, 3) managing interpersonal problems, 4) leadership issues. Next, the study checks the applicability of the organizing scheme utilizing data from semi-structured interviews with thirty tenure track academic scientists currently employed at universities classified as having very high research activity. Interview data indicate that the organizing scheme resonates well with currently collaborating scientists, and further, the data suggest the addition of a fifth common challenge category to the organizing scheme: managing external influencers. The study concludes that collaboration management strategies are likely to be most effective when they are tailored to the various contextual elements of a collaboration. Additionally, a key aspect of effective management is developing parity of expectations among collaborators in regards to various facets of work such as equitable workloads, crediting procedures, and appropriate approaches to problem solving. Ultimately, adopting intentional, strategic, and appropriate management practices can help to smooth coordination processes, promote congruent expectations, mitigate conflict, and provide awareness of the connections between a collaboration and its external context.

Introduction

Studies of scientific research collaboration provide evidence that collaborating can offer benefits in terms of increased scientific productivity and influence (see B. Bozeman, Fay, and Slade, 2013 for an overview) and that it also has the potential to promote a number of broader social, economic, scientific, and even political goals (Sonnenwald, 2007). The promise of these benefits elicits significant and, in recent history, increasing resource commitments from policymakers, scientists, and administrators. For example, Hale (2012) reports that pass-through funding at universities for research and development expenditures can be used as a measure of multiple-institution collaboration and that these expenditures have more than doubled in recent years, growing from $1.4 billion in 2000 to $3.8 billion in 2009. Additionally, in 2013 the National Science Foundation awarded 2,975 grants, totaling approximately $2.1 billion to projects with multiple principal investigators, up from 2,508 grants and approximately $1.5 billion in 2004 (National Science Board, 2014).

Beyond the funding dedicated to collaborative efforts, numerous other "resources and human energies are invested in facilitating, inducing, and *managing* [emphasis added] collaboration" (B. Bozeman et al., 2013, p. 4). Specifically, collaboration management refers to the process by which participants coordinate and organize human, technological, and fiscal resources to facilitate their scientific activities and objectives. It encompasses the practical actions that researchers take in order to establish and maintain a functional collaborative environment. Examples of collaboration management activities include developing recognition and crediting procedures, handling interpersonal conflict, and ensuring compliance with funding and reporting requirements. During the collaboration process scientists develop strategies for dealing with these areas, and "whether the strategies are formal and systematically applied or informal and ad hoc, they guide collaboration activities and coordinate collaborators' pursuits of individual and communal goals and thus have a significant effect on the day-to-day collaboration experience" (B. Bozeman, Gaughan, Youtie, Slade, & Rimes, forthcoming).This study argues that researchers' abilities to manage their pooled resources are critical to reaping the benefits of collaborative work and further, that these abilities are subject to a variety of intellectual, organizational, and relational obstacles. The study investigates a number of these barriers by identifying and exploring common collaboration management challenges faced by academic researchers.

The chapter begins by discussing challenges within the research collaboration context and then outlines the boundaries for this study's investigation of collaboration management challenges. Next, it reviews the scholarly literature, identifying four common challenges areas: 1) coordination costs 2) leadership issues, 3) contribution/crediting concerns, and 4) managing interpersonal dynamics. The study discusses current research findings in each of these areas and proposes an organizing scheme for considering collaboration management challenges. Then, it investigates the applicability of the organizing framework by utilizing data from semi-structured interviews with academic scientists. Interview data support the four challenge categories and suggest the addition of a fifth category, managing external influences. Findings portray collaborators' accounts of navigating management challenges in these areas and discuss the prevalence of various types of challenges. The chapter concludes by considering the practical implications of developing a systematic understanding of collaboration management challenges.

Key Concepts and Background

In the research collaboration context a challenge can be defined as any circumstance, behavior, or dynamic that acts as an obstacle to collaboration effectiveness. Challenges can develop as a consequence of a collaborative group's unique mixture of inputs, contextual, and environmental factors, or they may be introduced by participants' actions and conduct. There are two key considerations conveyed by this definition. First, defining challenges as obstacles to effectiveness does not automatically signal that their presence decreases collaboration effectiveness; rather, collaborator responses are the key determinant of how a challenge influences group dynamics and outcomes. If collaborators are unable to successfully manage challenges, then the group may be prevented from achieving its full potential, and, in worst-case scenarios, may cease to function as a viable collaboration. Alternatively, in the tradition of recognizing problem solving as a form of team building (Klein et al., 2009), collectively confronting and mastering challenges may have beneficial effects such as fostering group learning, increasing cohesion, and helping collaborators to better leverage their combined capabilities.

The second key aspect of this definition is that challenges are conceptualized broadly as obstacles to collaboration effectiveness rather than more narrowly as obstacles to productivity. The underlying assumption is that effectiveness is associated with achieving desired goals while productivity is associated with outputs. Although productivity is typically a crucial concern for collaborative work (Jonathon N. Cummings, Kiesler, Bosagh Zadeh, & Balakrishnan, 2013; Fox & Mohapatra, 2007; Lee & Bozeman, 2005; Ynalvez & Shrum, 2011), collaborations may have a number of goals beyond or in even in place of productivity. For example, in a mentor/protégée relationship, productivity may be deferred by the mentor in favor of protégée growth and development (Lee & Bozeman, 2005). Therefore, this conceptualization allows for consideration of obstacles that interfere with a collaboration's ability to achieve any of its desired goals.

As described above, the study's central concern is exploring challenges that are related to collaboration management. Previous work has found that collaborations have spheres of scientific and administrative authority (Shrum, Genuth, & Chompalov, 2007), implying that there are discrete sets of tasks within each of the respective areas. The tasks associated with administrative concerns can be conceptualized as management activities while those linked to the scientific aspects of the collaboration can be described as technical activities. Figure 4.1 provides an illustration using examples of both technical and management activities[23]. The dotted line suggests that the two sets of activities are not always cleanly dissociated. For example, effective communication is a key component of both sets, and other activities such as supervising and mentoring students do not fall wholly into one category or the other. Researchers routinely practice self-management and direction of collaborative work, performing tasks in both administrative and scientific spheres. However, management and technical activities often demand the utilization of disparate skills sets and are susceptible to diverse challenges, and as some have observed (B. Bozeman et al., forthcoming; Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2004), excellent scientific skills do not necessarily translate to excellence in research management.

Although there is no overarching theory of management for scientific collaborations, efforts are beginning to emerge at a variety of levels to expose participating researchers to both general theories of group management and teamwork as well as practical tools specific to the coordination of scientific work. For example, some university management schools offer courses

[23] Figure 4.1 is not meant to be a depiction of the entire collaboration process. Collaborative projects have been conceptualized as a sequential processes with a number of stages. While, scholars have offered different perspectives on the numbers and appropriate labels for these stages (Kraut, Gallagher, Egido, 1987; Sonnenwald, 2007), various management and technical activities occur during each stage. By altering the activities to reflect the appropriate stage, Figure 4.1 can be superimposed over a stage model of the collaboration process.

or certificate programs for scientists and engineers to acquaint them with general management principles, noting the need to equip scientists for the tasks required by collaboration.[24] Additionally, some private consulting companies, also recognizing that the modern scientific environment creates a need for effective management skills, have begun targeting their services to academic scientists[25]. Researchers themselves have organized a variety workshops and conference panels that focus on the practical aspects of managing collaborations[26]. Other resources include field guides (Bennett, Gadlin, & Levine-Finley, 2010; Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2004) and experientially based articles detailing lessons learned and best practices (e.g. Kozikowski & Neale, 2011; Smallheiser, Perkins, & Jones, 2005; Ledford, 2008). Moreover, throughout the course of their careers individual researchers develop a body of tacit management knowledge based on their own work as well as insights passed on from mentors and colleagues.

Literature Review

In addition to the growing collection of knowledge that is aimed at the scientist-as-practitioner, a number of scholarly works provide theoretical and empirical perspectives on factors that are pertinent to collaboration management such as understanding coordination activities (Jonathon N. Cummings & Kiesler, 2007), developing trust between collaborative actors (Garrett-Jones, Turpin, & Diment, 2010), and establishing crediting procedures (Youtie & Bozeman, 2014). However, academic work that addresses collaboration management more extensively (Bammer, 2008; B. Bozeman et al., forthcoming; Shrum et al., 2007) is fairly

[24] For an example see http://www.kellogg.northwestern.edu/news_articles/2010/scientists.aspx
[25] For an example see http://www.barefoot-thinking.com/scientists.html
[26] For examples see http://news.lib.uchicago.edu/blog/2015/04/10/workshop-series-managing-your-research/ , https://grad.ucla.edu/careerhub/events/effective-collaboration-diversity-in-scientific-teams-workshop-21015/ , and http://www.scienceofteamscience.org/pre-conference-workshops

limited. To facilitate more systematic thinking about collaboration management, this study surveys the research collaboration literature for findings related to management challenges.

Three key boundaries delimit this search. First, Bozeman and colleagues (2013) note that it can be difficult to distinguish between levels of analysis in collaboration studies because collaborative relationships exist between and among individuals, groups, teams, and organizations. Regarding challenges, “barriers to collaboration exist at all levels from the individual to the organizational,” (Cullen et al., 1999, p. 137). This study focuses chiefly on understanding meso-level challenges, specifically, those obstacles that pertain to the internal management dynamics of the collaborative group as an entity. Pertinent findings from studies at the individual, organizational, and institutional levels are included only so much as they relate to understanding challenges to group management processes.

A second boundary for the search is that it highlights challenges within academic collaborations, primarily focused on the experiences of researchers in the United States. Studies of collaborations with international, industry, or government collaborators are not excluded, but beyond exploring management challenges related to collaborator heterogeneity in general, specific aspects of international and cross-sector collaboration management are not enumerated.

Finally, the study investigates routine challenges rather than pathologies. A growing stream of research examines what has been called the “dark side” (Youtie & Bozeman, 2014, p. 954) of research collaboration (e.g. student exploitation, falsifying data, fraud). Pathologies certainly create collaboration management challenges, and understanding their prevalence and warning signs is crucial to avoiding wasted resources as well as to mitigating the emotional and professional damage that they might cause. However, this study argues that it is likewise critical to understand more common challenges which are likely to arise in most routine collaborations and which, if not properly handled, may lead to frustration with the collaboration process and decreased group effectiveness. Within these limitations, the study reviews the scholarly literature on research collaboration in search of findings related to collaboration management challenges.

The review encompasses both theoretical writings as well as articles offering empirical evidence on collaboration challenges. Articles that explore aspects of collaboration management are drawn from peer-reviewed journals that focus on the dynamics of scientific research including *Research Policy*, *Social Studies of Science*, and *Scientometrics*. Additionally, the search is guided by several critical reviews of the broader research collaboration literature (B. Bozeman et al., 2013; Katz & Martin, 1997; Sonnenwald, 2007). For each article reviewed four key questions are asked: 1) Does the article investigate any aspects of collaboration management as defined above? 2) What are the key findings related to collaboration management challenges? 3) What do the authors identify as the sources of those challenges? 4) On what evidence do the scholars base their findings? To aid in analysis of this literature, a table is created summarizing the answers to these questions (See Appendix B).

Developing an Organizing Scheme for Collaboration Management Challenges

Based on this literature survey, the study proposes that common challenges associated with collaboration management can, in general, be grouped into four broad categories: 1) excessive coordination costs, 2) leadership issues, 3) contribution/crediting dilemmas, and 4) managing interpersonal problems. The categories and sources of challenges within each category are summarized in Table 4.1. While some of these challenge areas are similar to challenges that have been identified in research on team performance (Fiore, 2008; Stewart, 2006), they have manifestations specific to the research collaboration context. Additionally, the categories are not mutually exclusive. They intersect, and the challenges that fall within them may be correlated in a variety of ways.   For example, studies have connected increased numbers of coordination mechanisms (which increases coordination costs) with decreased interpersonal problems, citing the coordination activities as a means of building trust between collaboration participants (Jonathon N. Cummings & Kiesler, 2007). Similarly, others have found that establishing guidelines for contributions and credit can mitigate collaborator conflict (Devine, Beney, & Bero, 2005). Each category is discussed in more detail in the following sub-sections, and Table 4.1 presents a summary of the discussion.

Coordination Costs

Coordination costs are the expenditures of time, energy, and resources required to orchestrate communal activities. Landry and Amara (1998) approximate coordination costs in research collaborations based on the frequency with which collaborators employ joint decision making procedures. While coordination costs are a natural outgrowth of collective action and are not inherently problematic, they can generate collaboration management challenges when they become overly burdensome, detracting from or discouraging scientific activity and progress. In fact, they are the most often noted challenge related to collaboration management; seventy-seven percent of the studies reviewed include discussions of obstacles that can be categorized as coordination cost challenges.

First, coordinating shared resources introduces administrative requirements and procedures into the collaborative process. In STEM fields the preponderance of collaborative efforts operate under the auspices of grant funding, meaning that complying with reporting requirements, creating data management structures, and administering sub-awards are integral components of most collaborations. Challenges can emerge from the multiplicity of roles that collaborators must adopt. Boehm and Hogan (2014 p.135) describe the modern principal investigator as “a ‘jack of all trades’, taking on the roles of project manager, negotiator, and resource acquirer, as well as the traditional academic role of Ph.D. supervision and mentoring.” Each of these roles requires different skills as well as significant time investment; management challenges arise when collaborators make trade-offs between their management roles and their academic roles (Beaver, 2001; Boehm & Hogan, 2014; Hagstrom, 1964). Studies have argued that juggling these activities with the technical and social aspects of collaborative work, may produce role strain (Boardman & Bozeman, 2007) or impair creativity (Beaver, 2001). Research also suggests that administrative burdens may be linked more tightly to some types of collaboration organizational structures than others. For example, Garrett-Jones, Turpin & Dement (2010) find that researchers affiliated with university research centers are sometimes discouraged by the administrative requirements of their center affiliation, and Boardman and Bozeman (2007) find role strain more likely when researchers are affiliated with research centers that have no formal ties to their home department.

As collaborations encompass more researchers across multiple institutions, disciplines, and sometimes continents, there are simply more elements to coordinate and manage, multiplying the likelihood that problems will arise. In terms of management activities, when collaborators cannot effectively communicate, their coordination abilities are likewise hampered. Specifically, obstacles to direct communication include technological problems like inadequate or under-functioning communication infrastructure (Duque et al., 2005; Sooryamoorthy, Duque, Ynalvez, & Shrum, 2007), difficulties harmonizing participants’ schedules (Kraut, Galegher, & Egido, 1987), or simply geographic distance between collaborators. Cummings and Keisler (2007) find that collaborations that involve researchers from multiple universities have higher coordination costs than do collaborations in which all participants are located within the same university. Other studies also report challenges linked to coordinating remote or dispersed collaborators (Katz, 1994; Kraut et al., 1987; O'Cathain, Murphy, & Nicholl, 2008; Shortliffe, Patel, Cimino, Barnett, & Greenes, 1998; Walsh & Maloney, 2007).

Coordination barriers can also be indirect, rooted in the multifarious aspects of collaborative groups. Diverse collaborations are likely to be larger and more complex than more homogenous ones. Increased complexity has been linked to increased coordination needs (Vasileiadou, 2012). For example, disciplinary differences, including terminology, culture, and differing views on quality or appropriate approaches to problems may create communication roadblocks (Maglaughlin & Sonnenwald, 2005; Massey et al., 2006; O'Cathain et al., 2008; Öberg, 2009; Porac et al., 2004). Management within cross and multi-discipline collaborations involves determining "how to facilitate creation of a climate that will stimulate awareness of interdisciplinary challenges and thus enable planning, execution, and assessment of such work" (Öberg, 2009, p. 406). Other facets of group heterogeneity create similar challenges. Conflicting expectations and practices which have been ingrained from institutional affiliations (Jonathon N. Cummings et al., 2013) status, expertise, world-views or demographic characteristics (Curry et al., 2012) can lead to disagreements and misunderstandings. Bammer (2008 p.877) describes these types of challenges as the "harnessing of differences": a process of creating an environment that exploits the creative potential of beneficial differences while concurrently alleviating problems that are detrimental to research progress.

Relatedly, increased task complexity can also create management challenges. Studies point out that task interdependence raises coordination costs (Shrum, Chompalov, & Genuth, 2001; Walsh & Maloney, 2007) because it requires collaborators to jointly perform an activity rather than doing related activities separately, thereby increasing communication obligations.

Landry and Amara (1998) indicate that collaborative groups who organize using a team structure encounter more coordination costs than those who work individually and then combine their work, and Shrum and colleagues (2001) find that increased interdependence can cause more frequent group conflict.

Contribution/Crediting Procedures

Credit is central to the structure of reward and incentive systems for academic scientists (Dasgupta & David, 1994; Merton, 1973), and it creates a pathway for scientific accountability (Cronin, 2001). Because scholarly publications are the typical outputs of academic research collaborations, the most common management activity related to contribution and crediting is developing strategies for decision making about co-authorship inclusion and order[27]. Although norms vary by field, authorship order (with the exception of cases where it is alphabetical) often relays information about the relative contributions of members of the collaboration (Youtie & Bozeman, 2014). Notably, as collaborative groups increase in size, traditional methods of listing authors and using authorship order to indicate key roles becomes less capable of conveying anything truly meaningful about the relative contributions of participants. This generates a number of larger issues related to scientific motivation (Wray, 2002), ethical practices, and maintaining scientific integrity[28] (See Cronin 2001 and Claxton, 2005 for in depth discussions crediting problems) which have been the focus of a number of editorials, reflection pieces, and

[27] Other notable crediting mechanisms include acknowledgements on publications and reports, attribution in conference presentations, and inclusion on invention disclosures and patents. Management processes related to crediting for property focused goals are outside the scope of this study although discussions that relate to these issues can be found elsewhere. See Baldini (2008) for a review of the literature and Chokshi, Parker, and Kwiatkowski (2006) or Baca (2006) for suggested management strategies.

[28] This includes issues like guest and ghost authorships as well as employing professional or industry writers. These are not discussed here due to the field specificity of the latter and the fact that the former are generally considered unethical practices and thus fall outside the frame of this discussion of routine challenges.

proposals for improved processes, particularly in the biomedical fields (e.g. Lagnado , 2003; Rennie & Flanagin, 1994; Rennie, Yank & Emanuel, 1997; Tulandi, Elder, & Cohen, 2008) but which are applicable to the wider STEM community as well Bozeman and Youtie (2014).

Outside of these broader issues that collaboration raises for traditional crediting procedures, and more germane to the current investigation, studies indicate that collaboration management challenges associated with crediting can stem from differences of opinion or expectations, sometimes exacerbated by norms that vary across fields of study or even within sub-fields of a single discipline (Claxton, 2005). Challenges can also be caused by simple miscommunication or misunderstandings and by more intentional behaviors such as selfishness (D. P. Bozeman, Street, & Fiorito, 1999) and unethical conduct (B. Bozeman et al., forthcoming). Unresolved crediting issues have the potential to create significant, sometimes permanent, ruptures in working relationships. Often there are no generally accepted guidelines for making crediting decisions. Therefore, collaborators must devise their own methods, and these can range from formal agreements and scorecards (Devine et al, 2005) to decisions made solely by the principal investigator with no input from other collaborators (B. Bozeman et al., forthcoming). Devine and colleagues (2005) assert that establishing procedures that promote clarity, accountability, and fairness are crucial for reaching consensus on crediting decisions and preventing misunderstandings. In an empirical study, Youtie and Bozeman (2014) find that early discussions about crediting procedures make it less likely that a collaboration will face poor collaborative outcomes.

Managing Interpersonal Dynamics

Managing a collaboration includes managing the varied and sometimes dissonant personalities of the collaboration participants. Although intellectual conflict can be useful for stimulating new scientific ideas and directions (Creamer, 2005), interpersonal disputes are not as beneficial. Studies report three main bases of interpersonal tension among collaborators: personality clashes, work-style incompatibilities (B. Bozeman et al, forthcoming), and personal biases or prejudices (Lee & Bozeman, 2005). These issues can lead to outright conflict, or they can generate incessant irritations that prevent efficacious working relationships. Curry and colleagues (2012 p.15) assert that it is important to "establish mechanisms for conflict resolution as part of [the] internal research management process."

More subtly, effective collaboration management can also be undermined by the absence of positive interpersonal dynamics, namely, trust between collaborators (Chompalov & Shrum, 1999; Curry et al., 2012; Fox & Faver, 1984; Garrett-Jones et al., 2010; Kraut et al., 1987). Findings show that weak social ties between collaborators can foment a lack of trust (Cummings & Kiesler, 2005; 2008) which results in collaborators gravitating towards work with group members that they already know rather than working with all members of the group (Cummings et al., 2013) and contributes to failures to effectively integrate tasks (Hara et al., 2003). Lack of trust is also fostered by collaborative environments that are overly competitive. Atkinson and colleagues (1998) discuss how pressures to publish and be the one to receive credit for a major discovery can lead to distrust and an environment of secrecy in collaborative relationships, circumstances which other scholars assert are unhealthy for joint knowledge creation efforts and can impede scientific progress (Beaver, 2001).

Leadership Issues

Although, some scholarly research has discussed leadership as an aspect of collaboration management, it has not been the focus of much empirical work (Fiore, 2008). Those empirical studies that do report leadership related findings often discuss them only peripherally (Hara et al., 2003; O'Cathain et al., 2008). This circumstance may stem from tension created by the juxtaposition of leadership and scientific autonomy. Hagstrom (1964 p. 242) quotes an interviewee who shares the belief that in science "telling someone what to do is taboo. The greatest man in science cannot tell the lowest what to do." In spite of changing organizational structures of scientific work, almost fifty years later, Chompalov, Genuth, and Shrum (2002 p. 766) also acknowledge this "tension between the need for better management and the academic culture of intellectual autonomy." Curry and colleagues (2012) suggest that collaborative groups should think of leadership as a fluid role, aspects of which can be performed by multiple members of the collaboration, rather than as a position to be filled by subordinating some collaborators to others. Even within research centers with formal management teams, Garrett-Jones and colleagues (2010) find that collaborators become disgruntled when they feel that they do not have a strong influence on center management decisions. Along similar lines, Aagaard-Hansen and Ouma (2002) indicate that effective management may require seeking an acceptable balance of power between collaborators in participating disciplines.

In contrast to findings on the leadership/autonomy tension, other studies point out that leadership inheres in principal investigator status. Therefore, the behaviors and actions of those individuals may result in collaboration management challenges. For example, O'Cathain and colleagues (2008) find that when principal investigators of mixed methods research groups do not value methodological integration, collaborations are less likely to be able to successfully consolidate member contributions. Challenges can also occur if group leadership changes (Cullen et al., 1999), for example, if a principal investigator becomes ill and must step down or pass the duties to another scientist. Hara and colleagues (2003) report on a collaborative group that had several leadership changes which caused delays and confusion; they report that collaboration participants were unclear who the group leaders were and meetings between faculty members had to be postponed several times.

Investigating the Organizing Scheme

As described above, many studies have either observed or predicted challenges that have important implications for collaboration management. Notably however, these studies typically do not explore the prevalence of the challenges that they describe, and only a few of the studies (Aagaard-Hansen & Henry Ouma, 2002; Bammer, 2008; B. Bozeman et al., forthcoming) discuss collaboration management as a strategic process. In order to further investigate the organizing framework proposed above, this study employs data from semi-structured telephone interviews with thirty academic scientists.

Data and Methods

Chapter 3 of this dissertation contains an in depth discussion of the interview methods and coding process used to analyze the data, but to briefly summarize, interviews were conducted with tenure track professors at U.S. universities classified as having very high research activity. The interviewees and the collaboration experiences that they depict represent a wide variety organizational configurations across numerous scientific fields as well as demographic and geographic combinations of researchers (See Tables 3.1 and 3.2 in Chapter 3). The interview protocol (Appendix A) directed scientists to provide in-depth descriptions of one of their most recent collaboration experiences. Based on the evidence presented in the organizing scheme above, respondents were asked to share whether their collaborations had experienced challenges related to coordination costs, interpersonal relationships, leadership, and/or contribution and crediting. Answers to these questions were coded according to relevant categories from the literature search (summarized in Table 4.1) as well as emergent themes. An additional question also asked scientists to share their perceptions regarding what they felt were the biggest challenges of their most recent collaboration experience. Thematic coding of answers to this question allowed for challenges to emerge beyond those that had been identified in the initial literature review.

Findings

Overall, results indicate that scientists expect management challenges to be a routine part of research collaboration. They did not hesitate to pinpoint and expound on the challenging aspects of managing their collaborative work. The presence of these challenges does not signal that researchers view a collaboration experience negatively; many of the interviewees describe their collaborations as being simultaneously successful and challenging. In general, the common management challenges identified in the organizing scheme resonate with interviewees; all but three interviewees (90%) report encountering challenges in at least one of the four areas (frequencies displayed in Table 4.2). Additionally, based on interviewee responses a new category, labeled managing external influences, is identified and added to the organizing scheme. The following subsections detail findings and expansions related to each of the four previously identified challenge areas as well as the additional category. A revised organizing scheme for collaboration management challenges is presented in Table 4.3.

Coordination Costs

Obstacles related to coordination costs are the most common challenge area experienced by interviewees; approximately eighty-three percent respond affirmatively to experiencing some form of coordination cost challenge. Of those who report these types of challenges, their responses support the four categories outlined by the earlier literature review including obstacles to direct communication (52%), burdens caused by administrative requirements (37%), barriers rooted in task complexity (24%), and managing group heterogeneity (24%)[29].

Obstacles to direct communication are reported most frequently, and they affect collaborations regardless of size, disciplinary affiliation, or organizational structure, although they do occur more often in remote or dispersed collaborations. Reports include issues stemming from geographic distance:

> There's really no substitute for face to face meetings…you're really profoundly limited…Conference calls are not an adequate substitute, webinars are not an adequate substitute for face to face meetings, and in our particular discipline I would say there's really little substitute for actually going out in the field together.

difficulties managing conflicting schedules at both the institutional level:

> So you know we're compiling our data now for the end of the year report….They actually turn off the heat in most of the buildings on campus, and they pretty much shut down the university….So we lose two weeks in December basically…and I used to, you know, try to come down and I'd shiver and shake and then go home and do the work anyway….Now, [names another collaborator's institution] doesn't shut down, nor does [another institution] and I have to manage that.

and the individual level:

> Well, a collaboration of this size, I think the biggest challenge is finding the time when you can all get together to do the discussion of the science….just finding the time to really have these meetings…I think has probably been the most frustrating for the managers of the group. It's almost impossible to find the time when the six of us can get together for an afternoon.

and communication technology or software problems:

> You know Skype has its issues. If it weren't for problems with that software every so often then it would have been fine.

In some cases, these obstacles are also coupled with intentional barriers to direct communication such as mechanisms to ensure data security. For instance,

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[29] Note that responses are not mutually exclusive so percentages do not sum to one hundred.

> Well, there's two reasons we have difficulty sharing data. One, the data sets tend to be quite large so across institutions, you know, transferring that data around can be just a pain. And then the other thing is, the PI institution…also does secure work, and so, by default, a lot of their materials are what we call behind the fence…Even though this work isn't secure, that makes access more difficult.…more hoops to jump through, but that can slow things down as well.

In general, interviewees accept direct communication obstacles as the cost of doing research. They do not report proactively seeking ways to alleviate them other than some minimal recognition that there are some software tools that may be useful for managing scheduling.

In addition to barriers to direct communication, interviewees also discuss administrative burdens as collaboration management challenges. These sources of strain are particularly salient to researchers in large collaborations. Fifty percent of the interviewees who claim administrative burdens describe collaborations with twenty or more members, and among all of the interviewees who respond affirmatively to having these types of challenges, none have fewer than six participants. One interviewee states:

> When I got the… [names specific award] that was like I'd died and gone to heaven but having the center was like I'd gone to hell and I'm still alive….because [names funding agency] had these very over the top requirements, reporting requirements….we've had to turn in these essentially 300 page reports each year…so that was a major challenge…that kind of administrative burden on the PIs. You know, it seemed like [names funding agency] was basically trying to stop all science from occurring.

Another expresses discouragement not only with the time required by administrative demands, but also by what he describes as a systemic disconnect between the process of knowledge generation and the reporting procedures at his local institution:

> What I can really speak to is the hoops we have to jump through as a sub-contracting institution, and it's non-trivial…a lot of it does fall back to the scientists like myself to clarify and to, you know, make sure all the paperwork is in order and all the details. I'll give you an example…we have this five year project and our local grants and contracts office requires me to submit a statement of work. Well…the truth is this is science; you don't know where it's going to go. I understand the requirement for some statement of work to make sure I'm going to do something, but I can't tell you exactly what I'm going

> to be doing on this project next year…that's a misunderstanding of how something like this works.

Some interviewees report trying to mitigate administrative burdens. For instance, one collaborator indicates that they were able to negotiate with a funding agency to complete strategic plans biennially rather than annually. However, most interviewees discuss administrative burdens as intransigent obstacles, externally motivated, and an inherent part of the funding process, and as such non-negotiable.

A third type of coordination cost challenge is managing the differences found among members of a collaborative group. Interviewees that share issues in this area are usually affiliated with multi- or interdisciplinary collaborations. One interviewee remarks, "The biggest challenge is understanding terminology. We refer to the same things using different words in different disciplines." Other interviewees note issues that arise from working with collaborators in different institutional settings. For instance,

> One of the biggest challenges that we had is that, you know, the way a university functions…professors have different roles and they can only spend so much time on research. [Names company] and some of the other industry partners devoted one hundred percent of their time to this project, and they expected us to do the exact same thing. And we…were constantly fighting…I can't do that, you know, I have to teach so many classes a day, I have to do these other aspects.

Strategies for managing challenges rooted in collaborator differences center around regulating expectations and creating shared frameworks for interaction. Some interviewees report intentionally setting aside time to discuss differences and acclimate researchers to divergent aspects of their backgrounds. Alternatively, others liken working through differences to a negotiation process occurring throughout the course of the collaboration.

The final subdivision of coordination cost challenges, managing task complexity, is reported by twenty-four percent of interviewees. Increased complexity can be caused by the degree of integration of work that collaborators desire. Some groups capitalize on members' complementary areas of expertise by having them perform separate parts of a project and later joining those contributions. However, other groups aim to more fully integrate the work and thought processes of participants in an effort to stimulate new ideas and perspectives on problems. This higher degree of integration can produce significant challenges. One interviewee describes the following:

> The [names network] that was the sort of model for these research networks kind of came about organically, just a bunch of people that actually wanted to do this. And the rest of the networks were kind of shucked together, more externally driven than internally driven. So…some of those just didn't work as well...getting people, getting the groups to see, you know, how useful this was, was part of the problem.

Complexity can also cause challenges when a collaboration has many different moving parts and interrelated projects moving forward at the same time. An interviewee shares:

> Sometimes…there would be a subset working on something and then you'd think well gee, I could have worked on that. How come I'm not included in that particular topic?…But there was just so much going on, you know, that a group of three or four would get together some place and they would be solving problems and writing and…to be really in the thick of it you had to be constantly traveling.

Managing Interpersonal Issues

Interview questions also investigated management challenges related to interpersonal issues. This type of challenge is fairly common; forty percent of interviewees relate obstacles caused by interpersonal problems during their most recent collaboration. A higher percentage of interviewees involved in multi-disciplinary collaborations (48%) report interpersonal issues than do those who are in single discipline collaborations (11%). Among those who recognize interpersonal challenges, responses again support the categories identified by the organizing scheme including personal incompatibilities (64%), lack of trust (27%), and biases or prejudices (18%). The responses also suggest two expansions to the subsets of interpersonal issues developed from the literature review. First, personal incompatibilities, the most common type of interpersonal issue, can be divided into two general forms: personality clashes and divergent work-style preferences. Additionally, interviewee responses indicate a fourth interpersonal issue sub-category which is labeled conflict triggering behavior (18%).

Personal incompatibilities, both personality and work-style based, are particularly problematic for smaller collaborations because there are less opportunities for collaborators to use others to buffer their interactions. While seven interviewees recount challenges related to personal incompatibilities among collaborators, two of these are scientists in large collaborations, and both describe compatibility challenges ambiguously as something to be expected when human interaction occurs in large groups. One says,

> I think because of the diversity of the group, which brought all those positives that I talked about earlier can certainly bring about…some challenges…and I guess I just feel like almost in any group…you're going to have that kind of thing occur.

On the other hand, the remaining five interviewees belong to smaller groups and relate specific consequences of collaborator personality issues. For example,

> [We had a] student that was not a great fit, and I mean that was pretty difficult. I would spend a lot of my time in our individual meetings just trying to get her to be more friendly…to act less exasperated. You know just to be, I don't want to say kinder, but be more professional…eventually I'm not sure that we necessarily worked it out. She went to a different project.

The differences in the way compatibility issues are described could relate to the fact that larger collaborations are often more formalized, offering a scaffolding of processes and procedures to govern collaborator interaction and provide recourse when issues arise. Additionally, when more collaborators interact, participants may be able to dilute some of their interpersonal irritations by using more compatible collaborators to mediate their interactions.

Less frequently acknowledged than personal incompatibilities are challenges created by lack of trust between collaborators. Three interviewees relay issues in this area; they all indicate that trust issues emerge when environments or individuals are competitive rather than cooperative. An engineer notes that this can be a problem when intellectual property and patenting issues bring economic interests into a collaboration. She says,

> There was a concern initially from the software group, so there was a lot of resistance at the start…and I spent a lot of time saying…look I'm not here to take a chunk of your revenue from selling this software system; I'm just here to give you input from what the user thinks that they want.

The other two scientists describe trust issues rooted in academic competitiveness. One shares that, "you get a bunch of Type A personalities at this level…and…people trying to prove themselves…As a colleague of mine says…science is the easy part." Likewise, another interviewee states that in her collaboration,

> One person…was having an approach that was not open. So this person would withhold data to herself and not make them…available…it was like [she felt] we were, you know, stealing them. So that was a little bit odd to me because everyone else was very open.

Notably, no interviewees depict lack of trust due to weak social bonds or relational distance between collaborators which has been noted in previous work (Jonathon N Cummings & Kiesler, 2008; Jonathon N. Cummings & Kiesler, 2005). However, some do mention management activities designed to build productive social bonds. For instance, several interviewees describe meetings or workshops that create an intentional space and time for collaborators to put aside their other work and responsibilities and focus on building social and professional ties within the collaborative group to support and strengthen its efforts to achieve its goals.

In addition to personal incompatibilities and trust issues, collaborators may face serious hurdles to productive interaction in the form of biases or prejudices. Only two interviewees mentioned these types of issues, but it is likely that respondents are more reluctant to talk about them in relation to a specific collaboration because of the negative light in which they might paint fellow collaborators. The two interviewees that provide examples do so in regards to collaborations prior to the one they described in-depth for this study. One interviewee relates a pattern of perceived gender bias throughout her career:

> In every collaboration that I've been in where I was the junior co-author, the authority was centered in the senior co-author. And I find that when I am senior co-author this works fine with my women junior co-authors, but my male junior co-authors almost literally every one of them thinks they are in charge even if they are twenty years younger than me.

She says that she has responded to this situation by seeking out junior women as co-authors to mentor and provide with healthy collaboration experiences. A second interviewee explains that she experienced prejudice related to her professional background and experience. In this instance, potential industry collaborators were not willing to consider the value of having a new perspective from a collaborator in a field somewhat removed from what they anticipated:

> There was some push back from different groups within the industry about an industrial engineer working with an electrical company. You know… [things like] you don't even know what electrical engineering is or the power industry is so why are you even here. So we had some people that wouldn't even talk to us.

In addition to the subsets of issues related to managing interpersonal dynamics that were identified in the previous literature review, interviewee data also describe actions and behaviors that trigger instances of interpersonal conflict, thereby creating management challenges. This can happen even when collaborators previously felt compatible and enjoyed trusting working relationships. Two interviewees provide examples of tension triggering events. First, a manager in a very large collaboration recalls:

> There's one issue where somebody basically did the experiment that somebody else had said they were going to do because they could, because their lab was much more

> equipped to do the experiment. So that was a bit of a bummer, and so our science director…tried to kind of figure out what was going on there and…in the end everybody was…kind of fine with it. But it was a bit worrisome early on because it looked like somebody was, you know, essentially stealing somebody else's idea.

In a situation that was not as ethically ambiguous, the other explains,

> There was one time one of my cohorts was…giving me all this feedback right there at the meeting and I was like well I sent a draft of this paper out four months ago; it would have been nice to have this then…as opposed to like right here, right now when we had a big…presentation…to some really important folks. And all of a sudden I was getting all of this feedback, you know, just a day before I was going to be having to do this big talk which I was nervous about….so that was sort of, that was one of my…dramatic situations.

Although in both instances the interviewee reports that the collaborative group was able to reach a resolution and continue the pursuit of their scientific goals, each of the events left a lasting negative impression on collaborators and their relationships moving forward. Importantly, the former example illustrates the utility of having conflict resolution measures in place. The disputing parties were able to bring their issues to a neutral party, the science director, who acted as an arbitrator of the conflict.

Contribution/Crediting Issues

Seventeen percent of interviewees report collaboration challenges related to contribution and crediting issues. Their responses include disagreements and negative feelings in cases of miscommunication and divergent opinions about relative contributions:

> An undergraduate did a paper, and the psychology professor was not involved in it initially. So we were trying to get him involved on it…He was like well I didn't think I contributed to this, and I'm not a co-author. And we were like well maybe you're not a co-author because we forgot to put you on it. And it's been a couple of years since the undergraduate graduated, but he still wants his publication. So we're trying to deal with that.

differences in norms across fields of study:

> The way they do it is not the way it's done in math, [the way] they do it in engineering…It's not like alphabetical, so you have to actually discuss who's going be the first author…in math, you would all be, nobody would assume that [mattered], who was first and who was last. So I sort of had to learn their way of doing it.

and selfish behavior:

> My student had first co-author position with the postdoc at [names institution]. This postdoc, which was the same that was sort of holding the results back. She didn't like the idea of sharing first place with someone. So we had to do a little bit of convincing, but even her own boss tells her look, it's ok.

No interviewees report crediting challenges associated with unethical behavior in their current collaborations. However, one acknowledges having problems in the past. He shares,

> What I ended up doing was accusing a collaborator on the opposite side of the world of ethical misconduct and eventually took it to the point where I wrote a letter to his superiors with some great reluctance….The ethical issue was that…I withdrew my name from the collaboration, and then, contrary to my request, he submitted it to a different journal with my name still on the paper. I thought that might be happening, and so I had contacted the editor of the new paper, of the new journal, before that. And so the editor let me know that, that had happened and then basically left it up to me to decide what to do with the situation after that.

As previous studies have noted (B. Bozeman et al., forthcoming; Youtie & Bozeman, 2014), crediting problems typically occur when collaborators have failed to develop an explicit shared understanding of how credit will be assigned. Establishing this understanding does not have to be an elaborate formal process, it can be as simple as an intentional discussion about expectations for authorship order before a paper is written. When collaborators do not ensure equivalence of expectations, misunderstandings are more likely to occur and emergent issues more easily escalate into significant problems or conflict.

Leadership Issues

Thirteen percent of interviewees mention management challenges related to leadership in their current collaborations, and three additional interviewees provide evidence of these types of challenges in past collaborations. Their responses align with the categories identified in the literature review: tension between scientific autonomy and leadership, mismatch of leadership style to group characteristics, and leader instability or change. Specifically, three interviewees comment on the tension between leadership and individual scientific autonomy. Each describes these issues occurring in fairly large collaborations (more than twenty participants). Notably, in smaller collaborations among equally situated peers, scientific authority can more often be characterized as diffuse, with collaborators taking a shared approach to leadership. However, as collaborations grow larger, this approach becomes unwieldy, and specific individuals are often designated as leaders. One interviewee reflects on the situation that can occur if participants' desire for autonomy crowds out leadership structure.

> I think in some previous collaborations because the leadership and…decision making apparatus was not well defined, there was a lot of competition and egos get in the way and negatively impact the ultimate decision making…. it was almost like whoever's the loudest is the one who's making the decision and that's not a very effective [method].

A second interviewee asserts that one way to manage the autonomy/leadership tension is for PIs to utilize any resource distribution power that they may have as a means of pressuring collaborators to pursue more participatory behaviors:

> You know sometimes all the pieces don't come together as cleanly as you'd like, but when you do see that some of them are not functioning as the leader of that team you can make decisions on resources. And you can attempt to try to apply pressure…to get changes in behavior, but that's a hard thing to do with academics because of their independence. And so, you know, in general what we tend to do on that is move the resources to people who are more participatory.

Alternatively, another respondent reports success using a more transformational leadership (Bass, 1991) style approach:

> It was kind of my job to get people to do what we wanted them to do to collaborate. So at every all hands meeting I would again espouse what it is we were supposed to be doing, and why that was a good thing…It was not easy to get people to actually, you know, do

> these fairly frequent meetings and such. That was certainly a challenge for me to get…people on board with the whole idea.

In addition to autonomy issues, three interviewees also describe management challenges created by leadership instability or change. For instance, in one collaboration a PI had a serious illness which created a leadership vacuum. In the other cases, leaders also left the collaboration or withdrew from their leadership role for some reason, causing other collaborators to struggle to find new leadership or to take on added burdens themselves. These issues are particularly difficult to navigate because they often cannot be foreseen. As one interviewee states,

> The guy who leads ours is extraordinary and generous, but he is the guy with the vision…So, if he got hit by a bus tomorrow I just feel like it would be very hard to replace him. And I don't think anybody believes in their hearts that they could do a better job, and that's exactly the kind of person you want to get behind. You really need a strong lead to bring everybody together.

The third management challenge in the leadership arena is ensuring that a leader's style is a good fit for the rest of the members of the collaboration. One interviewee reports that,

> There was time pressure to…put the proposal together and…someone had to be the leader, you know, to coordinate the whole. We had our individual parts of it, but one person had…to actually submit the proposal…I think…we looked for someone who was on a tenure track and would need to get tenure at a top university, and we said well why don't you be the chief? You be the chief on this one because that will look good for your tenure case. So we didn't stop and think who really is you know the [best] leader, or the most recognized, or maybe even the most efficient. That's how we just decided on who it would help.

Although in this case the scientist feels that the leader ultimately performed fairly well, his response points to the importance of making strategic leadership choices. This idea is supported by a second respondent who details how leadership style misfits can result in conflict and poor collaboration outcomes:

> The leader…would set the agenda and always put his project first and our project last. He was really bad administratively with like managing budgets…He would have project

> meetings with just his students and not invite the other faculty members. He would ask kind of probing, damaging questions of us in front of our client.

Managing External Influences

In conjunction with the challenges discussed above, interviewee responses suggest that an additional category of management challenges should be added to the organizing scheme. This category is designated managing external influences, and thirty-three percent of interviewees report challenges in this area. This label encompasses two subsets of issues that can create management challenges for collaborators: detrimental influence from external stakeholders and barriers due to environmental or contextual factors.

First, external stakeholders are those entities who are not considered collaborators because they contribute no human capital to a collaboration effort (B. Bozeman et al., 2013) but who nonetheless have an interest in the outcome of the collaboration process. For example, external stakeholders may include funding agencies or funding agency representatives, government agencies, university administration, and non-governmental organizations. Although they do no scientific work themselves, they may seek to influence collaborators, and when their behavior impedes collaboration effectiveness it becomes a collaboration management challenge. For example, one interviewee describes a binational research collaboration that attracted interest from many political stakeholders. He says,

> Sometimes…environmental groups…tend to be advocates, pushing the science in one direction, agency folks tend to have a particular agency agenda, and they push the science in another direction. You know, academics sort of have their head in the clouds sometimes and don't realize sort of the implications of what they're doing…. [That’s] the other dimension of this…that sometimes inhibits…this particular project are the political sensitivities involved. So, typically our meetings are not just among the scientists but we have representatives of agencies…always sort of there and in the background as it were, kind of listening, and that can inhibit some conversations.

A second interviewee discusses problematic changes in collaboration organization stemming from funding agency influence:

> At times there has had to be a slight restructuring at the request of the funding agency…I have to be careful what I say here…so, let me just give an extreme example…Let's say that chemistry is funding this activity so they want to see chemistry going on, but that the team really wanted an economist to be on the team because we felt it was an area that was going to add to the overall approach. You can imagine that somebody on the chemistry side at the funding agency might say, I can't believe we're paying for an economist so you really need to remove the economist. And that I think is the only issue that we've faced…and I'm again using an extreme example on purpose…but we have had direction for the funding agency's own internal reasons having nothing to do with the team itself…So there might have been a direction that the team wanted to go in and the funding agency basically said no.

The second area of external influence in a collaboration comes from environmental and contextual factors. This set of influencers can encompass any of the diverse elements that make up a collaboration's context. Part of the collaboration management process can be envisioned as buffering the scientific work of collaborators from any environmental elements that might detract from their scientific goals. The most noted challenge in this area is obtaining continued funding (70%). Just as collaborations can extend beyond the boundaries of a publication (B. Bozeman et al., 2013), they can also extend beyond the bounds of a single award or grant. In these cases, if collaborations are to survive, they must continue to cultivate additional funding streams. Twenty percent of all interviewees report seeking continued funding for their collaboration as their biggest management challenge. Other contextual challenges included managing issues with technological or physical infrastructure:

> We were in a very old building…here on campus, it was built in 1928. And it had iron pipes and tons of…bacterial contamination in the iron. There were iron metabolizing bacteria and fungus for that matter, so trying to fight that battle to clean the endotoxin out of our water was really quite a challenge and it turned out [to be] quite expensive and slowed us down a great deal and consumed a lot of resources and time and money.

and retaining talented students:

> Sometimes there are students that look so promising…especially during the recession with jobs being so difficult, we'd have students that would just look so promising and then they'd say well you know what I've got a job. I'm taking a job with Google or Microsoft because you know they want me and…they pay big money. So [students] dropping out of the area; that's frustrating.

Contextual issues, with the exception of the need for continued funding, resemble challenges related to leadership change and instability in that they are difficult to predict, and often related to dynamics outside of collaborators' control. However, having a critical awareness of areas that may become problems may help collaborators to diagnose and respond to problems more quickly and strategically.

Discussion and Conclusion

The previously discussed findings should be interpreted in light of several limitations. First, for each collaboration represented in the study, only one member is interviewed. Therefore, collaboration characteristics and reports of management challenges are filtered through the perceptions of the single interviewee. Other participants may have differing perspectives on the cause of a challenge or the measures taken to address it. This may be particularly limiting in regards to exploring challenge in areas such as interpersonal dynamics because no single individual is likely to have a complete understanding of all interpersonal issues within a collaboration. A second limitation of the study is that not all interviewees were equally involved in collaboration management processes. While most interviewees had leadership or senior roles in their collaborations, others were junior members who may not have had as much awareness of the collaboration management issues, strategies, and responses. Finally, although the study has identified some strategies that collaborators use for navigating collaboration management challenges, it does not offer evidence about which approaches are most effective. Identifying these strategies does, however, pinpoint areas for future research. For example, in regards to overcoming the autonomy/leadership tension, are carrot or stick based approaches more effective? How often is negotiation a successful tactic in mitigating administrative burdens? What are the best methods and techniques for helping diverse collaborators to create a shared framework for successful work? How are scientific leaders identified, and what effect do they have on collaboration productivity?

Acknowledging these limitations, the proposed organizing scheme provides a framework for systematic consideration of the various components of collaboration management, particularly those areas that often present challenges or obstacles to collaboration effectiveness. Several practical lessons for collaborators can be drawn from the evidence presented above. First, there is no one size fits all approach to collaboration management. Suitable strategies depend on numerous factors including collaboration size, the level of trust between collaborators, the desired level of task interdependence, and outside organizational or institutional structures. For example, Barry Bozeman and colleagues (forthcoming) suggest that formal guidelines for collaboration management are often not needful or necessary in collaborations where relationships based on prior experience and trust have conditioned collaborators to develop convergent values for their work. By implication, larger collaborations and those that include researchers who do not have previous experience working together may find it appropriate to adopt more formal management processes.

Another lesson for collaborators is that good collaboration management involves developing shared sets of expectations among collaborators at various stages throughout the collaboration process. For instance, this is especially apparent regarding decisions related to crediting. Both interviewees and previous research indicates conflict arising when collaborators have differing opinions about what constitutes a contribution. Moreover, outlining shared expectations can help to alleviate the issues caused by combining diverse backgrounds and disciplines. Management processes that are participative and seek to ensure that collaborators feel expectations have been fairly negotiated may help to diminish future problems.

Collectively, interviewees' experiences indicate that many scientists approach collaboration management in a somewhat ad hoc manner, often developing mechanisms for handling challenges as they react to them rather than taking a more proactive approach. Barry Bozeman and colleagues (forthcoming) suggest four possible variables that may prevent scientists from employing strategic approaches to collaboration management; these include the collaborator's level of management skills, number of other time demands, tendency towards conflict avoidance, and desire to keep rather than share power. Overcoming these barriers and, adopting intentional, strategic, and appropriate management practices can help to smooth coordination processes, promote congruent expectations for shared workloads and crediting decisions, mitigate conflict, and provide awareness of the connections between a collaboration and its external context.

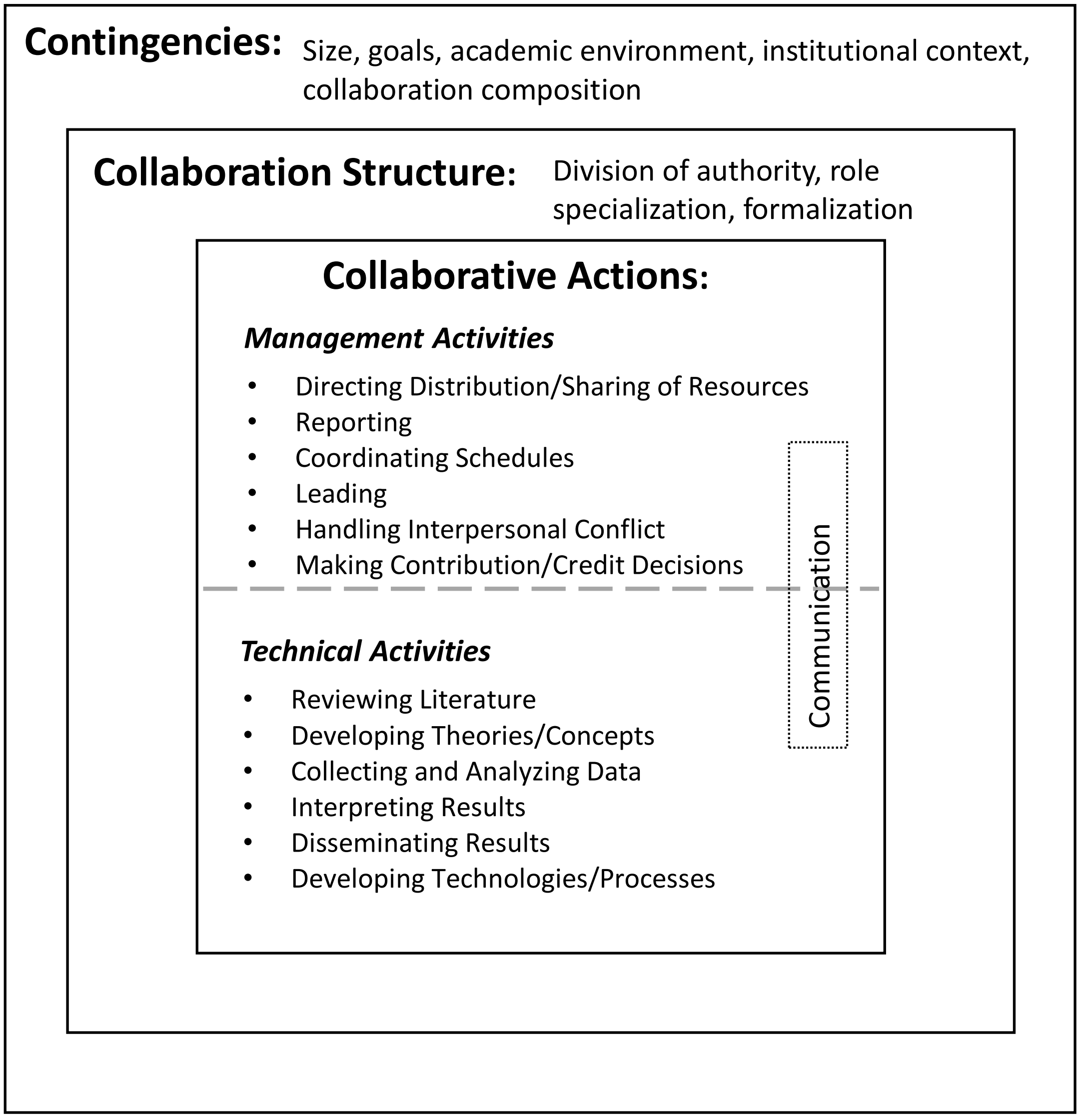

Figure 4.1 Collaborative Activities

Table 4.1: Collaboration Management Challenges: An organizing scheme

Excessive Coordination Costs	Contribution/Crediting Dilemmas	Managing Interpersonal Problems	Leadership Issues
Administrative Burdens	Differences of Opinions and Expectations	Lack of Trust	Tension between Individual Autonomy and Group Leadership
Obstacles to Direct Communication	Misunderstandings and Miscommunication	Personal Incompatibilities	Leadership Style Mismatch
Handling Differences	Selfish Behavior	Biases and Prejudices	Leadership Instability or Change
Task Complexity	Unethical Behavior		

Table 4.2 Frequency of Common Challenges

Challenge Category	Number of Collaborations Reporting an Issue in this Area
Coordination Cost Obstacles	27
Managing Interpersonal Dynamics	12
Co-Authorship/Contribution Issues	5
Leadership Issues	4
Managing External Influences	10

Table 4.3: Revised Organizing Scheme for Collaboration Management Challenges

Excessive Coordination Costs	Contribution and Crediting Dilemmas	Managing Interpersonal Problems	Leadership Issues	Managing External Influences
Administrative Burdens	Differences of Opinion and Expectations	Lack of Trust	Tension between Individual Autonomy and Group Leadership	Detrimental Stakeholder Influence
Obstacles to Direct Communication	Misunderstanding and Miscommunication	Personal Incompatibilities	Leadership Style Mismatch	Environmental or Contextual Barriers
Handling Differences	Selfish Behavior	Biases and Prejudices	Leadership Instability or Change	
Task Complexity	Unethical Behavior	Conflict Triggering Behavior		

CHAPTER 5: CONCLUSION

This dissertation presents three manuscripts that explore aspects of organizing and managing scientific research collaborations. Chapters 2 and 3 focus on the internal organizing characteristics that academic scientists utilize to structure their collaborative work processes. Findings indicate that collaborations exhibit a range of organizational characteristics, at times resembling formal organizations and at other times appearing more like work or project teams. Chapter 2 offers evidence that variations in degrees of role specialization and centralization of decision making can be linked to individual level characteristics of participating scientists such as career length and pre-collaboration relationships between scientists. Likewise, Chapter 3 pinpoints collaborators' relationships as being correlated to collaboration organizational characteristics. It also highlights collaboration size and contingencies such as institutional environments as being linked to the level of formalization and administrative complexity within collaborations. Conclusions in both chapters suggest that understanding the interplay between collaboration context and structure can help collaborators to develop better strategies for collaboration management.

In this vein, Chapter 4 delves into common collaboration management challenges. Interviews with scientists reveal that management challenges are a routine part of the collaboration process and that oftentimes scientists approach collaboration management in an ad hoc manner. As with collaboration organization, there is no one size fits all solution for collaboration management issues. However, the chapter suggests that instituting some type of formal or informal process for developing shared expectations is a key element of effective collaboration management. The National Research Council recently published nine recommendations aimed at promoting more effective research collaboration and team science that appear to be an excellent starting place for a broad gauge approach to improving collaboration management. The recommendations include promoting various training and professional development opportunities for scientists, particularly leadership training, considering how to develop and structure academic crediting and tenure decision systems to better recognize collaborative work, increasing funders roles in supporting collaborative work, drawing lessons from current research on work teams, and advancing more scholarly research on the elements of effective collaboration (Committee on the Science of Team Science, 2015).

As scientific work structures continue to shift away from individual and even small group endeavors towards larger teams and collaborative institutional arrangements, systematic knowledge about organizing and managing collaboration is increasingly important, not only for scientists but also for policymakers, funders, and academic institutions. The findings in this dissertation point towards a need to develop and promote more strategic and intentional approaches towards collaboration organization and management. Although a number of studies examine these topics (See Appendix B), they are currently fragmented across various fields of study (Committee on the Science of Team Science, 2015). There are some limited efforts in place to make existing knowledge more widely accessible to scientists and to avoid duplication of research efforts. For example, the National Cancer Institute hosts a website where users can share information and resources about best practices for effective team-based science[30]. However, scientists, particularly those who are most likely to be leading large collaborative

[30] See https://www.teamsciencetoolkit.cancer.gov/Public/searchAdvResult.aspx?st=a&sid=1

efforts, have limited time to devote these types of professional development activities, and wading through multitudes of user contributions to sift out specific practical applications for their own collaborations is unlikely to be seen as a productive activity. Conversely, other activities such as short panels or discussion groups at seminars and conferences may not be able to address these topics in adequate depth. Thus, this dissertation concludes by both calling for continued research on collaboration organization and management and by highlighting the need for better and more feasible conduits for bridging the gap from collaboration research to practice.

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APPENDIX A

INTERVIEW PROTOCOL

Background Information

1. About what percentage of your publications would you say are co-authored?
2. Of these co-authored publications, what percentage includes at least one peer co-author (as opposed to solely students or post-docs)?
3. Typically, about how many people do you collaborate with in a given year?
4. Is it typical for your collaborations to include researchers from other disciplines?
5. Is it typical for your collaborations to include researchers from outside of your university? (Probes are these usually industrial, government, researchers from other universities, etc.)
6. Currently, what are the top 3 funding sources for research projects in your field? Has the funding that you have applied for from any of these explicitly required cross or multi-disciplinary research collaboration?
7. Do you feel that your collaboration patterns have changed over the course of your career? How so?

Detail Information for Recent Collaboration Experience

8. Thinking about one of your most recent research collaboration please describe each of the following
    a. size of the collaboration
    b. time-scale of the collaboration
    c. if the collaboration cross or multi-disciplinary and if so how many disciplines were involved
    d. number and status of various collaborators (number of peer colleagues, students, etc.)
    e. how the various collaborators met each other and decided to join the collaboration (graduate school, at academic conferences, through mutual acquaintances, mentor/protégée relationship, etc.)
    f. most common coordination mechanisms utilized (email, conference calls, faculty supervision of students)

g. any special factors such as necessary technology, grant requirements, or geographic proximity of collaborators that had to be taken into consideration when setting up the collaboration
h. the main goal(s) of the collaboration and how collaborators were made aware of it/them
i. division of authority (designated scientific leader, administrative leader, etc.)
j. decision making procedures (consensual, hierarchical, etc.)
k. degree of role specialization
l. how co-authorship decisions were made
m. guidelines for data collection and sharing
n. presence of contracts
o. evaluation procedures (formal or informal and internal or external)
p. rules (formal or informal)
q. existence and authority of subgroups
r. whether there were any major organizational changes over the course of the collaboration

9. What have been the major outputs/outcomes of the collaboration? (publications, spin-offs, patents, awards, generated new data set, student used work for thesis/dissertation, partnership with government or industry, community relationships, continued collaborations/new collaborations formed by project collaborators)
10. For you personally, what would you say were this collaboration's biggest successes?
11. Do you feel that there were any organizational elements that helped work to flow particularly smoothly throughout the collaborative process?
12. What do you think were the biggest challenges that this collaboration faced?
13. Now we'll narrow the focus a little and discuss specific types of challenges. The next six questions ask whether you encountered any of a variety of potential challenges.
    a. Did the collaboration experience any challenges or issues related to leadership issues?
    b. Did the collaboration experiences any challenges or issues related to compatibility of collaborators (work style or personality)?
    c. Did the collaboration experience any challenges or issues related to communication/coordination?
    d. Did the collaboration experience any challenges or issues related to administrative requirements or procedures?
    e. Did the collaboration experience any challenges or issues related to co-authorship or contribution decisions?
    f. Did the collaboration experience any challenges or issues related to other types of decision making (scientific direction, publication outlets, etc.)?

14. Would you say that this collaboration was typical or representative of your usual experience with collaborations? Why or why not?
15. How do you personally evaluate whether it is worthwhile to participate in a collaboration?
16. During the collaboration process what are some signs that a collaborative effort is having difficulty? Are there things that researchers can do either before a collaboration begins or during the collaborative process to mitigate or avoid those difficulties?
17. Are there any additional comments about the organization of collaborative research or your personal collaborative experiences that you would like to add?

APPENDIX B

COLLABORATION CHALLENGES: LITERATURE REVIEW TABLE

Citation	Collaboration Management Challenges	Origins of Challenges	Evidence	Relevant Findings
Aagaard-Hansen, Jens, & Henry Ouma, John. (2002). Managing interdisciplinary health research–theoretical and practical aspects. *The International Journal of Health Planning and Management*, *17*(3), 195-212.	Coordination Costs, Leadership Issues	Time horizon, Disciplinary/Methodological Differences, Ease of access to colleagues, Availability of information, Leader Characteristics	Theoretical/ Conceptual; Case Study based on personal experience	Contextual factors including project complexity, communication channels, and personal characteristics of leaders can either facilitate or impede the level of integration in collaborations among researchers from different disciplines. The collaboration process can be supported with communication, developing a balance between the disciplines involved, balancing interdisciplinarity with managerial complexity, and establishing appropriate evaluation procedures.
Atkinson, Paul, Batchelor, Claire, & Parsons, Evelyn. (1998). Trajectories of collaboration and competition in a medical discovery. *Science, Technology & Human Values, 23*(3), 259-284.	Contribution/Crediting Issues, Interpersonal Issues	Motivation/Incentives, Limited Resources	Case Study	Collaboration and competition are not mutually exclusive Within collaborations, scientific competitiveness can lead to a lack of trust between collaborators resulting in less open and less productive collaborations. Pressure to get more funding, compete for funding, and be the first to publish a new discovery are factors that contribute to an atmosphere of competitiveness and secrecy among collaborators.

Bammer, Gabriele. (2008). Enhancing research collaborations: Three key management challenges. *Research Policy*, *37*(5), 875-887.	Coordination Costs, Interpersonal Issues	Collaboration heterogeneity, Disciplinary differences, resource and time limitations, political pressure, power imbalances between individuals or disciplines, idiosyncrasies, lack of flexibility preventing creativity, external stakeholder influence	Case Studies; Theoretical/ Conceptual	The paper focuses on three challenges: effectively harnessing collaborator differences, setting collaboration boundaries, and gaining legitimate authorization. It proposes a framework for thinking systematically about each of these issues.
Beaver, Donald. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics, 52*(3), 365-377.	Coordination Costs, Leadership issues, Interpersonal Issues	Administrative burdens, Multiple roles for PIs, Motivation/Incentives	Anecdotal; Theoretical/ Conceptual	Big Science structures can divert the creative talent of PIs to administrative tasks rather than science. They may also promote an environment of competitiveness that is detrimental to the advancement of science.
Boardman, Craig, & Bozeman, Barry. (2007). Role strain in university research centers. *Journal of Higher Education*, *78*(4), 430-463.	Coordination Costs	Multiple responsibilities for research center collaborators	Interviews	The authors find that role strain is more likely when faculty members are affiliated with a research center that has no formal ties to their department. Some scientists report work overload and incompatible expectations based on their dual affiliations.
Boardman, P. Craig, & Corley, Elizabeth A. (2008). University research centers and the composition of research collaborations. *Research Policy, 37*(5), 900-913.	Coordination Costs	Collaboration heterogeneity	Surveys and institutional data	Research center affiliation affects individual-level collaboration patterns. Industry-linked center affiliation was negatively correlated with collaboration at other universities and program-linked affiliation was not significantly correlated with collaboration at other universities. This is problematic because many federally funded research centers have a goal of increasing the ease with which researchers from multiple universities

				can work together. Center design, specifically regarding the diversity of stakeholders included, may be causing unintentional trade-offs in the time that individuals devote to research collaborations.
Boehm, Diana Nadine, & Hogan, Teresa. (2014). 'A jack of all trades': The role of PIs in the establishment and management of collaborative networks in scientific knowledge commercialisation. *The Journal of Technology Transfer, 39*(1), 134-149.	Coordination Costs; Leadership Issues	Time as a limited resource, Multiple roles for PIs	Case based interviews	PIs have a leading role in the maintenance, management, and sustainment of collaborative relationships. Juggling this role can lead to tradeoffs between management activities and academic roles.
Bozeman, Barry, Gaughan, Monica, Youtie, Jan, Slade, Catherine, & Rimes, Heather. (Forthcoming). Research collaboration experiences good and bad: Dispatches from the front lines. *Science and Public Policy*.	Coordination Costs, Interpersonal Issues, Contribution/Crediting Issues,	Lack of intentional management strategies, Personality clashes, Egoism, Selfishness	Interviews	Personality clashes, egomania, and selfishness can contribute to poor collaboration experiences. Attention to management strategies can reduce poor outcomes. Attention should be paid specifically to areas including exploitation, crediting procedures, and cultural/national dynamics.
Bozeman, Dennis P., Street, Marc D., & Fiorito, Jack. (1999). Positive and negative coauthor behaviors in the process of research collaboration. *Journal of Social Behavior & Personality*, *14*(2), 159-176.	Contribution/Crediting Issues; Interpersonal Issues	Lack of consideration, Lack of dependability, Selfishness	Focus Group Interviews, Surveys	The study identifies selfishness, consideration, and dependability as individual level behaviors that are key factors in research collaboration. The authors identify negative behaviors within each of these categories as obstacles to collaboration success.
Chompalov, Ivan, & Shrum, Wesley. (1999). Institutional collaboration in science: A typology of technological practice. *Science, Technology, & Human Values*, *24*(3), 338-372.	Interpersonal Issues, Coordination Costs	Lack of trust, Organizational/Structural Characteristics, Deadlines, Scientific Delays, Results checking	Both qualitative and quantitative data from 23 large multi-institutional collaborations	Organizing multi-institutional collaborations so that they have high levels of control may be linked to higher levels of collaborator conflict and disagreement. Participants in managerial collaborations report lower levels of trust, higher levels of stress, and more serious disagreements between teams. Decentralized projects exhibit higher levels of stress and

				conflict than routine collaborative projects.
Claxton, Larry D. (2005). Scientific authorship: Part 2. History, recurring issues, practices, and guidelines. *Mutation Research/Reviews in Mutation Research, 589*(1), 31-45.	Contribution/Crediting Issues	Lack of buy-in from stakeholders regarding crediting guidelines, Deceptive practices, Unethical conduct, Disagreements between co-authors, Conflicts of interest	Theoretical/ Conceptual	Because there is no universal set of guidelines for authorship issues, authors often confront issues on an ad hoc basis. Scientists can decrease time spent on authorship decisions and increase buy-in by having conversations throughout the course of a project with all involved stakeholders.
Cronin, Blaise. (2001). Hyperauthorship: A postmodern perversion or evidence of a structural shift in scholarly communication practices. *Journal of the American Society for Information Science and Technology*. *52*(7), 558-569.	Contribution/Crediting Issues	Increasing diversity of contributions including non-textual ones, Lack of widely accepted guidelines for making crediting decisions, Disagreements between co-authors, Lack of transparency, Equity concerns, Collaboration heterogeneity, Social distance, Collaboration size	Theoretical/ Conceptual	The study reviews the problems of hyperauthorship as they have manifested in biomedicine. It discusses why these same issues have not arisen in the realm of high energy particle physics despite the fact that HEP articles also have a high rate of hyperauthorship.
Cullen, Peter W., Norris, Richard H., Resh, Vincent H., Reynoldson, Trefor B., Rosenberg, David M., & Barbour, Michael T. (1999). Collaboration in scientific research: a critical need for freshwater ecology. *Freshwater Biology*, *42*(1), 131-142.	Interpersonal Issues, Leadership Issues	Motivation/Incentives, Collaboration Diversity, Organizational/Structural Characteristics,	Anecdotal and Personal Experience	Key obstacles to collaboration include competition, different organizational cultures, and organizational instability. Delays happen when key personnel leave and a project must be restructured.
Cummings, Jonathon N., & Kiesler, Sara. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science*, *35*(5), 703-722.	Coordination Costs, Interpersonal Issues	Geographic Proximity, Collaboration size, Social distance	Surveys	Dispersed collaborations face challenges of coordination related to effectively integrating their work in the absence of face to face meetings. Social bonds between scientists in different disciplines may be weak creating challenges for building trust and

				collaborator interdependence. Collaborations involving a greater number of universities are problematic for collaboration outcomes; this is mitigated by the number of coordination mechanisms utilized by the collaboration.
Cummings, Jonathon N., & Kiesler, Sara. (2007). Coordination costs and project outcomes in multi-university collaborations. *Research Policy, 36*(10), 1620-1634.	Coordination Costs	Collaboration Size, Geographic Proximity, Institutional Differences	Surveys	Collaborations involving multiple universities have higher coordination costs than those within a single university, and these coordination costs are significant barriers to project success.
Cummings, Jonathon N., & Kiesler, Sara. (2008). *Who collaborates successfully?: prior experience reduces collaboration barriers in distributed interdisciplinary research.* Paper presented at the Proceedings of the 2008 ACM Conference on computer supported cooperative work.	Coordination Costs, Interpersonal Issues	Geographic Proximity, Collaboration Size, Disciplinary Differences, Social Distance	Surveys	Geographic distance reduces the productivity of interdisciplinary research teams. Pairs of senior researchers who have no prior experience with each other and come from different disciplines and universities have a decreased likelihood of developing strong working relationships.
Cummings, Jonathon N., Kiesler, Sara, Bosagh Zadeh, Reza, & Balakrishnan, Aruna D. (2013). Group heterogeneity increases the risks of large group size: A longitudinal study of productivity in research groups. *Psychological Science, 24*(6), 880-890.	Coordination Costs	Collaboration size, Collaboration Heterogeneity, Social Distance	Bibliometric Data; Interviews	Interviewees indicate that communication problems in their research groups can be attributed to large group size as well as group heterogeneity. Relational distance between researchers interfered with group chemistry and resulted in members gravitating toward work with other members that they already knew. Increased heterogeneity decreased marginal productivity when collaborators were from different disciplines or institutions. Diversity may be more advantageous to smaller groups rather than larger ones.

Curry, Leslie A. , O'Cathain, Alicia, Clark, Vicki L. Plano, Aroni, Rosalie, Fetters, Michael, & Berg, David. (2012). The role of group dynamics in mixed methods health science research teams. *Journal of Mixed Methods Research 6*(1), 5-20.	Coordination Costs, Interpersonal Issues, Leadership Issues	Collaboration Heterogeneity, Lack of trust, Disciplinary/Methodological differences,	Theoretical/ Conceptual	Diversity and complementarity are intrinsic to mixed methods teams, but they present challenges. These challenges include dealing with differences, establishing trust, creating a meaningful group, handling conflict, and enacting effective leadership roles.
Devine, Emily Beth, Beney, Johnny, & Bero, Lisa A. (2005). Equity, accountability, transparency: Implementation of the contributorship concept in a multi-site study. *American Journal of Pharmaceutical Education, 69*(4), 455-459.	Contribution/Crediting Issues	Lack of clarity, Lack of fairness, Lack of transparency	Case Study based on personal experience	The authors review a case in which a formal contributorship process was implemented, and they find that such processes can alleviate collaborator concerns and promote equity, accountability, and transparency in the crediting decisions.
Duque, Ricardo B., Ynalvez, Marcus, Sooryamoorthy, R., Mbatia, Paul, Dzorgbo, Dan-Bright S., & Shrum, Wesley. (2005). Collaboration paradox: Scientific productivity, the internet, and problems of research in developing areas. *Social Studies of Science, 35*(5), 755-785.	Coordination Costs	ICT Infrastructure Inadequacies	Surveys	For scientists in third world countries the high coordination costs of collaboration and problematic information communication technologies can retard rather than facilitate collaboration productivity.
Fiore, Stephen M. (2008). Interdisciplinarity as teamwork: How the science of teams can inform team science. *Small Group Research, 39*(3), 251-277.	Coordination Costs, Leadership Issues, Interpersonal Dynamics	Not discussed	Theoretical/ Conceptual	Fiore suggests a number of ways that current work on teams in the field of organizational science can improve studies of team science.
Fox, Mary Frank, & Faver, Catherine A. (1984). Independence and cooperation in research: The motivations and costs of collaboration. *The Journal of Higher Education*, *55*(3), 347-359.	Coordination Costs, Interpersonal Issues, Contribution/Crediting Issues	Limited time and resources; Sluggish collaborators; Lack of trust; Motivation/incentives	Interviews	The authors identify two types of collaborative costs: process costs (time, expense, personal investment) and outcome costs (delays, crediting issues, and quality issues). Both types of costs can create strain in a collaboration and impede progress.
Garrett-Jones, Sam, Turpin, Tim, & Diment, Kieren. (2010). Managing competition between individual and organizational goals in cross-sector research and development centres. *The Journal of Technology Transfer, 35*(5), 527-546.	Coordination Costs, Leadership Issues, Interpersonal Issues,	Administrative burdens, Poor communication and feedback, Lack of Trust	Surveys	Researchers felt that management/administrative burdens distracted them from the goals of their research; this was particularly true when communication and feedback are inadequate. Researchers wanted a strong say in the management of the

				collaborative centers and tension arose when they did not feel that their voices were heard. Respondents expressed the need to trust collaborators competence and intentions in participating in the collaboration. When there was a lack of trust or failure along these lines then work was seen as competitive rather than collaborative.
Hagstrom, Warren O. (1964). Traditional and modern forms of scientific teamwork. *Administrative Science Quarterly*, *9*(3), 241-263.	Coordination Costs; Contribution/Crediting Issues; Leadership Issues	Collaboration Size, Disciplinary Differences, Greater Dependence on External Authority, Centralization of Authority in Research Organizations, Complex Division of Labor	Interviews, Secondary data; Theoretical/ Conceptual	The character of research groups are strongly influenced by their leaders. Large groups make it difficult to ascertain individual contributions. Multidisciplinary collaborations are characterized by social strain. Modern science is seeing a division of the roles of the scientist into administrator and technician. In these groups, scientific leaders must pursue funds and coordinate the work of others.
Hara, Noriko, Solomon, Paul, Seung-Lye, Kim, & Sonnenwald, Diane H. (2003). An emerging view of scientific collaboration: Scientists' perspectives on collaboration and factors that impact collaboration. *Journal of the American Society for Information Science & Technology*, *54*(10), 952-965.	Coordination Costs, Contribution/Crediting Issues, Leadership Issues, Interpersonal Issues	Lack of Communication, Disciplinary Differences, Leadership change, Social distance, Structural/Organizational Characteristics	Case Studies	Students are a key part of the collaboration process between two faculty members. Lack of communication between professors and students or between faculty members can cause collaboration failure. Students serve as ambassadors, communicating between the professors. Unclear ownership of research projects can be detrimental of project success. Changing leadership presented a challenge for one of the collaborative groups in the study. A lack of interpersonal relationships and trust is a barrier to integrative collaboration. The organization of collaboration in the research center setting presented challenges for some researchers

				because collaborations were not organized in a manner they were accustomed to.
Jeffrey, Paul. (2003). Smoothing the waters: Observations on the process of cross-disciplinary research collaboration. *Social Studies of Science, 33*(4), 539-562.	Coordination Costs	Disciplinary Differences	Case Study	Collaborators from different fields must develop common vocabulary as well as tools to promote understanding and decision making. Learning how to develop and utilize these tools for collaboration represents a learning curve.
Katz, J. Sylvan. (1994). Geographical proximity and scientific collaboration. *Scientometrics, 31*(1), 31-43.	Coordination Costs	Geographic Proximity	Bibliometric data	Research cooperation decreases with the geographic distance separating partners.
Kraut, Robert E., Galegher, Jolene, & Egido, Carmen. (1987). Relationships and tasks in scientific research collaboration. *Human-Computer Interaction, 3*(1), 31-58.	Coordination Costs, Contribution/Crediting, Interpersonal Issues	Geographic Proximity, Social Distance, Harmonizing collaborator's schedules, Delays in completing work, Maintaining equity of contributions, Lack of trust	Interviews	Collaborations progress through three stages and at each stage there are both relationship and task activities and challenges. The key conclusion is that a well-maintained personal relationship between collaborators is fundamental to collaborative success. Institutional arrangements and work techniques can help to mitigate collaboration process obstacles, but they are less successful in mitigating interpersonal issues.
Landry, Réjean, & Amara, Nabil. (1998). The impact of transaction costs on the institutional structuration of collaborative academic research. *Research Policy, 27*(9), 901-913.	Coordination Costs	Collaboration Size, Utilization of joint decision making procedures, choice of institutional structure	Surveys	Coordination costs are a factor that contribute to researchers' choices of institutional structures for their collaborative work. Coordination costs increase relative to the size of the institutional structure. They can be reduced by reducing joint decision making, and they are higher for collaborations in which researchers organize in teams than when they collaborate outside of teams.
Lee, Sooho, & Bozeman, Barry. (2005). The Impact of research collaboration on scientific	Interpersonal Issues	Discrimination	Surveys and CV data	Perceived discrimination does not appear to have a significant effect on collaboration productivity, but results

productivity. *Social Studies of Science, 35*(5), 673-702.				are viewed with caution because very few people in the sample report experiencing discrimination.
Maglaughlin, Kelly L, & Sonnenwald, Diane H. (2005). *Factors that impact interdisciplinary natural science research collaboration in academia*. Paper presented at the Proceedings of the ISSI.	Coordination Costs, Interpersonal Issues	Disciplinary Differences, Collaborator Compatibility, Limited Resources	Interviews; Longitudinal Field Study	The analysis identifies twenty factors that affect interdisciplinary collaboration in the natural sciences. Some factors facilitate and other impede interdisciplinary collaboration. Specific impediments discussed include administrative burdens, disciplinary biases and language differences, collaborator compatibility, and time as a limited resource.
Massey, Claire, Alpass, Fiona, Flett, Ross, Lewis, Kate, Morriss, Stuart, & Sligo, Frank. (2006). Crossing fields: The case of a multi-disciplinary research team. *Qualitative Research, 6*(2), 131-147.	Coordination Costs	Disciplinary and Methodological Differences	Case Study	The collaboration's multi-disciplinary composition had many advantages but it also created barriers to effective team operation.
Öberg, Gunilla. (2009). Facilitating interdisciplinary work: using quality assessment to create common ground. *Higher Education, 57*(4), 405-415.	Coordination Costs	Disciplinary Differences	Theoretical/ Conceptual	Collaborations that do not spend sufficient time addressing disciplinary differences and constructing common ground can encounter conflicts and problems. The study proposes a framework for addressing these differences.
O'Cathain, Alicia, Murphy, Elizabeth, & Nicholl, Jon. (2008). Multidisciplinary, interdisciplinary, or dysfunctional? Team working in mixed-methods research. *Qualitative Health Research, 18*(11), 1574-1585.	Coordination Costs, Interpersonal Issues, Leadership Issues	Disciplinary and Methodological Differences, Team history, Geographic Proximity, Values of the PI	Quantitative Content Analysis, and Qualitative Interviews	Respect for different methods, team members' abilities to work closely and communicate effectively, and principal investigators who valued integration were key ingredients for the successful integration of qualitative and quantitative contributions.
Porac, Joseph F., Wade, James B., Fischer, Harald M., Brown, Joyce, Kanfer, Alaina, & Bowker, Geoffrey. (2004). Human capital heterogeneity, collaborative relationships, and publication patterns in a multidisciplinary scientific alliance: A	Coordination Costs	Group heterogeneity, Social distance	Case studies	The authors studied two collaborative teams that were part of a larger alliance program. In particular, one team faced challenges in the form of disciplinary heterogeneity and infrequent interaction between collaborators

comparative case study of two scientific teams. *Research Policy, 33*(4), 661-678.				before joining the alliance. The productivity measures employed suggest that this team was able to overcome these challenges, and the authors interpret as favorable evidence for the use of inter-organizational alliances as structures for collaborative research.
Rossini, Frederick A., & Porter, Alan L. (1981). Interdisciplinary research: Performance and policy issues. *Journal of the Society of Research Administrators*, 13(2), 8-24.	Coordination Costs, Leadership Issues	lack of management structure/process	Theoretical/ Conceptual	The study identifies structural and process factors that are key to successful interdisciplinary research including leadership and communication among those factors. The study suggests frameworks for the social organization of interdisciplinary work.
Shortliffe, Edward H., Patel, Vimla L., Cimino, James J., Barnett, G. Octo, & Greenes, Robert A. (1998). A study of collaboration among medical informatics research laboratories. *Artificial Intelligence in Medicine*, *12*(2), 97-123.	Coordination Costs	Geographic Proximity, Structural/Organizational Characteristics, differences in collaborators' organizational cultures	Case Study	Geographic dispersion and differences in the organizational cultures of collaborators can introduce significant challenges to collaboration. Face to face meetings are important forerunners to effective use of information communication technologies. Conference calls can play important roles in project management.
Shrum, Wesley, Chompalov, Ivan, & Genuth, Joel. (2001). Trust, conflict and performance in scientific collaborations. *Social Studies of Science, 31*(5), 681-730.	Interpersonal Issues, Leadership Issues, Coordination costs	Lack of trust, Collaboration size, Organizational/Structural Characteristics, Disciplinary Characteristics, Collaborator Interdependence, Sub-contracting, Scientific delays	Both qualitative and quantitative data for 53 large multi-disciplinary collaborations in physics and related sciences	Trust is inversely related to conflict. Smaller collaborations and those that manage the topics that teams analyze are more likely to have between-team conflicts. Collaborations in field sciences are more likely to report conflict between scientists and project managers than collaborations in laboratory sciences. Conflict between scientists and project management is associated with bureaucratic organizational structures. Interdependence among collaborators is

				associated with increased conflict. Collaborations with an advisory committee outside of the project and collaborations that embrace autonomy in the analysis of shared data are more likely to experience delays in completing the project. Collaborations that rely heavily on subcontracting for instrumentation, have problematic initial results, or make mid-course changes to instrumentation are more likely to finish over-budget.
Sooryamoorthy, Radhamany, Duque, Ricardo B., Ynalvez, Marcus Antonius, & Shrum, Wesley. (2007). Scientific collaboration and the Kerala model: Does the internet make a difference? *Journal of International Development, 19*(7), 982-996.	Coordination Costs	ICT Infrastructure Inadequacies	Surveys	There is no evidence that increased access to information communication technologies has increased collaboration in Kerala.
Vasileiadou, Eleftheria. (2012). Research teams as complex systems: Implications for knowledge management†. *Knowledge Management Research & Practice, 10*(2), 118-127.	Coordination Costs	Team complexity; Organizational/Structural Characteristics	Theoretical/ Conceptual	The study conceptualizes research teams as complex systems. It proposes that some teams are more sensitive to external factors than others, that management structures at different levels can clash and cause conflict, and that increasing team complexity increases team coordination needs.
Walsh, John P, & Maloney, Nancy G. (2007). Collaboration structure, communication media, and problems in scientific work teams. *Journal of Computer-Mediated Communication, 12*(2), 712-732.	Coordination Costs, Interpersonal Issues, Contribution Issues	Collaboration Size, Geographic Proximity, Level of Task Interdependence, Level of Scientific or Commercial Competitive Pressure	Surveys	Larger collaborations are more likely to face challenges related to coordination, culture, trust, and information security. Remote collaborations are more likely to experience problems in terms of coordination, culture, and information security. Greater task interdependence results in increased communication demands and an increased likelihood of conflict. Scientific and commercial competition increase collaboration challenges.

Wilcox, Linda J. (1998). Authorship: The coin of the realm the source of complaints *JAMA: Journal of the American Medical Association 280*(3), 216-217.	Contribution Issues	Not discussed	Records from university Ombuds office	The percentage of authorship disputes increased between 1991 and 1997. Disputes over authorship can affect researcher morale and subsequent resource allocation to researchers.
Wray, K. Brad. (2002). The epistemic significance of collaborative research. *Philosophy of Science, 69*(1), 150-168.	Contribution/Crediting Issues	Motivation/Incentives	Theoretical/ Conceptual	Collaboration might erode the motivation of scientists because the diffusion of credit makes it more difficult to establish individual contributions.
Youtie, Jan, & Bozeman, Barry. (2014). Social dynamics of research collaboration: norms, practices, and ethical issues in determining co-authorship rights *Scientometrics, 101*(2), 953-962.	Contribution/Crediting Issues	Miscommunication, unethical behavior, legal disputes	Surveys	In some cases misunderstandings about crediting issues stem from miscommunication, but in others there is evidence of unethical behavior or legal issues. Having an explicit discussion about co-authorship reduces the likelihood of reporting a bad collaboration experience.