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THE EFFECT OF TEAM COMMUNICATION BEHAVIORS AND PROCESSES ON INTERDISCIPLINARY TEAMS' RESEARCH PRODUCTIVITY AND TEAM SATISFACTION

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ABSTRACT

Aim/Purpose	There is ample evidence that team processes matter more than the characteristics of individual team members; unfortunately, very few empirical studies have examined communication process variables closely or tied them to team outcomes.
Background	The University of Miami Laboratory for Integrated Knowledge (U-LINK) is a pilot funding mechanism that was developed and implemented based on empirically-established best practices established in the literature on the Science of Team Science (SciTS). In addition to addressing grand societal challenges, teams engaged in processes designed to enhance the process of "teaming". This study uses the Inputs-Mediator-Outputs-Inputs (IMOI) model as a blueprint for an investigation into how team communication processes (shared communication, shared leadership, formal meetings, informal meetings) influence intermediary team processes (goal clarity, role ambiguity, process clarity, trust) and team outcomes (team satisfaction, team productivity).

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Methodology Monte Carlo methodologies were used to explore both longitudinal self-report (survey of communication and team outcome variables) data and objective data on scholarly productivity, collected from seventy-eight members of eleven real-world intact interdisciplinary teams to explore how team communication processes affect team outcomes.

Contribution This study is among the few that centers communication practice and processes in the operationalization and measurement of its constructs and which provides a test of hypotheses centered on key questions identified in the literature.

Findings Communication practices are important to team processes and outcomes. Shared communication and informal meetings were associated with increased team satisfaction and increased research productivity. Shared leadership was associated with increased research productivity, as well as improved process and goal clarity. Formal meetings were associated with increased goal clarity and decreased role ambiguity.

Recommendations for Practitioners Team trainings should focus on communication practices that improve shared leadership and shared communication. Additionally, teaching best practices for formal (task-oriented) meetings can help improve goal clarity and decrease role ambiguity. Finally, the benefits of informal socializing should be recognized, and teams should be encouraged to meet informally (socially, without formal task agendas).

Recommendations for Researchers Studying intact interdisciplinary research teams requires innovative methods and clear specification of variables. Challenges associated with access to limited numbers of teams should not preclude engaging in research as each study contributes to our larger body of knowledge of the factors that influence the success of interdisciplinary research teams.

Impact on Society The success of interdisciplinary teams can be improved with trainings focused on communication skills. The success of these teams is critical to addressing societies' most pressing challenges, and careful consideration of team processes is critical to that success.

Future Research Future research should examine different team formation and funding mechanisms and extend observation and data collection for longer periods of time.

Keywords communication, science of team science, team processes, shared leadership, shared communication, team outcomes

INTRODUCTION

Bennett and Gadlin (2012) claim that, "The only people more foolish than two people falling in love are scientists starting a collaboration. When passionate about an exciting scientific idea, scientists often neglect to think realistically about the multiple tasks that will need to be accomplished to construct an effectively functioning scientific team" (2012, p. 773). However, while a new interdisciplinary team may want to focus foremost on how to conduct the proposed research, teams may want to first consider the process of collaboration itself. Although the literature on the science of team science (SciTS) has cited a wide variety of predictors of team success, it has yet to clearly delineate which specific team processes make a difference to teams' satisfaction and research productivity.

There is ample evidence that team processes matter more than the characteristics of individual team members (including team member intelligence, previous levels of productivity, or the number of disciplines represented on a team) (Jeong & Choi, 2015; Pentland, 2012; Woolley et al., 2010); unfortunately, very few empirical studies have examined communication process variables closely or tied them to team outcomes. This is partly a result of the challenges involved with measuring both antecedent variables and outcomes as well as the nature of real-world research with intact interdisciplinary teams. The number of interdisciplinary teams operating under similar conditions which are available and willing to be studied is generally quite small. Additionally, there are few validated measures that correspond to many of the constructs that are of interest to researchers engaged in the science of team science (SciTS); even core constructs like "team success" are challenging to operationalize. In this study, we describe a program to incubate innovative interdisciplinary research and describe processes that, based on the empirical literature, may help to explain differences in team outcomes, including satisfaction and research productivity. This work addresses an acute need to add to the empirical literature on the processes engaged in by real-world interdisciplinary teams and the outcomes that may result.

Specifically, this study argues that teams that engage in processes such as shared communication, shared leadership, formal (task-oriented) meetings, and informal (socially-oriented) meetings, are more likely to have higher levels of research productivity and report higher levels of satisfaction. These ultimate outcomes of productivity and satisfaction are preceded by intermediate states that include behavioral indicators of trust, role ambiguity, process clarity, and goal clarity. Because shared communication, shared leadership, formal meetings, and informal gatherings represent behaviors that can be easily cultivated in teams, they represent potentially fruitful targets for both intervention and study.

Following the literature review, we describe our use of Monte Carlo methodologies to explore both self-report (survey) data and objective data on scholarly productivity, collected from real-world intact interdisciplinary teams who received pilot funding to advance innovative research on grand challenges to society. We conclude with a number of recommendations designed to advance the work of both SciTS researchers and practitioners who support interdisciplinary teams.

THEORETICAL FRAMEWORK

Interdisciplinary teams are those which "engage in a mode of research… which integrates information, data, techniques, tools, perspectives, concepts and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice" (National Academies of Science, 2004, p. 26). The particular dynamics that govern interdisciplinary teams are of special interest to SciTS researchers, but this body of research draws from work done to describe teams in more general contexts. The IPO (Inputs – Processes – Outputs) framework (McGrath, 1964) dominates most empirical work on the practices used by successful teams. It posits that successful teams are associated with inputs and contextual features like team member goals and the processes teams use to share information. These inputs and processes result in outcomes that range from the depth and continuity of connections among group members, members' influence on each other's behaviors, and the quality of group outputs.

More recently, researchers have pressed for a more sophisticated approach, as represented by the Inputs – Mediators – Outputs – Inputs model (IMOI) (Ilgen et al., 2005; Mathieu et al., 2019), which acknowledges the dynamic nature of teams. This modified framework acknowledges a wider array of variables that constitute team processes and mediators (like communication) which are subsequently associated with a team's emerging states, including a shared mental model and a sense of psychological safety. However, methods and measures commonly used in empirical research have not yet caught up to theorizing in this area. While researchers appear to agree on the usefulness of the framework, there appears to be little consensus about causal constructs. For example, does trust between individuals predict the formation of a team? Or is trust an emergent state that is the product of other processes (or time spent working together)? Alternately, can trust be viewed as an outcome of the processes used by successful and productive teams? (The answer to all of these questions appears to be "yes".)

Thus, while Mathieu and colleagues (2019) have identified a constellation of variables that are associated with effective teams, additional research is required to establish clear causal pathways. The demand for more sophisticated methods and measurements may, ironically, preclude further identification of the directionality of the relationships between variables identified in a "grand model" of effective teams. For example, while social network analysts can provide a sophisticated view of how researchers from diverse disciplines can contribute to discovery and innovation, it will be difficult for this approach to incorporate an assessment of the impact of goal clarity or shared communication practice. Similarly, research employing natural language processing (NLP) analytic techniques can provide a valuable snapshot of specific dynamics within teams by linking complex, real-time communication patterns to team outcomes. In other words, there is currently no one set of analytic tools or approach to research that can fully account for the variables specified in the larger theoretical approach. For now, researchers must continue to assemble the complex pieces of the "team effectiveness" puzzle in discrete sections in hopes that knowledge generated in each area can be merged at a future point. Because it delineates the relationship between complex factors, we use the IMOI Model as a foundation for our examination of the impact of communication processes on outcomes associated with team productivity and success.

Because it is difficult to employ methodologies that permit attention to all processes that are specified in the IMOI model, we have elected to focus on a subset of variables identified by this framework. A comprehensive review of meta analyses of team effectiveness research conducted by Mathieu and colleagues (2019) indicate that team outcomes (such as productivity, trust, and satisfaction) are predicted by processes like specifying goals and identifying strategies for attaining those goals. These processes result in emergent states such as shared leadership and a sense of psychological safety. Figure 1 represents a conceptual model of the relationship among the variables relevant to the present study rather than all dynamics specified in the IMOI framework.

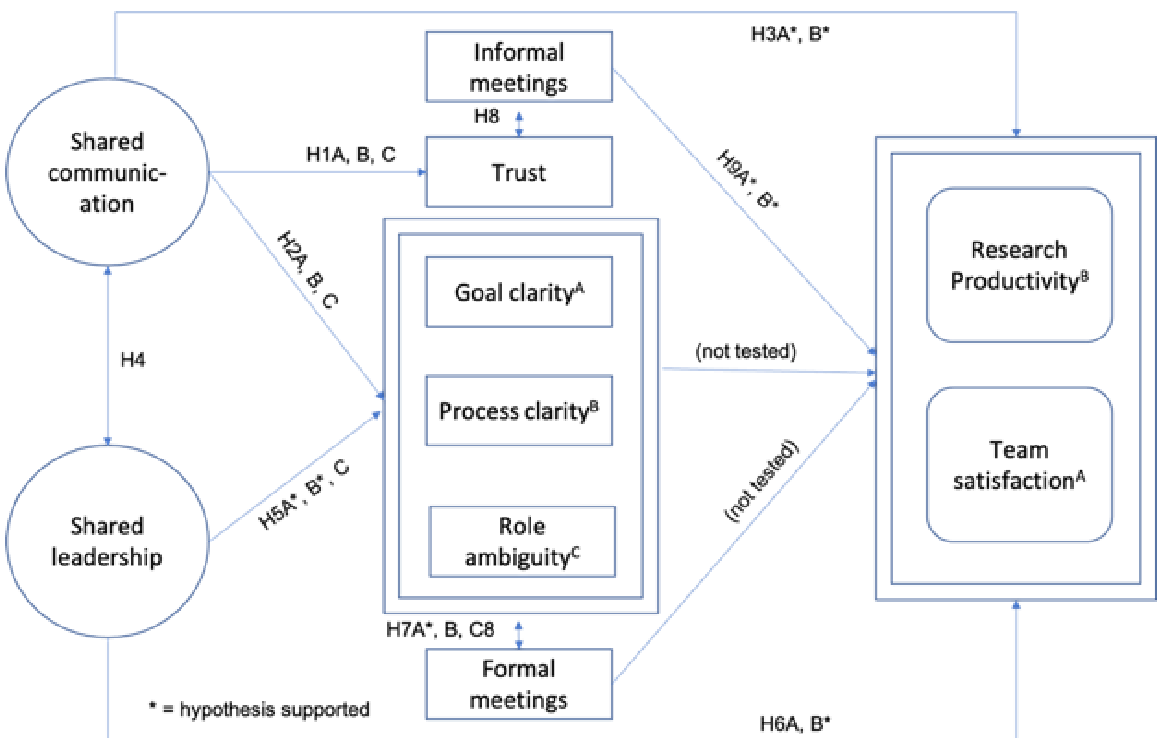

Figure 1. IMIO-Based Conceptual Framework:
Process Variables and Effects on Team Success

TEAM PROCESSES

Researchers have identified a number of group communication processes and practices that support interdisciplinary team success (Fiore, 2008). Wooten et al. (2014) provide a comprehensive list that includes creating a shared vision, developing a team identity, creating a team charter, building consensus, holding regular, face-to-face meetings that are agenda-driven, soliciting and integrating contributions from all team members, and exploring synergies among team members. Communication is, of course, central to all of these processes; consensus cannot be created and a vision for the team's work cannot emerge without the clear communication among a team's members.

The exchange of information is perhaps the most crucial work performed by a team, and yet researchers often treat this as a straightforward, instrumental task. Wittenbaum et al. (2004) add nuance to this approach by providing evidence that the transfer of knowledge across disciplines can be described as a process of motivated information sharing. This framework acknowledges that features of the organizational context and team member goals affect communication processes, including what information is shared, how it is shared, and with whom it is shared. These processes are linked to task-related outputs (like the quality of outcomes) and the relationships between members of the group.

While the motivated information sharing theoretical framework was originally designed to develop predictions for how information sharing guides group decisions, it is nonetheless useful for understanding how communication processes can affect team outcomes. Unfortunately, there are few theory-based empirical investigations that examine processes in real-world interdisciplinary teams (rather than simulated teams created for the purpose of study). In this study, we use the IMIO approach as a foundation to focus on four specific communication-driven processes. These processes were selected because (1) they are measurable and (2) they represent behaviors that can be targeted for change in team training/development interventions. An important goal of our work is to identify a possible set of best practices that can be employed by interdisciplinary teams to enhance their success and to support a variety of important intermediate goals. These practices include (1) shared communication, (2) shared leadership, (3) formal, task-focused team meetings, and (4) informal (social) team gatherings, all of which allow teams to engage in the processes that have been posited as being central to team success, including research productivity and team satisfaction (Wooten et al., 2014).

SHARED COMMUNICATION: VALUING ALL CONTRIBUTIONS

A number of researchers have argued that communication is not only key to the success of teams (Bennett et al., 2018; Hinrichs et al., 2016), but is at least as important as the soundness of the scientific rationale for a team's work (Hall et al., 2019). Communication is not just a tool required for the coordination of activities, or a discussion of the scientific merits of a question or the process to be pursued--it is also essential for the establishment, strengthening, and maintenance of team dynamics (Bennett & Gadlin, 2012). In other words, while it may be tempting to think of communication as a means for achieving knowledge integration among team members through regular discussions (to use one example), good team communication also helps to build personal and professional bonds among collaborators. Attending to both the instrumental and relational functions of communication within team processes ultimately predicts the success of teams (Marlow et al., 2018; Read et al., 2016). Researchers have argued that it is possible to understand why some teams work well and others do not simply by studying their communication behaviors (Eisenbeiss et al., 2008; Lehmann-Willenbrock et al., 2017; Pentland, 2012).

While researchers' calls for "good communication" rarely define a particular set of practices, shared communication entails specific behaviors that team members can implement. Shared communication involves a more-or-less even distribution of conversational turns, and an equal amount of speaking time allows each team member to be heard and (potentially) to feel valued (Cheruvelil et al., 2014; Duhigg, 2016; Pentland, 2012; Woolley et al., 2010). The amount of energy in a team is evidenced by the number of exchanges in a meeting and how well those exchanges are distributed among team members (Pentland, 2012). Additionally, Pentland (2012) argues that team members should communicate with all other members and not just those in leadership roles, a recommendation echoed by Read and colleagues (2016).

Because turn-taking and the amount of talking time can be measured (albeit with the use of advanced monitoring devices and sophisticated analytic techniques; see Pentland, 2012), these practices can be empirically tied to team outcomes. Shared communication is associated, not surprisingly, with greater knowledge exchange among members, as well as greater knowledge integration (i.e., knowing what others know and being able to make sense of it relative to the topic being researched) (Cooke et al., 2017; Kozlowski & Ilgen, 2006, Mumford et al., 2002; Okhuysen & Eisenhardt, 2002; Read et al., 2016; Waruszynski, 2017). Additionally, a study of 52 novel teams (i.e., those that had no previous experience working together) conducted by Salazar and Lant (2018) demonstrates the importance of communication in the process of attaining both goal and process clarity. Further, it is through shared communication, not the traits or accomplishments of individuals, that collective intelligence is created, allowing teams to effectively and efficiently solve problems (Woolley et al., 2010). Of course, shared communication implies openness and respect for individual members by their colleagues, and it is likely that it is through this willingness to learn about others' expertise that a sense of psychological safety and trust is established, allowing for greater creativity and risk-taking in the quest for innovative solutions (Stokols et al., 2008) as well as greater satisfaction with the experience of working with the team (Guenter et al., 2017), which serves as an important predictor of long-term success of teams (Kauffeld & Lehmann-Willenbrock, 2012).

There is broad agreement that knowledge integration is paramount to the effective functioning and eventual outcomes of an interdisciplinary team. In fact, a consensus report commissioned by the National Academies (National Research Council, 2015) details the processes that are central to effective team science, which include knowledge integration. While the mechanism of effect differs from that specified by theorizing around transactive memory (Wegner, 1986), this difference does not contradict the basic premise that it is important for teams to develop an understanding of "who knows what." In order to create new conceptual frameworks, theories, models, and applications, and achieve transdisciplinary outcomes (i.e., those that transcend disciplinary boundaries) all members of a team must communicate freely and frequently. Individuals must be willing to share what they know, know what others know, and be willing to express this knowledge in ways that allow people from other disciplines to understand. While the National Research Council terms this process "developing shared knowledge" (National Research Council, 2015, p. 14), this can be achieved only through a process of "shared communication." Indeed, the consensus report states that communication is "the essential building block of team cognition" (p. 65). Their recommendation that funding agencies require grant applicants to submit a plan for how deep knowledge integration will be accomplished across disciplines points to the importance of signaling to interdisciplinary teams that shared communication processes should be valued and developed. Based on the empirical evidence presented in earlier research and the strength of recommendations by funding agencies and policy makers, we advance the following hypotheses related to shared communication:

H1: Shared communication is positively associated with behavioral trust.

H2: Shared communication is positively associated with goal clarity (H2a), and process clarity (H2b), as well as lower levels of role ambiguity (H2c).

H3: Shared communication is associated with team success, as evidenced by research productivity (H3a) and survey scores on team satisfaction (H3b).

Shared Leadership: Transforming Traditional Thought

Although shared communication is a process that supports the success of interdisciplinary teams, the equal distribution of conversational space should be accompanied by additional communication-based processes, particularly shared leadership. However, unlike communication best practices, there is no consensus in the "science of team science" literature on the most effective model of leadership. Instead, there appears to be a general assumption that there is, in fact, a leader or Principal Investigator (PI) who sets priorities and directs the activities of the team, albeit one who can be encouraged to adopt a "flat structure" (Mumford et al., 2002) or an "authentic leadership style" (Guenter et al., 2017). What is agreed upon, though, is that (1) leaders have a powerful effect on outcomes (National Research Council, 2015) and (2) it is difficult to train effective leaders (Eisenbeiss et al., 2008; Wooten et al., 2015). Some researchers have come to distinguish traditional leaders from "transformative leaders" who stimulate team creativity and innovation by inspiring team members through the articulation of a compelling vision and by stimulating team members to think in new and exciting ways; this stands in counterpoint to more traditional styles of leadership which focus on the status quo and the completion of well-defined tasks according to set performance objectives (Eisenbeiss et al., 2008). However, identifying a cohort of transformative leaders sufficient to populate all teams within an institution or organization would surely prove to be a daunting challenge.

There is also evidence that shared leadership fosters the development of shared mental models because of improved team communication and knowledge exchange (Guenter et al., 2017). Shared leadership of interdisciplinary teams is characterized by mutual influence and distributed responsibility which leads to a positive team climate (Guenter et al., 2017). Survey data from 142 research teams, collected by Guenter and colleagues (2017) demonstrated that shared leadership practices influence team effectiveness through enhanced team coordination, satisfaction with the team, and the development of shared mental models. The authors posit that transparency, open and authentic relationships among team members, and positive emotional contagion all contribute to the effectiveness of teams. These findings are consistent with studies finding that team structures that promote an abundance of communication and "open, dynamic contact" contribute to innovation (Mumford et al., 2002, p. 731). Wang et al.'s (2014) meta-analysis demonstrated that shared leadership of a team is associated with the development of a shared mental model as well as multiple measures of team effectiveness, including satisfaction, commitment, cooperation, cohesion, and team productivity.

The actual type of responsibilities that are shared among team members makes a difference to team outcomes, however. Traditional leadership models are associated with the successful initiation (and structure) of interdisciplinary projects, but teams appear to be more successful overall when they use a shared leadership model. Moreover, when team members collectively create an appealing vision of a future state and share a common mental model, researchers' intrinsic motivations are validated and ultimately, team members generate new individual and collective aspirations (Wang et al., 2014).

Frequency of communication may be a hallmark of shared leadership. Pentland (2012) argues that emerging leaders of groups not only communicate a lot with team members but connect team members with each other in a way that earns them the label of "charismatic connectors." Because people who lead teams well have an ability to communicate in ways that are inclusive and respectful of members, regardless of background or discipline and that empower members of a team to share their knowledge and act autonomously (Baldwin & Chang, 2007; Benoliel & Somech, 2014; Eisenbeiss et al., 2008; Salazar & Lant, 2018), they are, in essence, fostering shared leadership of the team's goals and activities. There is evidence that individuals on teams that share leadership create a common vision for their future work and develop a shared mental model for how to achieve their goals (Wang et al., 2014). A shared mental model is an "emergent state" of a team whereby members have a shared understanding of their goals and how they will accomplish them, enabling members to integrate their efforts and perform effectively (Benoliel & Somech, 2014). Of course, the need for a shared mental model is obviated in teams with a single leader who provides direction and vision for the team's work. While the published literature makes frequent mention of the importance of shared mental models, there have been few attempts to operationalize or measure this important outcome stemming from shared leadership. We believe that goal and process clarity (the degree to which the goals, purposes, objectives, and activities of the team are clearly defined; Bang et al., 2010) and reduced role ambiguity (the degree to which individuals understand what is expected of them and how their activities will contribute to team goals; Tubre & Collins, 2000) serve as an indicators that a shared mental model has been achieved; further, we believe that teams that operate under a shared leadership model are more likely to experience these positive outcomes.

H4: Shared leadership is positively associated with shared communication.

H5: Shared leadership is associated with greater goal clarity (H5a), improved process clarity (H5b), and lower levels of role ambiguity (H5c).

H6: Shared leadership is positively associated with team satisfaction (H6a) and research productivity (H6b).

RQ1: How does team collaboration over time affect perceptions of shared leadership, role ambiguity, goal clarity, process clarity, and the number of formal and informal meetings?

Formal Meetings: Creating Opportunity for Creativity

While few people will admit to liking spending time in meetings, the literature is quite clear on the importance of formal meetings for efficiently advancing the work of a collaborative scientific team. Formal meetings are those in which team members primarily focus on working toward the objectives of the team. While meetings tend not to be popular, they may constitute a case where "more is more" (at least up to a weekly schedule; more frequent meetings are very likely to yield diminishing returns) (Baldwin & Chang, 2007; Wang et al., 2014). A number of researchers have identified regular meetings as a key process that supports the success of teams (Bosque-Pérez et al., 2016; Cummings & Kiesler, 2005; Huang et al., 2020; Jeong & Choi, 2015; Wooten et al., 2015). Frequent meetings appear to enhance the development of shared mental models (Wang et al., 2014), achievement of team consensus (Wooten et al., 2015), the accomplishment of knowledge sharing and integration (Kauffeld & Lehmann-Willenbrock, 2012), and the cultivation of creative approaches to problems (Parker & Hackett, 2012), all of which enhance team effectiveness. It is primarily through face-to-face meetings that teams are able to identify problems and their potential solutions (Kauffeld & Lehmann-Willenbrock, 2012; Marlow et al., 2018). Meetings may also be important because they provide a venue for "knowledge demonstrability," which occurs when the group realizes the importance of what each individual team member knows; the more teams meet in person, the clearer it becomes that each person's knowledge is important for the accomplishment of team goals (Kane, 2010).

There is, of course, a "dark side" to meetings. Attendees often perceive meetings to be without a clear purpose and as a result, disengage (Kello, 2015). Virtual meetings, which increased dramatically during the Covid-19 pandemic and which are a necessity for geographically distributed teams, can make it more difficult for individuals to connect with each other (Allison et al., 2015; Jeong & Choi, 2015; Kello, 2015; Pentland, 2012; Waruszynski, 2017). The cohesion of geographically distributed teams can be enhanced with a concerted effort to have in-person team launch meetings and annual in-person retreats (Allison et al., 2015; Cheruvelil et al., 2014; Parker & Hackett, 2012). Team satisfaction is also enhanced when team meetings are perceived to be effective (Kello, 2015). Fortunately, there are clear sets of published best practices that can improve the effectiveness of meetings (Cichomska et al., 2015; Kello, 2015). Additionally, it is imperative that, during scientific team meetings, members create a sense of psychological safety for all members of the group to enhance the team's willingness to advance their most creative and innovative ideas (Parker & Hackett, 2012; Salazar & Lant, 2018; Wooten et al., 2015). Thus, effective meetings are critical to the achievement of the confluence of thought required to generate productive outcomes, particularly when members of collaborative teams have diverse disciplinary approaches to a set of scientific and real-world challenges.

H7: The number of formal meetings will be positively associated with goal clarity (H7a), and process clarity (H7b), and negatively associated with role ambiguity (H7c).

Informal Meetings: An Essential Frivolity?

Although the business world has always recognized the importance of informal interactions as supporting profitable deal-making, research-focused institutions appear to view having fun with collaborators as a frivolity that, at best, shouldn't be discussed openly. Researchers focusing on best practices to enhance team science, however, identify informal meetings as a vital process for team success (Baldwin & Chang, 2007; Cheruvelil et al., 2014; Parker & Hackett, 2012; Salazar et al., 2012; Stokols et al., 2008; Thompson 2009; Waruszynski, 2017). Informal meetings may be spontaneous or planned, but while the work of the team may be discussed, social bonding is the main objective. During informal meetings, team members learn about each other and enjoy shared laughter and fun. "Social time turns out to be deeply critical to team performance, often accounting for more than 50% of positive changes in communication patterns," even in a setting as efficiency-focused as a call center (Pentland, 2012). Nobel Prize-winning collaborators Amos Tversky and Daniel Kahneman famously had fun while doing their ground-breaking work. Bennett and Gadlin (2012) quote Kahneman's description of his experience:

> "[W]e met in Jerusalem to look at the results and write a paper. The experience was magical. I had enjoyed collaborative work before, but this was different. … [A]nd we were not just having fun. I quickly discovered that Amos had a remedy for everything I found difficult about writing. With him movement was always forward … [A]s we were writing our first paper, I was conscious of how much better it was than the more hesitant piece I would have written by myself."

Thus, the "power of socialization" (Baldwin & Chang, 2007) allows researchers to become more productive than they would have otherwise been.

Why are these social connections so important? Researchers have identified several mechanisms by which informal interactions produce greater team success. First, informal interactions create team cohesion which in turn supports team effectiveness (Guenter et al., 2017; Stokols et al., 2008; Waruszynski, 2017). It appears that when people like each other and enjoy spending time together, the resulting interpersonal and group bonds can facilitate the accomplishment of the difficult scientific work being demanded of the team. Shared emotional bonds are created through ongoing communication and the resulting relationships support a sense of collective identity and scientific receptivity (Parker & Hackett, 2012; Stokols et al., 2008; Thompson, 2009). According to multiple meta-analyses, when team cohesion is increased, team effectiveness is enhanced, particularly for teams with high interdependence, which is characteristic of interdisciplinary teams with a mission to generate novel, high-impact outcomes (Beal et al., 2003; Gully et al., 1995).

Second, informal interactions improve collective communication competence within the group, which ultimately fosters the development of team trust. The development of a set of team norms for appropriate communication happens only over time and through experience (Thompson, 2009). The social exercise of "getting to know each other" allows team members to know how to interpret each other's communication behaviors, which means that conflict based on misunderstanding is more likely to be averted (Thompson, 2009). Improved communication competence facilitates the type of relationship development necessary for interdisciplinary collaboration through the creation of trust (Read et al., 2016). Increased trust is accomplished through shared laughter and shared experiences (Cheruvelil et al., 2014; Thompson, 2009). Trust, in turn, is predictive of team members' willingness to integrate knowledge in a way that creates a shared understanding of a problem and ultimately, generates creative, innovative ideas (Benoliel & Somech, 2014).

Third, sharing aspirations and the inspirations for one's own work can facilitate the process of achieving a shared mental model for the work of the team as a whole. The experiences described by Cheruvelil and her colleagues (2014) are instructive. Their large, interdisciplinary team gathered regularly outside the workplace for informal team outings and teamwork exercises to build interpersonal skills and to renew group bonds. Through these activities, team members developed shared research goals, developed and affirmed standards for behavior, and created a shared vision for project management. These are all prerequisites for effective team functioning and high-impact outcomes (Hinrichs et al., 2016).

Thus, it is through informal social processes that truly creative and innovative ideas can be advanced, according to Hargadon and Bechky (2006). Their ethnography of engineering, consulting, and design firms indicates that rather than identifying the most creative and intelligent people to be members of collaborative teams, we should work to create the right interaction environment. Indeed, if we accept that researchers aren't merely breathing machines executing designated tasks but are, in fact, wholly human, then we (i.e., administrators, leaders, and research development professionals) must also accept that supporting and even facilitating relaxed and enjoyable get-togethers among team members is an essential part of outcome-driven team science. Because the relational development functions of communication that support a sense of psychological safety in a team can conflict with the need to move toward goal fulfillment (i.e., scientific tasks and team coordination) (Thompson, 2009), informal meetings are arguably not a frivolous distraction for a team but instead, may enhance its productivity and success.

H8: More frequent informal meetings are associated with greater behavioral trust.

H9: More frequent informal meetings are associated with greater team success, including satisfaction (H9a), and team productivity (H9b).

METHODS

INTERDISCIPLINARY RESEARCH FUNDING PROGRAM

U-LINK (**U**niversity of Miami **L**aboratory for **IN**tegrative **K**nowledge) is a unique interdisciplinary pilot research program designed to incorporate the empirical findings described in the literature on the science of team science. In partnership with the Clinical Translational Science Institute (CTSI), the Graduate School, and university Libraries, it awards (through a highly competitive process) a significant amount of funding in two phases to teams that plan to address any grand challenge to society. (Teams advance their own vision of a grand challenge – they are not specified by the university.) A diverse, interdisciplinary internal advisory board reviews all applications and makes funding decisions. Teams awarded Phase I funding receive \$40K for an 8-month period intended to support the process of "teaming." During this phase, teams aim to integrate their knowledge and build relationships with key stakeholder groups in order to develop a full plan for their subsequent research activities. At the conclusion of Phase I, teams compete for \$150K in Phase II funding (renewable for a second year), which is designed to support the development, feasibility testing, and/or pilot data collection required for the team to successfully compete for external funding. Approximately half of Phase I teams are competitively awarded Phase II funding. Phase II teams are required to apply for external funding as a condition of their awards. Thus, one measure of program success is grant funding as well as an important antecedent of funding, research publications.

Each year, awardees are required to attend a full-day team science training workshop that provides evidence for best practices for interdisciplinary team collaborations and a hands-on opportunity to develop key skills. (Additional details about the team science workshop content and the evaluation of its effectiveness are provided in Morgan et al., 2021). Additional professional development activities designed to enhance the knowledge and practice of interdisciplinary collaboration occur throughout the academic year. Further, each team works with a librarian who is embedded with the team. Details about the functions of the team librarian and outcomes of their work with interdisciplinary teams are provided in Miller et al. (2020). U-LINK funded its first teams in January 2018; the program continues with some modifications in 2021.

PARTICIPANTS

Participants for this study were awardees of the U-LINK internal funding program in 2018, 2019 and 2020; the program is described below. Eleven teams had at least one person respond to the survey; the total number of participants providing responses for all three time points was 78, with 40 participants identifying as female, 31 identifying as male, and 7 declining to identify. Participants were mostly faculty members (*n* = 64; 81%), but also included team librarians (*n* = 4; 6%). Faculty participating in the survey were distributed in rank as follows: assistant professors (*n* = 18; 23.1 %); associate professors (*n* = 22; 28.2%), full professors (*n* = 17; 21.8%), non-tenure track faculty including and clinical and research professors (*n* = 7; 8%), including senior lecturer (*n* = 1). Participants came from a number of different departments across STEM and non-STEM disciplines; please see Table 1 for a complete list.

Table 1. Team Compositions and Descriptive Statistics (n = 97)

Team Name	# Team Members	% Male	% non-STEM	# External Grants Applied	# External Grants Received	$ Awarded	# Peer-reviewed Publications	# Conference Papers	# White Papers
Team 1 (Facial Profiling)	4	50.0	75.0	1	1	$33,932	1	0	0
Team 2 (Brain Injury)	7	28.6	25.0	1	0	0	0	2	0
Team 3 (Hyperlocalism)	6	33.3	66.7	4	1	$50,000	1	12	7
Team 4 (Child Well-Being)	8	25.0	62.5	2	1	$150,000	0	1	0
Team 5 (Data Inclusion)	6	0.0	83.3	1	0	0	0	0	0
Team 6 (Next-Gen Coastal Structures)	9	66.7	62.5	3	0	0	3	11	0
Team 7 (Online Virality)	5	40.0	80.0	1	0	0	0	0	0
Team 8 (SCORE/ CONNECT)*	10	50.0	60.0	3	0	0	6	4	2
Team 9 (Coastal Resilience)	7	57.1	28.5	4	2	$3,016,814	1	6	0
Team 10 (HURAKAN)*	7	57.1	60.0	1	0	0	2	3	0
Team 11 (Ocean & Human Health)	9	22.2	55.5	2	2	$239,995	4	5	0

*After the analyses were performed, teams applied for and received a total of two grants totaling $2.4M in federal funding from NSF and NOAA.

DATA COLLECTION PROCEDURES

Data for this study are drawn from two different sources. First, teams' annual progress reports provide data on scholarly outcomes, including publications, conference presentations, grant proposals submitted, and grant applications that have been externally funded. Second, we collected (self-report) survey data from grant awardees. Using Qualtrics, we compiled the measures described below to create the survey, which was emailed to all awardees along with a follow-up reminder. No incentives were provided in exchange for completing the survey. This study was determined to be exempt from IRB review because it falls under "process improvement" rather than human subjects research. Data were collected three times (January 2019, February 2019, and July 2019) using identical survey questionnaires (with some deletion of items in time 2 to improve scale reliabilities). Measures described below reflect the final items used for all analyses. Data related to teams' productivity including number of grants submitted, number of white-papers, peer-reviewed manuscripts, and conference papers were obtained from the institution's Office of Vice Provost for Research and were current as of June 2020.

MEASURES

Behavioral trust disclosure

Behavioral trust disclosure was measured using a five-item instrument that was developed by Gillespie (2003). Sample items include "*Share your personal feelings with your team", "Confide in your team about personal issues that are affecting your work*", and "*Discuss how you honestly feel about your work, even negative feelings and frustration*." Items were rated on a 5-point Likert scale that ranged from "Not at all willing" (1) to "Completely willing" (5). A composite score was created by averaging responses on five items, with higher score indicating higher level of one's willingness to share personal feelings and issues related to the work. The internal consistency measured by Cronbach's alpha was high (α = .90 for time 2; α = .91 for time 3).

Team Satisfaction

Team satisfaction was measured using three items that were revised from Hackman and Oldham's (1974) job satisfaction survey questionnaire. Sample items include "*I enjoy the kind of work we do on this U-LINK team*," "*Working on this U-LINK team is an exercise in frustration*" (reverse-coded), and "*Generally speaking, I am very satisfied with this U-LINK team*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by averaging responses on three items, with higher score indicating higher level of satisfaction with U-LINK team. This measure was included in the survey beginning at time 2; internal consistency measured by Cronbach's alpha was acceptable (α = .82 for time 2; α = .83 for time 3).

Role ambiguity

This two-item measure was drawn from Peterson and colleagues' (1995) measurement of role ambiguity, conflict, and overload. The items are "*I know exactly what is expected of me on my U-LINK team*" and "*I know what my responsibilities are on my U-LINK team*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by reverse-coding responses on two items and then averaging them, with higher score indicating less certainty about one's role around U-LINK team. The internal consistency measured by Cronbach's alpha was high at times 1 (α= .90) and 3 (α = .91) and was acceptable at time 2 (α = .77).

Goal clarity

This four-item measure was revised from Sawyer's (1992) measurement of goal and process clarity. Sample items include "*I am clear about my responsibilities on this U-LINK team*", "*I am confident that I know what the goals are for my U-LINK team*," and "*I know how my work relates to the overall objectives of my U-LINK team*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by averaging responses on three items, with higher score indicating higher level of goal clarity. The internal consistency measured by Cronbach's alpha was high at each time point (α = .90 for time 1; α = .93 for time 2; α =.89 for time 3).

Process clarity

This three-item measure was revised from Sawyer's (1992) measurement of goal and process clarity. Sample items include "*I know how to go about my work on my U-LINK team*," "*I know how my team will move* *forward with its work on our U-LINK project*," and "*I am confident that my U-LINK team is using the right processes to move forward with its work*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by averaging responses on three items, with higher score indicating higher level of goal clarity. The internal consistency measured by Cronbach's alpha was relatively low at time 1 (α = .56 for time 1) but was acceptable at subsequent time points (α = .87 for time 2; α = .85 for time 3).

Shared communication

This two-item measure was created for this study, following information contained in the National Institutes of Health (NIH's) Collaboration and Team Science Field Guide (Bennett et al., 2018. Sample items include "*I think it's important for every member of our U-LINK team to speak during meetings*" and "*It's important for members of our U-LINK team to find ways to elicit equal participation from our team members during our meetings*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by averaging responses on two items, with higher scores indicating higher levels of shared communication. The internal consistency measured by Cronbach's alpha was low at time 1 and time 3 (α = .64 for time 1; α = .54 for time 3) but was good at time 2 (α = .83).

Shared leadership

This two-item measure was created for this study, following information contained in the National Institutes of Health (NIH's) Collaboration and Team Science Field Guide (Bennett et al., 2018). Sample items include "*It's important for all of our U-LINK team members to share leadership responsibilities*" and "*All of our U-LINK team members have the potential to make equally important contributions to our project outcomes*." Items were rated on a 5-point Likert scale that ranged from "Disagree" (1) to "Agree" (5). A composite score was created by averaging responses on two items, with higher level indicating higher perception of shared leadership. The internal consistency measured by Cronbach's alpha was relatively low at time 1 and time 2 (α = .53 for time 1; α = .61 for time 2; α = .79 for time 3).

Formal meetings

Following the example of Chatman and Flynn (2001), we used a single-item measure for individuals to self-report the number of formal meetings they attended since receiving pilot funding.

Informal meetings

Following the example of Chatman and Flynn (2001), we used a single-item measure for individuals to self-report the number of informal meetings they attended since receiving pilot funding.

Analytic Strategy

After aggregating the individual scores to each team, we used SPSS (IBM SPSS Statistics for Windows, 2017) to obtain descriptive statistics and frequencies that summarize team characteristics and team-level scores on all measures. Then, a series of repeated-measures Analysis of Variances (ANOVA) or paired *t*-tests were used to examine whether team scores significantly changed over time. For any team scores showing a significant difference over time, we performed a post-hoc analysis using Bonferroni adjustment (Gamst et al., 2008) to control for the family-wise type I error rate. This process identified the time points at which teams on average reported differently.

Our goal was also to empirically test the model shown in Figure 1, where teams' success (i.e., satisfaction survey scores and research productivity measured by numbers of publications and external grants being secured) is related to team-level processes. However, given that the number of teams that comprise the sample (n = 11) is too small to obtain sufficient statistical power to perform a path analysis, as an exploratory step, we conducted a series of Monte Carlo simulations in Mplus (Muthén

& Muthén, 1998-2011) based on the estimated value in a path analysis using our team sample size of 11. In a Monte Carlo simulation, 50 teams' responses that were first generated from a multivariate normal distribution. A multivariate normal distribution was based on the estimated parameter values using a team sample size of 11. Then, these teams' simulated responses were used to run a series of path models, as shown in Figure 1. With 500 replications, the probability of detecting a significant relationship when it exists (as known as an empirical statistical power = 1 - β, which is denoted as π in this study) was computed. Only those relationships (*b*) with π (an empirical statistical power) greater than 0.80 are considered to be meaningful (as by convention, 80% of statistical power is an acceptable in the field) and will be discussed. We also reported the average of estimated parameters and their standard errors from a simulation with 500 replications.

RESULTS

TEAM CHARACTERISTICS

Table 1 summarizes team characteristics by team size, member composition by gender, a profile of external grants (i.e., applied, received, and grant funds secured), and publication record. As shown in Table 1, the number of team members ranged from 4 to 10 (M = 7.09, SD = 1.81). The percentage of male team members varied from 0-67% (M = 42%, SD = 21%). Only 1 team had an equal number of male and female members, with 6 teams composed of more females and 4 teams with fewer females. Years of U-LINK funding ranged from 1 to 3, with 2 teams in their third year of funding and 3 teams in their second year of funding. Although all 11 teams had applied for external grants (*Min* = 1, *Max* = 4), only 5 teams secured external funding, with 2 of those 5 receiving two grants each. The amount of external grant funding secured by those 5 teams ranged from $33,932 to $3,016,814, with a total sum of $3,490,741. These 11 teams published a total of 18 peer-reviewed manuscripts (*Min* = 0, *Max* = 6), presented at 44 conferences (*Min* = 0, *Max* = 12), and wrote 9 white papers (*Min* = 0, *Max* = 7).

TEAM-LEVEL PROCESSES AND OUTCOMES OVER TIME

To address RQ1, we examined change in process variables that past research has shown to impact team success. While the number of informal meetings did not change significantly over time, significant differences were found over time for the following variables: (1) shared leadership, (2) role ambiguity, (3) goal clarity, (4) process clarity, and (5) number of formal meetings.

First, teams' shared leadership scores were significantly different across time, $F(2,18) = 11.78$, p = .001, *partial* η^2 = .29. The partial eta-squared value indicates large effect size. Teams showed a significant increase in their shared leadership from time 1 (M = 4.01, SD = .50, n = 11) to time 2 (M = 4.62, SD = .29, n = 11), p = .01. As shown in Figure 2, this result suggests that the team's perceived level of shared leadership significantly increased and then remained steady over time.

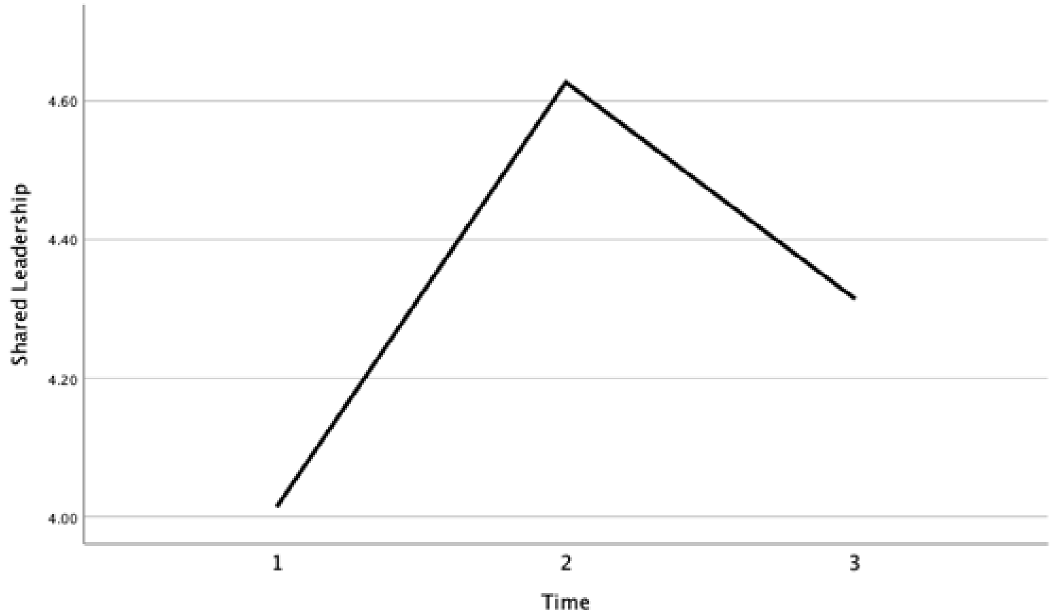

Figure 2. Comparison of Shared Leadership Over Time

Second, team-level role ambiguity scores were significantly different across the three-time periods, $F(2,18) = 19.11$, $p < .001$, *partial* $\eta^2 = .68$. The large effect size implies that there are important differences across time points. Post-hoc analysis showed (Figure 3) that teams significantly increased in role ambiguity from time 1 ($M = 4.02$, $SD = .33$, $n = 10$) to time 2 ($M = 4.48$, $SD = .39$, $n = 10$), $p = .004$; and time 1 to time 3 ($M = 4.65$, $SD = .45$, $n = 10$), $p < .01$.

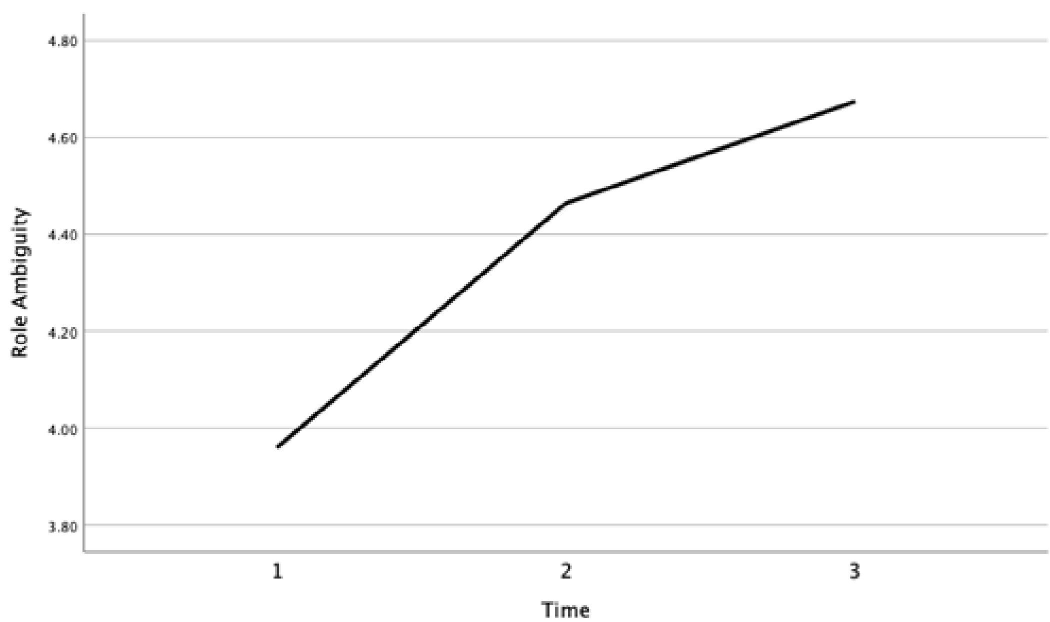

Figure 3. Comparison of Role Ambiguity Over Time

Third, team-level goal clarity scores were significantly different across the three-time periods, $F(2,18) = 9.90$, $p = .001$, *partial* $\eta^2 = .52$. The partial eta-squared value of .52 suggests a large mean difference over time in team-level goal clarity scores. As shown in Figure 4, teams significantly increased their goal clarity scores over time (*M* = 4.29, S*D* = .23, *n* = 10 at time 1; *M* = 4.62, S*D* = .32, *n* = 10 at time 2; and *M* = 4.66, S*D* = .36, *n* = 10 at time 3).

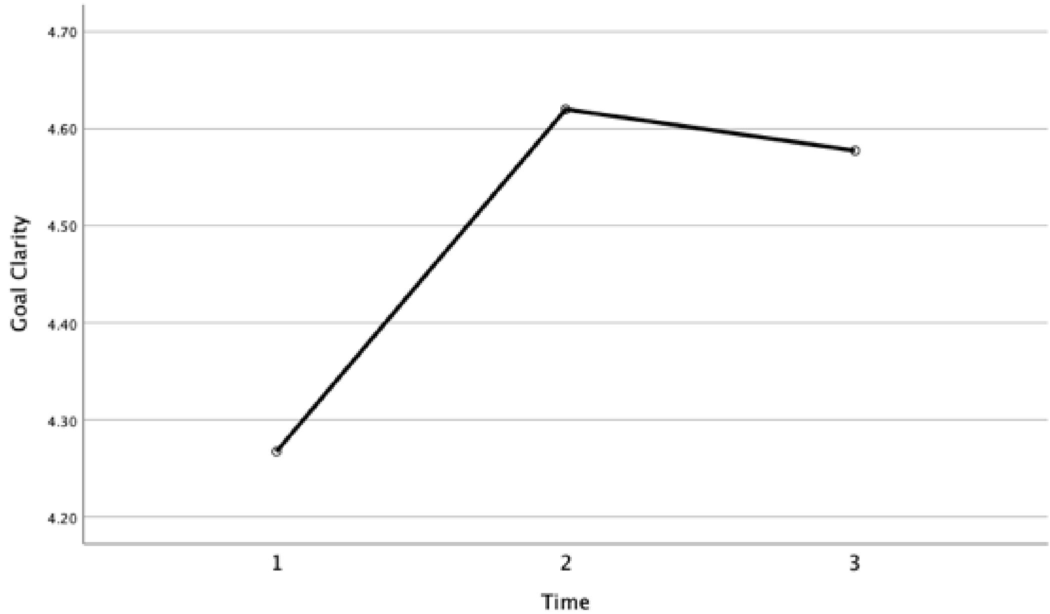

Figure 4. Comparison of Goal Clarity Overtime

Fourth, team-level process clarity scores were significantly different across time, $F(2,18) = 11.78$, $p = .001$, *partial* $\eta^2 = .57$. Teams showed a significant mean difference in their process clarity between time 1 (*M* = 4.10, S*D* = .31, *n* = 10) and time 2 (*M* = 4.49, S*D* = .38, *n* = 10), $p = .02$; time 1 and time 3 (*M* = 4.57, S*D* = .31, *n* = 10), $p = .003$. As shown in Figure 5, this result suggests that team-level process clarity scores were significantly increased and then remained steady over time.

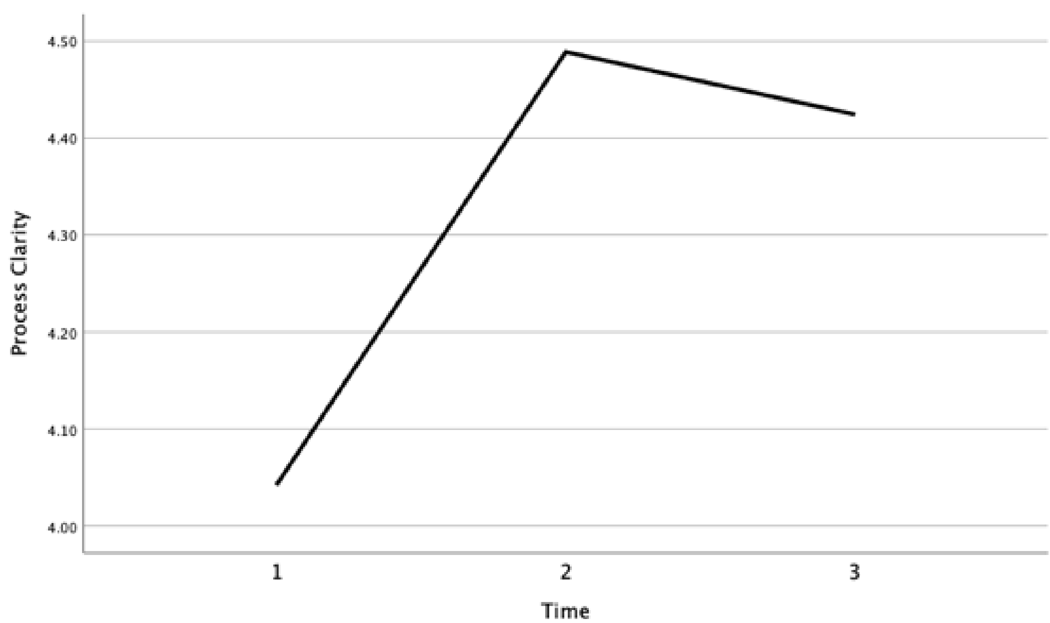

Figure 5. Comparison of Process Clarity Over Time

Lastly, on average, teams had held 4.63 meetings (SD = 4.90, n = 11) before time 1; 10.77 (SD = 4.90, n = 11) between times 1 and 2; and 21.25 between times 2 and 3 (SD = 10.53, n = 11). As shown in Figure 6, the number of times teams met formally significantly increased over the 3 time periods, $F(2,18) = 51.25$, $p < .001$, *partial* $\eta^2 = .84$. The effect size measure is extremely large, indicating meaningful increases in the number of formal meetings over time.

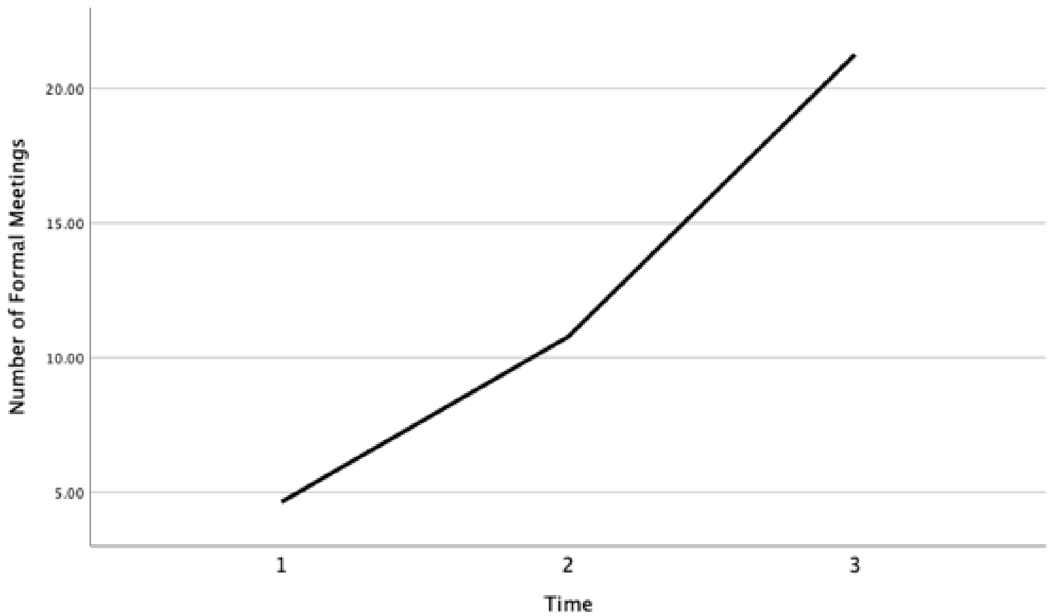

Figure 6. Comparison of Formal Meeting Frequency Over Time

Relationships Between Team-Level Processes and Team-Level Outcomes

Table 2 provides the parameters estimated from our sample that were used to generate the simulated data for 50 members in Monte Carlo simulations. The goal of conducting these Monte Carlo simulations is to provide insights about the relationships between team-level outcomes and team-level processes, if a sufficient number of sample size is collected to test the proposed model. These Monte Carlo simulations allowed us to test the hypotheses advanced in this study.

We had several hypotheses that focused on the role of shared communication. Our first hypothesis, which predicted that shared communication would be positively associated with behavioral trust, was not supported by the data. H2 predicted that shared communication would be associated with goal clarity (H2a), process clarity (H2b), and lower levels of role ambiguity (H2c). The data did not support this set of hypotheses. Our third set of hypotheses predicted a positive relationship between shared communication and research productivity (H3a) and team satisfaction (H3b). Our analyses showed that shared communication did predict research productivity in the form of the number of grant proposals submitted, ($\overline{b}$ = -5.08, $\overline{SE}$ = 0.35, π = 1.00), as well as overall team satisfaction ($\overline{b}$ = -.20, $\overline{SE}$ = .04, π = .99), which is an important predictor of long-term team success. These findings support both H3a and H3b.

Table 2. Parameters used for Monte Carlo Simulations

	Satisfaction as an Outcome			N Grants as an Outcome			N of Publication as an Outcome		
	b	*se*	π	*b*	*se*	π	*b*	*se*	π
Satisfaction									
Role ambiguity	0.09	0.05	0.54	-5.83	0.17	1.00	-17.92	1.37	1.00
Process clarity	0.40	0.05	1.00	-3.04	0.31	1.00	-23.52	2.4	1.00
Goal clarity	-0.17	0.06	0.77	13.03	0.24	1.00	45.71	1.78	1.00
Communication	-0.2	0.04	0.99	-5.08	0.36	1.00	-14.34	1.85	1.00
Leadership	0.13	0.05	0.77	3.5	0.4	1.00	35.43	3.15	1.00
Informal meeting	0.04	0.005	1.00	-0.009	0.04	0.06	0.62	0.15	0.96
Role Ambiguity									
Communication	-0.01	0.11	0.07	-0.21	0.14	0.35	-0.19	0.14	0.29
Leadership	0.13	0.12	0.19	0.27	0.2	0.31	0.31	0.2	0.34
Formal meeting	0.02	0.01	0.50	0.06	0.01	1.00	0.06	0.01	0.99
Process Clarity									
Communication	0.05	0.11	0.09	0.21	0.09	0.64	0.23	0.09	0.71
Leadership	0.29	0.11	0.75	0.9	0.13	1.00	0.92	0.13	1.00
Formal meeting	0.02	0.01	0.33	0.01	0.008	0.29	0.008	0.008	0.21
Goal Clarity									
communication	-0.05	0.07	0.11	0.16	0.11	0.35	0.11	0.11	0.19
Leadership	0.08	0.08	0.20	0.19	0.16	0.22	0.14	0.16	0.14
Formal meeting	0.03	0.008	0.98	0.04	0.009	0.95	0.04	0.009	0.98
Communication									
Informal meeting	0.06	0.01	0.99	0.01	0.01	0.16	0.01	0.01	0.16
Trust									
Communication	0.18	0.07	0.78	0.1	0.09	0.2	0.1	0.09	0.22
Informal meeting	0.02	0.01	0.42	0.01	0.01	0.24	0.01	0.01	0.24
Leadership & communication	0.21	0.04	1.00	0.07	0.02	1.00	0.07	0.02	1.00

We also tested the associations between shared leadership with a number of important outcomes. Hypothesis 4 predicted a positive association between shared leadership and shared communication but this was not supported by the data. Our fifth set of hypotheses predicting that shared leadership would be associated with goal clarity (H5a), process clarity (H5b) and role ambiguity (H5c) was partially supported. Shared leadership predicted goal clarity ($\overline{b}$ = .90, $\overline{SE}$ = .13, π = 1.00), supporting H5a, and process clarity ($\overline{b}$ = .92, $\overline{SE}$ = .13, π = 1.00), supporting H5b. However, H5c was not supported. Our sixth set of hypotheses focused on the association between shared leadership and satisfaction (H6a), which was not supported, and research productivity (H6b) which was supported; teams reporting higher perceptions of shared leadership also had a higher number of publications ($\overline{b}$ = 35.43, $\overline{SE}$ = 3.16, π = 1.00) and a higher number of grant proposal submissions ($\overline{b}$ = 3.50, $\overline{SE}$ = 0.40, π = 1.00).

Hypotheses 7-9 examined the role of formal and informal meetings on team outcomes. H7 focused on the ways in which formal meetings could enhance goal clarity, process clarity, and role ambiguity. Our data indicate that formal meetings enhance goal clarity ($\overline{b}$ = .03, $\overline{SE}$ = .009, π = .98), supporting H7a; formal meetings also reduce role ambiguity ($\overline{b}$ = .04, $\overline{SE}$ = .01, π = .95), supporting H7c. However, formal meetings did not appear to have an impact on process clarity. Hypothesis 8 predicted that informal meetings would have a positive effect on behavioral trust among team members, which was not supported by the data. Hypothesis 9 focused on the ways in which informal meetings support team success through enhanced satisfaction (H9a) and increased productivity (H9b). Informal meetings did appear to enhance team satisfaction ($\overline{b}$ = .04, $\overline{SE}$ = .005, π = 1.00), and was associated with a larger number of publication ($\overline{b}$ = .61, $\overline{SE}$ = .15, π = 0.96), which supports H9a and H9b.

DISCUSSION

The hypotheses advanced in this research were designed to evaluate the extent to which specific team processes affect the success of interdisciplinary scientific teams. The analyses of data were based on survey responses, and the teams' own annual reports of scholarly productivity. Consistent with the findings from empirical studies over the last decade, our study indicates that shared communication processes should be considered by interdisciplinary teams. While shared communication was not more likely to lead to a greater sense of trust or increased clarity about the team's goals, roles, and processes, it was positively associated with team satisfaction and greater research productivity. These findings, which are presented in a visual summary in Figure 7, are consistent with the literature (see Pentland, 2012). Shared communication, of course, is easier recommended than achieved. However, because communication is a skill, it can be taught and enhanced through practice, particularly if team members' awareness of individual behaviors can be heightened (perhaps through reviewing recordings of team meetings or by a presentation of summary statistics of the number of conversational turns taken and the amount of talking time each person had during a meeting). Pentland (2012) discusses methodological advances made possible through the use of sociometric "badges" that record conversational turns and times, but such technology is fairly specialized and making sense of the resulting mountain of data collected across teams requires specific, advanced data analytic techniques. Nonetheless, this is a clear avenue for being able to measure the impact of training and development interventions designed to promote shared communication. For interdisciplinary team scientists, though, developing an awareness and appreciation of the importance of sharing conversational space may be enough to accomplish measurable changes in team functions and satisfaction.

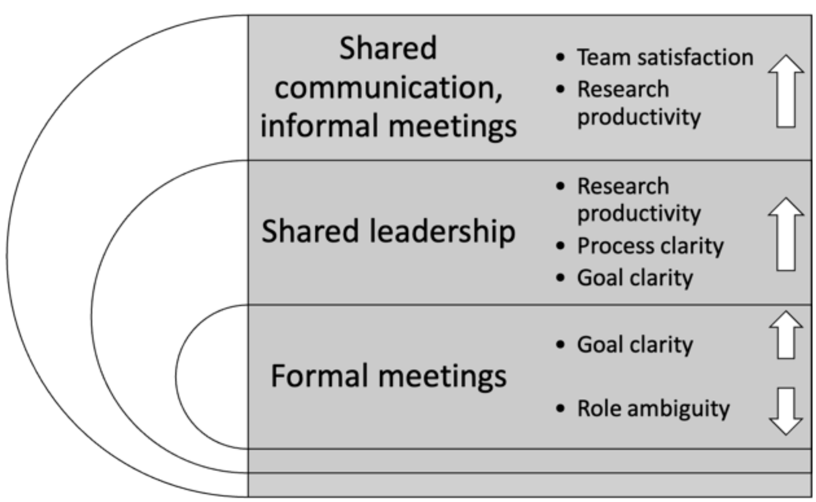

Figure 7. Visual Summary of Study Findings

Other findings related to team processes were mixed. Engaging in greater shared leadership of an interdisciplinary team created greater goal and process clarity, but role ambiguity was not improved. Nonetheless, stronger scores on shared leadership were significantly associated with greater research productivity, including publications and grant applications. While there is no clear consensus in the literature about the value of shared leadership relative to other, more traditional models of leadership (see Ziegert & Dust, 2020), this is likely because there are few opportunities to empirically test these principles. Further, it is difficult to assign some real-world teams to a shared model of leadership (which avoids labels like "Principal Investigator" in favor of "accountable lead") and other teams to a traditional model of team leadership in which one person generally directs the activities of other team members, making a clear comparison on outcomes very difficult. Future research should look at the evolution and longevity of teams employing different types of leadership models, including how team processes change over time. Most research on interdisciplinary teams provides a snapshot of one (or relatively few) point(s) in time; longitudinal research focusing on the evolution of dynamics of interdisciplinary teams would yield valuable insights for researchers as well as research development professionals.

Teams' meeting activities also had an impact on specific outcomes. For example, more frequent formal team meetings were predictive of an understanding of the team's goals and greater clarity about each individual's roles on the team. Moreover, teams that connected with each other through informal gatherings were more likely to report greater satisfaction and to report a higher number of publications stemming from the work of their teams. Curiously, informal meetings did not result in higher levels of behavioral trust.

Finally, the extent to which teams engaged in specific processes changed over time. Shared leadership, goal clarity, process clarity, role ambiguity, and the number of formal meetings all improved over time. Based on these findings, it does appear that with time and experience, teams become more highly functional. However, it should be recognized that an important part of the interdisciplinary initiative that provides funding for these teams is the mandatory participation in team training and development activities, which are described elsewhere (Morgan et al., 2021). This is a competing explanation for these improvements.

There are several important limitations to this study which we hope future research can address. First, the number of teams comprising the sample size is too low to empirically test a theoretical model using traditional analytic strategies. While certainly better than a case study of a single team in many respects, a limited number of teams presented us with data analytic challenges because the number of "subjects" is essentially the number of teams under study; just 11 teams is too small for traditional statistical approaches. Future research with a larger number of teams (or with a combination of interview and/or ethnographic data) could address team dynamics over time in a way that our current study could not. Additionally, all of our teams were embedded within the same university and were subject to the same guidelines and requirements associated with the pilot funding program, which means that certain types of variance that might occur across universities (like the freedom to work within established teams rather than being required to assemble novel teams) are not generally possible with the program described here. Thus, future research studies should be developed in partnership with additional universities with similar programs and goals for the support of interdisciplinary research teams. Finally, we experienced some issues with our measures. Some of the measures we used were found not to be sufficiently reliable, and there are key concepts in SciTS research, including shared communication, for which no measures currently exist. The process of measure development, testing, and refinement takes considerable time and energy, but we are hopeful that the research community will help move this work forward.

Pragmatically, there are specific actions that interdisciplinary teams and research development professionals/administrators can take that are warranted based on the findings from this study and the extant literature in which our work is grounded. First, interdisciplinary teams should consider incorporating behaviors that foster both shared communication and shared leadership by creating structures (such as a providing a period of time dedicated to the teaming process) that allow every member to share their knowledge about the research issue being addressed by the team. Second, teams should consider regular meetings (probably weekly, and likely not more) a vital part of their work; it is the means by which shared understanding of the team's work and its processes emerges. Our informal observation is that interdisciplinary teams that meet weekly are more productive than those that meet less often. Third, teams may benefit by incorporating informal gatherings into their "official" team activities. Such activities would provide an alternative pathway for members to get to know each other and establish trust in ways that support the processes that lead to more favorable research team outcomes.

Research development staff and high-level administrators must make important decisions about the design of funding programs designed to support interdisciplinary research. The empirical literature focused on the "science of team science", including the current study, point to a couple of key recommendations. First, rather than assembling teams based on the productivity of individual researchers (see Ahn et al., 2021, it would be more productive to provide training programs for communication and collaboration skills for interdisciplinary scholars. Second, while we do not have direct data in support of this specific design feature, the U-LINK program provided 8 months of funded time for teams to engage in the "teaming process;" that is, to learn about one another's disciplinary perspective on a complex research topic and to develop an agreed-upon approach that transcends disciplines. This can happen only through extensive conversation and debate. This collective "visioning" also helps to build trust and satisfaction among team members, which should lead to greater research productivity, according to the existing literature. Empirical investigations of accuracy of these recommendations should certainly be conducted.

Indeed, what may be needed to both address the limitations of this study (and others like it) would be to collect data on interdisciplinary teams across institutions. A team of interdisciplinary investigators representing a variety of academic institutions could collaborate to select and develop core constructs for measurement and collect data from internally funded teams on a shared set of measures. While it is inevitable that features of internal funding programs would vary, these could be coded and statistically controlled if the number of participating institutions is adequate. This is certainly an ambitious research agenda but one that could be highly fruitful for the SciTS field.

Conclusion

This study was conducted in response to multiple calls for research to investigate team processes and the factors that are antecedent to team success (National Research Council, 2015; Wooten et al., 2015). We looked at four specific processes (shared communication, shared leadership, formal meetings, and informal meetings) on intermediate outcomes of goal clarity, process clarity, and role ambiguity, and their impact on two outcomes (research productivity and team satisfaction) using both self-report (survey) and objective (research output) data and found that teams that encourage all members to share conversational space, meet frequently, and share leadership responsibilities have the most favorable team outcomes. Communication behaviors are central to all four of the processes we examined; while almost all SciTS scholars have touted the importance of communication for the outcomes of scientific teams, this study is among the few that centers communication practice and processes in the operationalization and measurement of its constructs and which provides a test of hypotheses centered on key questions identified in the literature.

While administrators generally can't (and probably shouldn't) control the process of team assembly (see Ahn et al., 2021, it is clear from previous empirical research that the specific composition of teams, particularly the level of accomplishment of individual team members, matters far less than the processes that teams engage in. The findings from this study reaffirm these assertions in the context of real-world interdisciplinary scientific teams with diverse memberships. While our sample size is small, our study benefits from the external validity afforded by the ability to study a group of 11 real-world teams.

Empirical evidence is urgently needed in order to develop strategies that are likely to work; a lot of money is wasted on pilot funding for teams that fail to "stick" or which do not generate meaningful outcomes. Based on our findings, we have offered a number of recommendations that are relatively straightforward for researchers and administrators to implement in real-world settings. These include reserving ample time for teams to engage in the process of "teaming," to hold frequent research team meetings, and to take time to get together in informal/social settings. Formal communication skills training and team development programs constitute investments that may be just as important as pilot funding that covers direct costs. Universities and other research-focused organizations have questioned how best to support teams charged with developing innovative approaches to grand challenges facing society; offering effective team development initiatives that enhance team cohesion and individual communication skills can help create positive, productive teams (Cheruvelil et al., 2014; Morgan et al., 2021).

Cheruvelil and colleagues (2014) recommend that "members of the scientific community… redefine research success to include collaborative outcomes, promote teamwork training for [researchers] at all career stages, and pay deliberate attention to and guide how teams are formed and maintained" (p. 37). Clearly, communication processes that are central to the formation and maintenance of teams that are both productive and satisfying should be deliberately and carefully cultivated as any other knowledge or skill that impacts scholarly outcomes.

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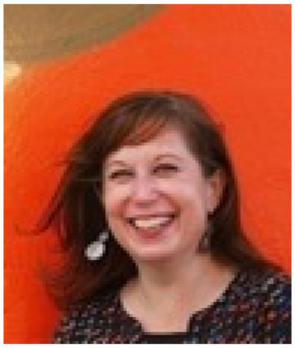

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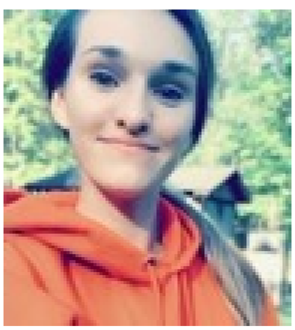

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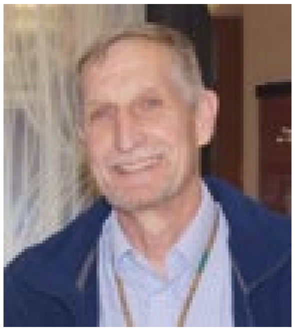

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