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Developing Leadership Capacity in Multiteam Systems

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Abstract

Multiteam systems (MTSs), or teams of teams, have recently become a standard for collaboration—ranging from traditional office teams to those setting a course for Mars. Although leadership is often identified as a critical lever for effective MTS functioning and success, there is little research to inform the question of *how* to develop these leadership skills. Furthermore, despite multiteam systems being an applied phenomenon, a richer qualitative understanding of the MTS experience is noticeably absent from the literature. In an effort to bridge these gaps, this dissertation takes a practical view of multiteam systems to uncover the barriers to promoting effective leadership relationships. I studied multiteam system leadership in the context of space exploration due to the inherently interdisciplinary and multiteam nature of this work. Here, I present three studies: Study 1 is a quantitative analysis of social forces discovering foundational processes shaping the formation of leadership relationships in multiteam systems; Study 2 is a mixed quantitative-qualitative study developing and evaluating a training intervention targeted at enhancing the necessary skills to promote leadership relationships in multiteam systems; and finally, Study 3 is a qualitative analysis using interviews to understand how participants experience working in, and leading, multiteam systems.

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Executive Summary

Collaboration has become a standard component of organizational work, in everything from consulting to long-distance space exploration and beyond. Recently, a collaborative form known as a multiteam system (MTS), or a team of teams, has emerged as an effective solution for complex endeavors. Although leadership is identified as a critical lever for navigating the complexity of MTSs and enabling their functioning and success, the critical question of *how* to develop the requisite leadership skills to combat the challenges of MTS work remains. In this dissertation, I use a three-study mixed-method approach to investigate the challenges of multiteam systems and MTS leadership. In addition to creating a training intervention to develop the skills needed for building effective leadership (i.e., inter-group) relationships in multiteam systems, I also engage in a more in-depth exploration of the MTS experience, uncovering a disconnect between the scientific study of multiteam systems and members' experiences.

In Chapter 1, I briefly review the literature on multiteam systems. I detail that, when organizing the existing empirical work in this area, three core challenges emerge. The first, coordination, is a behavioral element of MTS work focused mainly on between-team efforts. The second is navigation of the goal hierarchy, which is a cognitive challenge. The goal hierarchy can be particularly difficult if team-level goals are not compatible with one another, as a requirement of multiteam systems is that all team goals integrate towards the accomplishment of the MTS-level goal(s). Finally, the third challenge is inter-team dynamics, which present an affective challenge for members working in a multiteam system. Moreover, although leadership is offered as a solution to these challenges, a review of the MTS leadership literature highlights just how complex leadership is in itself—in particular, leadership is often undefined and informal

in this setting. Therefore, I turn my focus to the practical skills and abilities of MTS leadership, and I ask: *How can multiteam system members create conditions that support the emergence of effective inter-group relationships?* Furthermore, I discuss how the interdisciplinary and multiteam structure of work done in the space exploration context provides an ideal setting for studying MTS leadership in order to answer this question.

Chapter 2 provides a first step towards this end—I outline a quantitative examination of leadership in multiteam systems, investigating the social forces that predict MTS leadership emergence. This study addresses a critical challenge of MTS leadership, which is that effective MTS functioning requires members to build relationships across team boundaries, but leadership is often not formally prescribed. Instead, members must rely on complicated social processes to determine leadership. This study seeks to identify these foundational processes and I empirically tested the link between three categories of social forces and the formation of leadership relationships in multiteam systems: (1) social norms, including reciprocity, transitive closure, and popularity; (2) social differentiators, including disciplinary team membership and propinquity; and (3) cognitive factors, including task- and team-related shared mental models. Results suggest that although all three types of social forces affected the development of MTS leadership ties, social differentiators had the strongest (and most positive) influence on the formation of leadership relationships.

Building on Chapters 1 and 2, Chapter 3 details my evaluation of an MTS leadership intervention called Project RED (Red planet Exploration and Development) tabletop. This intervention is an interdisciplinary multiteam task designed to target the MTS challenges uncovered in Chapter 1 and enhance the critical skills needed to promote the emergence of effective leadership relationships discovered in Chapter 2. Although the intervention did not show evidence of significant increases in participants' understanding of coordination, goal hierarchy, or inter-team dynamics when compared to the control task (Towers Market, a cross-functional team task), supplemental analyses of *t*-tests found a significant increase in coordination after Towers Market compared to before Towers Market, as well as significant increases in both coordination *and* inter-team dynamics after Project RED tabletop when compared to before Project RED tabletop. Additionally, analysis of post-task reflections revealed a positive reaction to the Project RED intervention—more so than the reaction to Towers Market. Finally, if students' post-task reflections are viewed as behaviors in themselves, linguistic analysis demonstrated that behaviors became more collective, less power-driven, and more self-assured after Project RED tabletop compared to after Towers Market. Together, these findings provided initial evidence of the effectiveness of the intervention as a multiteam system leadership training tool.

Finally, Chapter 4 outlines my exploration of the experience of MTS work and leadership. Given the discrepancy between participants' quantitative and qualitative responses discovered in Chapter 3, I considered that the academic characterization of multiteam system work might not match what active MTS members experience. Therefore, in a departure from previous studies of multiteam systems, I employed an inductive thematic analysis of the MTS experience. I analyzed interviews with members from some of the most cutting-edge space multiteam systems presently operating, including NASA employees, astronauts on the International Space Station (ISS), and astronaut candidates in the Scientific International Research In a Unique terrestrial Station (SIRIUS) analog. This study sought to understand MTS work and leadership in the context of the “live” working environment, and thus, interviews with members embedded in MTSs helped capture these aspects of multiteam systems as they happened in the field. Findings indicated 20 unique challenges of multiteam system work across four themes (Structure, Climate, Integration, and Space Context), as well as 20 unique responses to challenges across five themes (Structure, Climate, Communication, Space Context, and Non-Leadership Behaviors). I found that challenges and responses were often quite similar, demonstrated by the names of themes (i.e., challenges include a Structure theme, as do responses), as challenges along one dimension likely prompted responses to address or prevent them. There were also several challenges and responses unique to the space context in which the multiteam systems operated in this study. Finally, challenges and responses were complex in and of themselves and typically consisted of component challenges/responses across several themes. These findings may have implications for creating MTS training interventions as they suggest weaving together challenges, rather than parsing them apart as is the case in most training interventions.

Collectively, results from these three studies serve to advance both the science and practice of multiteam systems. Regarding implications for science, this dissertation addresses how informal leadership relationships—a vital component for multiteam systems—emerge in the multiteam system context. This work has also expanded our understanding of the challenges of working in MTSs. Whereas the literature has focused on three core challenges of integration (i.e., coordination, goal hierarchy, and inter-team dynamics), this work finds challenges related to structure and climate, in addition to integration. Through a more novel approach to MTS study, qualitative analysis, findings help provide a new framework for understanding and studying multiteam systems. Additionally, these findings have practical implications. First, I provide a uniquely multiteam system-focused training tool for MTS members to learn to lead across groups. This dissertation also provides a rich picture of the challenges of MTS work that leaders can address to leverage and build effective inter-group relationships and findings provide evidence for the necessary skills to develop leadership relationships in multiteam systems. Furthermore, the qualitative work was able to pinpoint the challenges and responses of MTS work unique to the space context, which may have implications for NASA, who is currently looking for countermeasures to support multiteam systems and multiteamwork and have identified training as a critical leverage point toward this end.

CHAPTER 1

LEADING MULTITEAM SYSTEMS

Collaboration has become a standard practice in everything from consulting to long-distance space exploration and beyond. Recently, a collaborative form known as a multiteam system (MTS) has emerged as an effective solution for especially complex endeavors. A *multiteam system* refers to “two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals” (Mathieu, Marks, & Zaccaro, 2001, p. 290), and when executed effectively, multiteam systems can accomplish incredible feats. For example, astronauts on the International Space Station (ISS) routinely work with various teams to carry out data collection, physical exercise, and one of the most coveted tasks: extravehicular activities, or EVAs.

In May 2017, two astronauts completed the 200th EVA in the history of the ISS, which, despite its relatively mundane nature, was an incredibly intricate task (Harding, 2017). The main goal was to replace a part on the exterior of the space station. However, the task began long before the repair. Weeks in advance of the excursion, a team of engineers and scientists first manufactured the replacement part, later delivered to the ISS by teams of flight controllers and mission managers via the OA-7 Cygnus spacecraft. This initial process delayed the EVA by more than a month. Finally, upon arrival, the astronauts suited up and worked with ground control to eventually make the replacement. This complicated yet routine EVA is just one example that demonstrates how multiple teams with—sometimes conflicting—team level goals (i.e., engineers and scientists need adequate time to build a working replacement part, but astronauts need the replacement part as soon as possible to ensure the integrity of the space station, and flight controllers and mission managers work to align both of these goals on a schedule) all simultaneously work towards a common superordinate goal (i.e., keep the ISS running safely up-to-date). Additionally, all teams exhibited interdependence with one another in order to conduct their work. The astronauts depended on the ground-based teams to manufacture and send the physical parts, make calculations regarding the environment and when it would be safest to perform the EVA, and provide instructions on how to accomplish these tasks; the ground teams were dependent on the astronauts to complete everything correctly and report details of the mission to inform future EVAs. In other words, this excursion is a perfect example of multiteam systems in space.

However, as demonstrated by this EVA, multiteam systems are inherently complex, and their effective functioning does not come without challenges. As detailed in Table 1, prior research identified key challenges including coordination, goal hierarchy, and inter-team dynamics (Davison, Hollenbeck, Barnes, Sleesman, & Ilgen, 2012; Luciano, DeChurch, & Mathieu, 2018; Mathieu et al., 2001), and even offered some solutions, such as leadership (Carter & DeChurch, 2014; Davison et al., 2012; DeChurch & Marks, 2006; Mathieu et al., 2001; Zaccaro & DeChurch, 2012). However, in its identification of leadership as a potential solution to multiteam system challenges, the literature often neglects the complexity of leadership itself. Leadership is equally, if not more complex than the issues it is attempting to address in multiteam systems and the critical question of *how* to develop the requisite skills and abilities of leadership to combat multiteam system challenges remains.

Although the literature on leadership development provides a solid foundation toward answering this question, there are several critical multiteam system considerations not covered by the traditional leadership development practice. For example, the structure of a multiteam system complicates the current leadership development recommendations. Whereas research on leadership development has suggested a model predicated on commitments, mutual respect, and trust (Day, 2000), multiteam systems entail several social processes and task-based goals, which are often competing between the team and system levels (Luciano et al., 2018; Mathieu et al., 2001; Zaccaro, Marks, & DeChurch, 2012). Previously straightforward concepts, like commitments, become murky, as members switch from working within their team to between teams, and respect and trust may erode in the process. With this in mind, and in line with arguments outlined in the multiteam systems literature (i.e., Luciano et al., 2018), I posit that we must generate a distinct set of guidelines to address the challenges of working in—and more specifically leading—a multiteam system.

This dissertation seeks to bridge the gap between the science and practice of multiteam systems, and I ask: *How can multiteam system members create conditions that support the emergence of effective inter-group relationships?* Through a series of three studies, I aim to both understand the challenges of working in a multiteam system, as well as provide actionable steps towards preparing individuals to effectively work in this collaborative setting.

Multiteam Systems

Although multiteam systems are a unique form of collaboration, they are utilized often and across many different fields. In *Team of Teams: New Rules of Engagement for a Complex World*, General Stanley McChrystal discusses his time as leader of the Joint Special Operations Task Force in the formative years of the Iraq War (McChrystal, Collins, Silverman, & Fussell, 2015). General McChrystal recounts that, despite his teams' incredibly high levels of skill, they were ineffective as long as they operated separately. It was only when they realized their inherent interdependencies and worked together across team boundaries towards the larger goal that they found success. There are also other, more common examples of multiteam systems, such as the emergency medical technicians (EMTs), firefighters, and surgeons who respond to car crashes and fires; cockpit and cabin crews who transport us safely on flights; and hardware, software, and marketing teams who bring the latest technology to market. Multiteam systems are ubiquitous and powerful, and as such, it is crucial to understand what they are and how they operate.

In their seminal article, Mathieu and colleagues (2001) advanced multiteam systems as a scholarly concept and delineated five defining characteristics. The first is that multiteam systems are composed of at least two teams, with each team of the MTS referred to as a "component team." Second, MTSs are typically smaller than an organization but larger than the average team, and it may be the case that members of the system come from different organizations. Third, all component teams are dependent on at least one other team in the system with respect to the input, process, and outcome of component team tasks. This interdependence is an important defining characteristic, as it suggests that teams *must* coordinate with one another in order to achieve the superordinate MTS goal. Fourth, multiteam systems operate as a function of their environment. Stated another way, the MTS structure changes depending on the environmental demands; multiteam systems must be adaptable. Finally, while not all component teams share proximal goals, all teams share and are invested in a superordinate system-level goal.

Since these principles were set forth by Mathieu et al. in 2001, there has been a surge in the research conducted in this area, and subsequently, our understanding of multiteam systems has grown. Recently Luciano, DeChurch, and Mathieu (2018) integrated this research, drawing on individual, team, and organizational literatures to build a meso-theory of MTS functioning. This meso-theory provides the basis on which we can begin to explicate the complexity of multiteam systems. In their framework, the authors suggested that individuals' needs and motives, as well as collective emergent states (i.e., affective motives, belonging needs, and cognitive motives), are associated with multiteam system structural forces, including boundary-enhancing and disruptive forces. Furthermore, these forces are responsible for generating the overarching multiteam system structural features. The features are differentiation, which address the shape of the MTS structure and dynamism, or how the MTS changes over time (Luciano et al., 2018; Ranson, Hinings, & Greenwood, 1980). Together, the interplay of these features, forces, and individuals' needs and motives creates the complexities of MTS functioning—but not without challenges.

Multiteam System Challenges

Nearly two decades of research on multiteam systems have uncovered the many challenging factors of working in this setting, which can be organized into three areas. The first is behavioral, and that is the challenge of coordination—particularly between teams. The second is navigating the goal hierarchy, which is a cognitive challenge. Lastly, research has identified the affective challenge of inter-team dynamics.

The first and most widely researched challenge of multiteam system work is coordination. Coordination is arguably *the* central tenet of the original MTS framework (Mathieu et al., 2001) and for a good reason: It is often the make-it-or-break-it factor in system functioning and success. Multiteam systems that demonstrate effective coordination also show improved team (Mathieu, Maynard, Taylor, Gilson, & Ruddy, 2007) and system performance (Davison et al., 2012; DeChurch & Marks, 2006; DeChurch & Zaccaro, 2010; Marks, DeChurch, Mathieu, Panzer, & Alonso, 2005; Mathieu et al., 2001). However, coordination is extremely difficult. Effective MTS work requires individuals from several, often functionally distinct teams, interact with one another to fuel inputs, processes, and outcomes for their own component teams *and* the system at large (Mathieu et al., 2001). In addition to the tasks themselves being quite complicated, other factors like the size of the system, the level of specialization within teams, and the physical distance between teams make coordination tricky as well (Davison et al., 2012; Shuffler, Jiménez-Rodríguez, & Kramer, 2015).

The second challenge of working in a multiteam system is the goal hierarchy, whereby teams pursue different, sometimes competing, team goals that are intertwined at the superordinate level. Whereas the EMTs arriving on the scene of a fire may want to jump in and treat victims as soon as possible, the firefighters may need to first extinguish the fire before any other personnel are active on the scene. Here, although everyone has the same overarching goal of saving the victims, the proximal goals of the EMTs and firefighters are not aligned, likely causing friction between the two component teams. This is often the case in multiteam systems. Not only is this inter-team goal interdependence a central tenet of the original MTS framework (Mathieu et al., 2001), but goal discordancy, or the "dissimilarity and incompatibility of goals and goal priority across component teams" is a key dimension of the structural feature of differentiation outlined by Luciano et al. (2018, p. 1072).

Finally, the third main challenge of multiteamwork is inter-team dynamics. These dynamics constitute the social processes between MTS members, such as identity, cohesion, and trust, among others. Inter-team dynamics are challenging because they tend to emerge as countervailing forces, where the dynamics that benefit the team hinder the system, and vice versa (Asencio, Murase, DeChurch, Chollet, & Zaccaro, 2016; DeChurch & Zaccaro, 2013). Take the social process of identity, for example. Individuals naturally categorize others, but in instances of collaboration, this translates to team members representing the "ingroup" and puts everyone else in the "outgroup" (Tajfel, 1978; 1982; Tajfel & Turner, 1985). This phenomenon is derived from social identity theory, and it explains a host of social interactions—namely, we tend to look favorably upon those in our ingroup and less favorably upon those in the outgroup (Tajfel, 1978). However, in multiteam systems where different teams are necessarily interdependent on one another, people categorized as being in the outgroup are now required for ingroup success. The result is dissonance within individuals and conflict across the system. Indeed, research on inter-team identity has found that effective inter-group performance depends on the ability to create an inter-group relational identity (Hogg, van Knippenberg, & Rast, 2012). Importantly, identity is just one example of how inter-team dynamics present a challenge in MTS work, and many other social processes have a similar effect, including cohesion and trust (DeChurch & Zaccaro, 2013).

In addition to outlining challenges of multiteam system work, research has also attempted to identify potential solutions to meet these needs. One of the most commonly offered solutions is leadership. Although similar to team leadership, multiteam system leadership is a unique construct with its own body of literature.

Multiteam System Leadership

Although leadership may take many forms, multiteam system leadership is often defined in light of functional leadership theory; that is, "to do, or get done, whatever is not being adequately handled for group needs" (McGrath, 1962, p. 5). For more than a century, individuals, teams, and organizations have attempted to understand the impact of leadership on teamwork and its ability to drive team functioning and success (Lord, Day, Zaccaro, Avolio, & Eagly, 2017). Indeed, research indicates that leadership improves team performance, particularly by enhancing affective, behavioral, and cognitive team processes (Zaccaro, Rittman, & Marks, 2001). For example, effective leadership would facilitate information sharing and sense-making (behavioral processes), which helps build strong mental models (cognitive processes; Klimoski & Mohammed, 1994; Zaccaro & Klimoski, 2002). It comes as no surprise, then, that the study of multiteam system leadership stems from the foundation set by team leadership research, exploring the same group mediators set out by Zaccaro and his colleagues in 2001 (i.e., affective, behavioral, and cognitive processes) from an *inter-group* perspective.

Findings regarding the impact of leadership in multiteam systems are similar to the findings from the teams literature. In their initial article outlining what a multiteam system is and how it operates, Mathieu and colleagues (2001) focused a great deal on leadership, identifying it as a critical lever for MTS success. DeChurch and Marks (2006) later empirically verified this notion. The authors manipulated leader strategizing and coordinating in multiteam systems and found that not only did the leader training improve leadership and coordination efforts, but also that leadership was positively related to MTS performance. Davison and colleagues (2012) also found that leadership had a positive effect on system performance, but their findings were a bit more specific. The authors found that leadership was positively related to MTS performance when leadership actions centered around the component team most critical to addressing the demands of the task. Finally, research investigating the impact of shared leadership in multiteam systems and found it is positively related to team goal attainment and MTS success (Bienefeld & Grote, 2014).

In addition to aligning with leadership at the team level, leadership in multiteam systems must also account for features and forces not present in the team setting. Jonassen (2015) acknowledged the difficulty of leading in a multiteam system and argued that leadership is uniquely complex in this environment. This complexity is due to the fact that leaders must "transform subgroup self-interest and detrimental competition between groups into collaboration and co-operation that optimize inter-group performance" (Hogg et al., 2012, p. 235). Leaders must constantly shift their focus between their component team and the larger system (Mathieu et al., 2001; Morgeson, DeRue, & Karam, 2010), fulfilling both macro-level functions, such as sense-making and strategy, and micro-level functions, such as managing the flow of information and providing feedback (DeChurch, Burke, Shuffler, Lyons, Doty, & Salas, 2011). In turn, this impacts the level of specialization leaders can exhibit (Contractor, DeChurch, Carson, Carter, & Keegan, 2012)—for example, if a leader is too involved with planning and organizing, he/she may sacrifice the ability to provide developmental feedback to team members. Together, both of these MTS-specific conditions create the need for informal leadership (Carter & DeChurch, 2014), in addition to formal leadership, in the MTS setting.

However, despite the scholarly proposal and defense of leadership as a solution to the challenges of MTS work, our understanding of leadership is quite simplistic. The literature suggests leadership can address the difficulties of working in multiteam systems, but practically speaking, what does this look like? What exactly are the skills needed to promote conditions that support the emergence of productive inter-group relationships, and how can we develop these skills in multiteam system members (and prescribed leaders, where applicable)?

Leadership Development in Multiteam Systems

Despite the characterization and examination of conditions that make MTS work especially challenging, and the broadly-offered solution of leadership, there are many remaining questions—particularly for those in need of actionable steps towards creating productive inter-group relationships in the MTS context. In this dissertation, I aim to address these critical gaps by studying the challenges of multiteam system work, with a focus on requisite skills needed to promote effective inter-group relationships (and thus, effective MTS functioning).

The context: Space exploration. The history of space exploration is quite rich, especially given its age. Human space exploration began in the late 1950s with Russia's Vostok program in 1958; shortly thereafter, the United States launched Project Mercury, which put a human in orbit around the Earth. This was the start of what is collectively known as the Human Spaceflight program. The program began with several shorter, but impactful missions, such as Project Gemini and the famous Project Apollo, where Neil Armstrong became the first person to walk on the Moon. Then, in the 1970s, the space exploration missions became much longer. The Space Shuttle launched in 1972 and concluded its mission in 2011. The United States also launched its first space station, called Skylab, in the early 1970s, which paved the way for the International Space Station that currently orbits the Earth today. The ISS will conclude its mission in 2030, when NASA will pursue the newest frontier in the Human Spaceflight program: deep space exploration, to Mars and beyond.

In addition to learning an immeasurable amount about space, the Human Spaceflight program has also provided a rich context through which we have learned a great deal about humans—particularly the trials and tribulations of collaboration. In fact, teamwork is a major pillar of the Behavioral Health and Performance Element of NASA's Human Research Program. Landon, Vessey, and Barrett (2016) recently detailed this in a report titled *Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team*, where they cited "Team Risk" as a serious constraint for mission exploration. Interestingly, NASA's definition of a team "can encompass both the spaceflight crew and the individuals and teams in the larger multi-team system who are assigned to support that crew during a mission" (Landon et al., 2016, p. 8). Thus, as we saw with the ISS EVA example, the integration of many specifically interdependent teams is often the landscape of collaboration in space, which provides an ideal context for this dissertation.

Importantly, although the Human Spaceflight program has been a source of knowledge and national pride, there have also been several poignant failures that have occurred as a result of this climate and the necessary multiteamwork. The Apollo 1 mission (NASA, 2017), as well as the launch of the Challenger (Encyclopedia Britannica, 2020) and Columbia shuttles (Dooling, n.d.) are just a few. After action reports of these disasters point to organizational factors as causes, meaning that future deep space exploration, where missions will last three or more years, depend on advances like those addressed in this dissertation. This series of studies first seeks to progress the theory of multiteam systems by elaborating challenges experienced in rich, real-world multiteam systems operating in the U.S. and Russian space agencies. The second aim of this dissertation is application focused—to design an intervention to build leadership capacity in multiteam systems. Towards these aims, I will conduct three studies, as outlined in Table 2.

The first study employed a quantitative approach, analyzing data collected as part of a larger study on multiteam systems in a mixed lab-field setting. I explored how informal leadership relationships emerged in a multiteam system, and empirically tested the link between three categories of social forces and the formation of MTS leadership relationships: (1) social norms, including reciprocity, transitive closure, and popularity; (2) social differentiators, including disciplinary team membership and propinquity; and (3) cognitive factors, including task- and team-related shared mental models. The goal of this study was to understand the foundational social processes that shape leadership relationships in multiteam systems, where leadership is often not formally prescribed (Carter & DeChurch, 2014). Findings suggest that although all three types of social forces affected MTS leadership relations, social differentiators were the strongest influences. More specifically, individuals were more likely to form leadership ties with teammates compared to members of other teams, as well as with members who were more proximal to them than with members who were more distant.

As a goal of the dissertation is to advance the science of leadership development, Study 2 used the findings from the conceptual review and Study 1 to build and test an MTS leadership intervention, called Project RED tabletop. This intervention aims to target and enhance the critical skills needed to promote the emergence of effective leadership relationships in multiteam system settings. I tested Project RED tabletop in an education setting (cf. Waller, Lei, & Pratten, 2014) where students spent one class period (approximately 3 hours) engaged in the task, selecting one of four locations on the Red Planet where a well with a sustainable water supply could be built. Each person assumed a functional role on a given team and received an initial briefing on the multiteam system and task objectives. They then decided on the best location for the well as an individual, then as a team, and finally as a multiteam system. As they progressed through the task and added layers of collaboration, students were required to continually update their collaborative strategy to adapt to the environment, which highlights the different skills needed for effective relationships at the team and MTS levels.

First developed and pilot-tested in an undergraduate Communication course on collaborative leadership in Spring 2019, results indicated the original Project RED tabletop task was not effective in training the necessary leadership skills to combat the challenges of coordination, goal interdependence, and inter-team dynamics. It was thus completely reconstructed. After various rounds of task development and validation, I tested the new Project RED tabletop in a collaborative leadership course in the Master of Science in Communication program in Fall 2019. Although findings were stronger with respect to the learning when compared to a control task, the results were statistically insignificant. However, results of post hoc *t*-tests uncovered significant increases in coordination and inter-team dynamics after Project RED tabletop compared to before Project RED tabletop, indicating that the intervention did aid in the training of skills around coordination and inter-team dynamics. This finding speaks to the learning dimension of the Kirkpatrick (1959; 1976) evaluation of training programs, but I also analyzed the reaction and behavior of participants. The reaction to the Project RED intervention in post-task written responses was overwhelmingly positive and more so than the reaction to Towers Market, suggesting students felt the intervention was valuable. Lastly, linguistic analysis of their written responses indicated a shift in behavior, from singular after Towers Market to plural/collective after Project RED tabletop. Curiously, post hoc analyses also revealed a discrepancy, whereby participants did not demonstrate a stronger understanding of goal hierarchy after either task compared to before the tasks, but discussed goal hierarchy most frequently in the post-task reflections.

This discrepancy between the quantitative and qualitative responses around goal hierarchy prompted Study 3, which attempted to clarify the experience of MTS work and leadership from the perspective of members actively embedded in this setting. This study sought to contextualize multiteam systems to understand the challenges of this work—and thus, where leadership can be developed for effective processes and performance—more deeply. In a departure from the vast majority of work on multiteam systems, this study utilized a qualitative approach. This approach speaks to recent calls by several researchers for a more substantial consideration of the multiteam system context. In a review on the MTS literature, Shuffler, Jiménez-Rodríguez, and Kramer (2015) noted: “Although the environment is often understood to be a factor in shaping MTS processes and performance, more direct attention to these contextual features is necessary to ensure that appropriate measures are taken to respond to environmental features” (p. 688). Mathieu, Luciano, and DeChurch (2017) put forth a similar call in their review, citing consideration of MTS context as a next critical step in multiteam systems research.

Therefore, in response to findings from Study 2 and calls to address the multiteam system environment, I conducted a thematic analysis (Braun & Clarke, 2006) on archival interviews of NASA employees, astronauts on the ISS, and astronaut candidates in the Scientific International Research In a Unique terrestrial Station (SIRIUS) analog. There were four core themes of challenges, and each theme included several subthemes: I found multiteam systems were *structurally* complex, created dynamic *climates*, and required *integration*; there were also challenges unique to the *space context*. Analysis of responses to these challenges resulted in five core themes: I found multiteam system members worked through *structural* complexity by managing their contribution to the *climate* and utilizing *communication*; they also employed responses unique to the *space context*, and there were a handful of *non-leadership behaviors* that occurred in response to challenges as well. Results from this study suggest that the themes of challenges and responses are quite similar and highlight how each response corresponded to a particular challenge. However, challenges unfolded differently than did responses, despite the nominal similarities across challenges and responses. I found that challenges and responses were also complex in and of themselves, and a focal challenge/response often described elements across different themes. Finally, there appear to be many more specific and intricate paradoxes to multiteam system work, beyond different teams working towards a system goal and countervailing forces.

CHAPTER 2

SOCIAL FORCES BEHIND MTS LEADERSHIP RELATIONSHIPS

As teams face new, complex, and specialized challenges, they are often required to work interdependently with other teams. Organizational scholars have begun studying the functioning and performance of these “teams of teams,” or multiteam systems (Cuijpers, Uitdewilligen, & Guenter, 2016; de Vries, Hollenbeck, Davison, Walter, and van der Vegt, 2013; Marks et al., 2005; Mathieu et al., 2001; Mell, DeChurch, & Leenders, 2018), identifying leadership as a critical component of MTS functioning and success. More specifically, researchers suggest leadership is a key force that enables multiteam systems to pull various teams with different goals together toward the achievement of the superordinate system goal (Carter & DeChurch, 2014; DeChurch & Marks, 2006). Therefore, given the vital role of leadership in multiteam systems, an important question is: *How do multiteam system features/forces impact the formation of leadership relationships?*

This question reflects an important shift in the leadership literature, which has moved from a “person or leader centric” view to a relational view (Avolio, Walumbwa, & Weber, 2009), and inherent in this perspective is a focus on leadership as an informal and emergent relationship (DeRue & Ashford, 2010). Moreover, with this shift also comes a renewed interest in understanding the process through which leader-follower relationships come about. Though a large body of research explores leadership emergence in teams (Foti & Hauenstein, 2007; Ilies, Gerhardt, & Le, 2004; Taggar, Hackett, & Saha, 1999), multiteam systems involve the need for coordination both within and between different teams; here, I extend research on leadership emergence to understand the factors that affect leadership emergence in multiteam systems.

This study explores three social forces and their roles in the formation of MTS leadership relationships: social norms (reciprocity, transitivity, and popularity), social differentiators (functional team membership and propinquity), and shared cognition (task- and team-related mental models). Social norms are standards shared by group members, used to assess one another's behavior (Bettenhausen, & Murnighan, 1985; Birenbaum & Sagarin, 1976). Social differentiators characterize the degree of social differences and separation between the teams in a multiteam system (Luciano et al., 2018). Differentiation enhances component team boundaries, which makes ingroup/outgroup dynamics salient, and ingroup preference (Tajfel, Billig, Bundy, & Flament, 1971) then increases liking of ingroup members. Finally, shared cognition refers to members' shared cognitive structures (i.e., knowledge representations); such structures enable team members to organize and distribute their information more efficiently (Kozlowski & Ilgen, 2006). One form of shared cognition is a shared mental model, or an organized mental representation of the team's task, members, and environment (Klimoski & Mohammed, 1994).

In this study, I extend both the work of leadership emergence and social forces to the multiteam system level. I explore the impact of social forces on leadership emergence in multiteam systems using 10 MTS networks consisting of a total of 1,320 unique dyads. Social network analysis allows for testing relationships both within *and* across teams (Wölfer, Faber, & Hewstone, 2015), and can provide a uniquely helpful picture of relationships between multiteam system members (Carter, DeChurch, Braun, & Contractor, 2015; Park, Grosser, Roebuck & Mathieu, 2020).

Leadership in Teams and Multiteam Systems

Leadership has always been a cornerstone of team functioning and success, and the scholarly examination of leadership has traditionally focused on two areas: (1) *leadership effectiveness*, or how leadership enables the team and its members to be successful, and (2) *leadership emergence*, or how and why leadership arises (Hiller, DeChurch, Murase, & Doty, 2011). Regarding effectiveness, we know that leadership helps facilitate team functioning and serves as a critical lever for team success (Hogg et al., 2012; Zaccaro & Klimoski, 2002). Regarding emergence, researchers have investigated who tends to emerge as a leader, and findings suggest that it is those high in intelligence, self-efficacy, self-monitoring, and conscientiousness (Foti & Hauenstein, 2007; Taggar et al., 1999). Of note in this literature is the difference between effectiveness and emergence. Whereas leadership effectiveness is a relatively static view of leadership focused on team outcomes, leadership emergence is an inherently more dynamic view that considers the process of how leadership emerges throughout a team's lifespan.

This conceptual shift in understanding leadership is mirrored in the teams literature. With the advent of multiteam systems, which are complex and often fluid collaborations (Mathieu et al., 2001), the study of teams has become much more dynamic too. Although research links leadership to team and MTS success (Carter & DeChurch, 2014; Zaccaro & DeChurch, 2012) and identifies how leadership emerges in singular teams (Foti & Hauenstein, 2007; Ilies et al., 2004; Taggar et al., 1999), it has not explicated how leaders emerge in the MTS setting. In particular, we lack an understanding of how a relational leadership process (leadership emergence) operates in a relational system (multiteam system). One potential explanation is yet another type of relational process: social forces. Figure 1 details three types of social forces that may shape the formation of leader-follower relations in multiteam systems.

Social Forces

Social Norms

Social norms are shared standards that members of a group can use to judge the appropriateness of one another's behavior (Birenbaum & Sagarin, 1976), and they are some of the strongest known influences on group processes (Bettenhausen & Murnighan, 1985; Marks et al., 2001; Zaccaro et al., 2001). For example, a team may have a norm that it is not acceptable to talk to anyone outside the team. If a member decides to break that norm and make contact with an outside resource, it could upset the team's processes, and even impact its outcomes. Social norms tend to have an exceptionally strong influence on how people behave, even causing them to do or say things they know are objectively wrong (Asch, 1951; Sherif, 1936). Thus, social norms have a uniquely powerful hand in determining collaborative processes, including leadership.

There are many different types of social norms, one being the norm of reciprocity (Gouldner, 1960). Reciprocity is the idea that if a person provides information, resources, etc. to another person, the recipient will then provide something in return. For example, when one person displays friendship to another, the recipient usually reciprocates that friendship (Krackhardt & Kilduff, 1999; Snijders, van de Bunt, & Steglich, 2010). Whereas prior research examined the reciprocity of social relations including, friendship (Krackhardt & Kilduff, 1999; Snijders et al., 2010) and trust (Serva, Fuller, & Mayer, 2005), among others, I extend this theory of reciprocity to leadership in multiteam systems.

The norm of reciprocity likely does not hold for leadership relations in multiteam systems. Given the inherent asymmetrical nature of the resources exchanged in a leadership relationship, reciprocity is not likely (Carley & Krackhardt, 1996). This logic is in line with the work of Emery, Carnabuci, and Brinberg (2011), who found that leadership was not an inherently symmetrical relationship, and reciprocity was not common in leadership relations in informal social groups. These findings imply that multiteam system members will follow a “do not follow your follower” rule. In other words, if Member A provides leadership to Member B, Member B is then less likely to provide leadership to Member A. Thus, I posit:

Hypothesis 1: Individuals are less likely to form leadership relations with their followers than with non-followers (i.e., leadership ties are non-reciprocal).

Another social norm that is often displayed in collaborative processes is transitivity (Heider, 1946; Holland & Leinhardt, 1971). Transitivity is the idea that if Member A has a tie with Member B and Member B has a tie with Member C, Member A will likely have a tie with Member C as well. Transitivity comes about as individuals seek cognitive consistency and balance in their social relationships (Heider, 1958; Holland & Leinhardt, 1971; Robinson & Balkwell, 1995). If the ties represented friendship, for example, this would translate to the following: if Member A is friends with Member B and Member B is friends with Member C, it is likely that Member A and Member C will also be friends. This concept derives from Heider’s (1958) balance theory, which suggests that a friend of a friend is also a friend. Similar to reciprocity, research supports transitivity in the context of social relationships like friendship (Gollob, 1974; Krackhardt & Kilduff, 1999; Snijders et al., 2010) and cognition (Monge &

Contractor, 2003). However, here I extend the principle of transitivity to understand the formation of leadership ties in multiteam systems.

When applied to leadership, balance principles form the basis of social hierarchies, and there are two sets of findings to suggest that leadership relations will exhibit transitivity. First, the theory of cognitive consistency suggests that leadership relations should be transitive. Cognitive consistency theory says that individuals tend to compare their evaluations to others around them (Latane & Darley, 1968), so when two people do not share an evaluation of a third person, they will change their evaluations until they match in order to achieve cognitive consistency (Harary, Norman, & Cartwright, 1965; Holland & Leinhardt, 1975). Therefore, if Member A was relying on Member B for leadership (thus, granting B status) and sees that Member B is actually relying on Member C for leadership (thus, granting C status), Member A is going to be very likely to rely on Member C for leadership; by moving to Member C for leadership, Member A achieves cognitive consistency with Member B. Second, unlike reciprocity, transitivity can be symmetric in leadership relations (Emery et al., 2011). Drawing on relational schema theory (Jannick & Larrick, 2005), Emery and colleagues' (2011) examined how social cognition allowed leaders to coordinate at the group level via the emergence of leadership structures within informal social groups. They found that leadership was, in fact, transitive. Therefore, research on the transitive nature of leadership ties, as well as research on cognitive consistency, suggests that the social norm of transitivity should hold for leadership relations—akin to a "follow your leader's leader" rule—and I posit:

Hypothesis 2: Individuals are more likely to form leadership relations with the leaders of their leaders, than with individuals who are not leaders of their leaders (i.e., leadership ties are transitive).

Finally, there is the social norm of popularity, or preferential attachment (Barabási & Albert, 1999). Preferential attachment is the idea that when one person receives a tie, they then become more likely to receive ties from other actors in the network. Due to the size and complexity of multiteam systems, with different teams pursuing various sub-goals, preferential attachment is very likely in the formation of these leadership relations. As individuals cope with the ambiguity of working toward superordinate goals (Luciano et al., 2018), MTS members are more likely to follow those whom others are following to increase their sense of control and order. Looking at the evolution of networks via Wikipedia pages, which can also be quite large and complex forms of collaboration, Barabási and Albert (1999) suggested that new nodes attach to nodes that are already well-connected. More recently, Abbasi, Hossain, Leydesdorff (2012) found that, among scientific collaborators, new authors preferred to attach to well-connected authors; thus, preferential attachment did hold in social networks. Taken collectively, the literature on multiteam systems and preferential attachment in large and complex social networks indicates that leadership relations will also likely exhibit popularity via preferential attachment. As such, I posit:

Hypothesis 3: Individuals are more likely to form leadership relations with those whom others are following, than with those without a follower or followers.

Social Differentiators

Leadership emergence is both an intra- and inter-group relational process in multiteam systems. Similar to the process of leadership emergence in teams, individuals are claiming and granting leadership, and doing so based on group membership (DeRue & Ashford, 2010). However, due to the interdependent nature of multiteam systems, group boundaries and ingroup preference become exceptionally salient in the process of collaboration (Mathieu et al., 2001). The integration of distinct teams creates a set of differentiation factors, considered to be among the most influential factors to shape behavior in multiteam systems (Luciano et al., 2018). Differentiation refers to "the degree of difference and separation between multiteam system component teams at a particular point in time" (Luciano et al., 2018, p. 1067), and includes differences in teams' goals, work processes, and behavioral norms.

The social differentiators that create structural separation among component teams also likely shape the emergence of leadership relations in these systems. Once a group forms, members tend to establish boundaries around the group (Ashburn-Nardo, Voils, & Monteith, 2001), preferring members of the ingroup while also looking unfavorably upon those who are not in the ingroup (Tajfel et al., 1971). Furthermore, social identity theory suggests that when people identify with others who are like the self, there is a higher chance of social acceptance (Tajfel, 1978; 1981; Tajfel & Turner, 1979). In terms of forming leadership ties, this means that when individuals form component teams, they will be more likely to prefer one another—in terms of information, advice, and as such, leadership. Accordingly, I posit:

Hypothesis 4: Individuals will be more likely to form leadership ties with teammates than with members of other teams in the multiteam system.

In addition to team membership, physical proximity is also a source of social identification. The classic study by Festinger, Back, and Schachter (1950) found that college students who lived on the same floor of a building were more likely to be friends with one another than were those that lived on different floors of the same building. This finding has been replicated with street arrangements and legislative seating, among other configurations of people in groups (McPherson, Smith-Lovin, & Cook, 2001). Extending the propinquity effect to leadership emergence, I suggest that propinquity serves as an essential factor in determining who relies on whom for leadership. In particular, members should rely on teammates who are physically close to them for leadership, compared to more geographically dispersed members. Thus, I posit:

Hypothesis 5: Individuals will be more likely to form leadership ties with members with whom they have greater physical propinquity than with members with whom they have less physical propinquity.

Shared Cognition: Mental Models

Whether there are as few as 3 or as many as 30 people on a team, each person inherently views the team and its task(s) in his/her own unique way. However, one process that supports team functioning and success is shared mental models. A shared mental model occurs when each member has the same conceptualization of team members and the task(s) at hand, or a shared organized representation of critical elements in the team’s environment (Klimoski & Mohammed, 1994). For example, if members of a sales team all define success in the same way—perhaps, reaching a minimum of $150,000 in sales for the quarter—they would have a robust mental model.

Importantly, shared mental models can be further broken down by subject matter: task-related shared mental models, and team-related shared mental models. Task-related mental models concern the task at hand. For a group of researchers, an example of a task-related shared mental model would ask, "How related are conducting research and writing papers in the publication process?" Team-related mental models, on the other hand, have to do with the team processes. So, for example, "How related are sharing information and motivating one another in the publication process?" The task mental model asks about components of completing the task, while the team mental model asks about how members relate to one another in the course of completing the task. Importantly, two individuals can share the same mental representation about the team but not about the task, and vice versa. Therefore, task and team shared mental models are separate forms of shared cognition.

Prior research links shared cognition with the emergence of leadership, suggesting a reciprocal relationship between the two processes. Klimoski and Mohammed (1994) first explained how leadership has the potential to form mental models. They suggested that leadership functions include information integration and interpretation, and adjudicating disagreements or directing individual team members into action. Importantly, each of these functions is focused on the task and team, respectively. Thus, if you rely on an individual for leadership, it is likely that you have been interacting and building a shared mental model with that person; this would hold for both task- and team-related elements of the mental model. Carson, Tesluk, and Marrone (2007) later built on this work, indicating shared mental models may enable the emergence of leadership and suggesting a continuously reciprocal relationship. Therefore, I suggest that shared mental models (both task- and team-related) increase the probability that a multiteam system member will rely on another multiteam system member for leadership. Accordingly, I posit:

Hypothesis 6a: Individuals will be more likely to form leadership relations with members with whom they share greater task mental model similarity.

Hypothesis 6b: Individuals will be more likely to form leadership relations with members with whom they share greater team mental model similarity.

Methodology

Sample and Setting

The sample includes a total of 96 unique individuals participating in a NASA space exploration multiteam system simulation task. Sixteen of these participants were living and working in the Human Exploration Research Analog (HERA; Cromwell & Neigut, 2014) in Houston, Texas, in one of 4, 4-person simulated space crews for 30 days each. The remaining 80 individuals were undergraduate students at an advanced Southeastern technological institute, who participated in this study for course credit or payment ($10/hour) and worked as a member of one of 10, 8-member Mission Control Centers (MCC). Because the HERA crews were confined in the analog for 30 days, I studied each of them multiple times. Two of these crews completed the MTS task 3 times each, and 2 of the crews completed the MTS task 2 times each. Every session was staffed with a different MCC, meaning that each MCC member completed the task only once. This design produced 10 networks of 12 participants, resulting in a total of 120 individuals for the network analyses.

Task and Procedure

Project RED (Red planet Exploration and Development) is an interdisciplinary multiteam task where 12 individuals collaborate to provide a sustainable water source for life on Mars by building a well in the Argyre Quadrangle. Members work on one of four, 3-person functional teams. The task demonstrates an essential MTS feature, which is that component teams each pursue a subordinate goal as well as one or more superordinate goals. Therefore, in addition to the superordinate goal of building a sustainable well, each team pursues a different subordinate team goal. The Planetary Geology team pursues the goal of finding the location with the most usable (i.e., clean and accessible) water, the Extraterrestrial Engineering team pursues the goal of assembling the materials and procedures to ensure the highest well efficiency, the Space Robotics team pursues the goal of selecting robots and rovers that would ensure efficient and effective construction of the well, and the Space Human Factors team pursues the goal of finding a location that had high accessibility, safety, and usability.

Each of the 10 multiteam systems participated in a 3-hour simulation. The 3 hours consisted of training (1.5 hours), task completion (1 hour), and survey completion (30 minutes). All metrics are based on data captured using the survey administered at the end of the session.

Analytic Approach

I used StatNet to conduct the social network analyses, which is a program that simulates and estimates exponential random graph models (ERGM), or *p** models (Handcock, Hunter, Butts, Goodreau, & Morris, 2003; Hunter, Goodreau, & Handcock, 2013; Lusher, Koskinen, & Robins, 2013). First, the program implements Markov Chain Monte Carlo (MCMC) maximum likelihood estimates, comparing the observed leadership network to simulations of the network to see whether the relations in the observed network occurred by chance or not (Shumate & Palazzolo, 2010). A parameter estimate of zero indicates the event was no more or less likely to occur than by chance, while an estimate higher than zero indicates that the event was more likely to occur than by chance, and an estimate lower than zero indicates that the event was less likely to occur than by chance. As outlined in de la Haye, Robins, Mohr, and Wilson (2010), effects are tested using a *t*-ratio.

In order to test each hypothesis—that a social force explains the observed leadership network structure—it was necessary to construct an ERGM term that captured variation on the focal substantive concepts of interest. Figure 2 presents motifs of the structural signatures of hypothesized social forces affecting leadership tie formation; that is, what it would look like in the network if the given social force was at play. The following section details the substantive variables and the associated ERGM term that were entered in the model to provide an inferential test of each hypothesized social force.

Metrics and Measures

Leadership. Leadership networks, the dependent variable in the analysis, were elicited using a sociometric survey administered after the task. Respondents were asked, “Who did you rely on for leadership?” and then provided with a roster with the roles of the 11 other multiteam system members to identify leaders. So, for example, if Member A relied on the Sedimentologist for leadership, he/she would check the box next to “Sedimentologist.” This round-robin method (Carson et al., 2007; Kenny & La Voie, 1984) captured directed leadership ties among the 12 multiteam system members. The resulting leadership network could have anywhere from 0 to 132 leadership ties across the multiteam system. If all 12 members reported relying on all other

11 multiteam system members for leadership, 132 (i.e., N*(N-1)) leadership ties would exist. Each of the 10 multiteam systems had a separate leadership network, so I constructed a 120 x 120 "megamatrix" for use in the ERGM analysis. The megamatrix included each of the 10, 12-node leadership networks on the diagonal with structural zeros in off-diagonal cells. The structural zeros were appropriate, given that a leadership tie could not form between members of two different multiteam systems.

Leadership reciprocity. Leadership reciprocity was an observed property reflecting whether or not leadership relationships tended to be mutual. That is: if A relied on B for leadership, was B more or less likely to rely on A for leadership than would be expected by chance? Figure 2a depicts this network motif. I used the "mutual" ERGM term computed on the leadership network to represent leadership reciprocity in the analysis.

Leadership closure. Leadership closure, or transitivity, was an observed property reflecting whether or not leadership relationships tended to be transitive. That is: if A relied on B for leadership and B relied on C for leadership, was A more or less likely to rely on C for leadership than would be expected by chance? I used the "dgwesp" ERGM term computed on the leadership network to represent leadership transitivity in the analysis. Figure 2b depicts this network motif.

Leadership popularity. Leadership centrality was an observed property reflecting whether or not leadership tended to be a central position. That is: if B relied on A for leadership, was C then more or less likely than would be expected by chance to rely on A for leadership? I used the "idegreepopularity" ERGM term computed on the leadership network to represent leadership centrality in the analysis. Figure 2c depicts this network motif.

Team membership. Team membership was a manipulated variable. Individuals were randomly assigned to roles (and thus to teams) within the multiteam system. As a result, each pair of individuals was either on the same team or different teams, making team membership, in effect, a manipulated independent variable. This variable was thus a node attribute. Given that there were 4 teams per multiteam system across 10 multiteam systems, teams were numbered from 1-40, with each disciplinary team in each system represented by a unique number. Figure 2d depicts this network motif. I used the “nodematch” ERGM term to represent team membership in the analysis.

Propinquity. Propinquity was a manipulated variable, created by using the two locations for this study. Participants were not randomly assigned to these conditions, as they were recruited and selected for the study through different procedures (i.e., NASA selected the space crew, and the university research team recruited the MCC members). HERA crew members were located in Houston, Texas, and MCC members were located at a Southeastern technical institute. Furthermore, there were four rooms at the MCC location, with members of each disciplinary team located in separate rooms. Thus, propinquity was a dyadic attribute coded at three levels, where 1 represented a dyad in the same room of the same building, 2 represented a dyad in different rooms of the same building, and 3 represented a dyad in different buildings altogether. Figure 2e depicts this network motif. I used the “edgecov” ERGM term to represent dyadic propinquity in the analysis.

Shared mental models. I used pairwise comparisons of 5 vital elements of the Project RED task, as well as 5 key teamwork processes elements, to generate the task and team shared mental models. The task elements included in the measure were: comparing location for the well, designing an effective well, minimizing costs to the disciplinary team and/or other disciplinary teams, sending calculations to other disciplinary teams, and experimenting with different calculations. The team elements included in the measure were: motivating one another, coordinating work, managing conflict, monitoring team progress, and sharing information. A complete list of items for the task and team mental models are in Appendix A. Participants rated team and task attributes on a scale of 1 “totally unrelated” to 7 “very strongly related.” I used Pathfinder to represent the degree of similarity in the mental representations of each pair of individuals, where 0 represented dyads with shared mental models above the grand mean (i.e., more dissimilar), and 1 represented dyads with shared mental models below the grand mean (i.e., more similar). Figures 2f and 2g depict the network motifs for the task- and team-related shared mental models, respectively. I used the “edgecov” ERGM term to represent dyadic shared mental models in the analysis.

Controls. I controlled for two elements inherent in the task design and in the nature of the HERA habitat that may have influenced leadership relationships outside of the hypothesized social forces. The first was formal leadership roles. NASA assigned each HERA crew member to an astronaut role, one of which was the ‘Commander.’ In addition to viewing this individual as the Commander for the overall mission, it is likely crew members (and potentially even Mission Control members, should they become aware of this role) could have interpreted this person to be a formal leader for the Project RED task. There was also a “habcom” role given to the Structural Geologist in the Mission Control, who was responsible for bridging messages between the Mission Control and the crew (i.e., “the task has started,” or “please advise when the crew is ready”). To control for the potential that crew members or Mission Control members looked to either of these individuals for formal leadership, I included an attribute variable designating the Commander and Structural Geologist as 1, and all other MTS members as 0.

The second element I controlled for was team membership, particularly membership on the Planetary Geology team. The way the Project RED task is configured, the Planetary Geology team is critical for task completion. For example, they are the only members with the ability to select a location in the interface, and they are the only team whose goals align with the MTS goal. It is thus likely that other members of the multiteam system would look to the Geology team for leadership, and to account for this, I included an attribute variable where 1 represented Geology team members and 0 represented all other members of the system.

Supplemental analyses. In addition to testing the combined megamatrix of MTS networks, I also tested all hypothesized network structures in the individual MTS networks of 12 members each. This practice enables researchers to understand the extent to which there is heterogeneity in the overall patterns observed (here, leadership formation in the multiteam system) across all networks (cf. An, 2016).

Results

Table 3 presents descriptive statistics for each of the five observed variables in this study. The two manipulated variables, team membership and propinquity, are not summarized in Table 3 because study design features determined their values (assignment to teams and location, respectively). Table 3 reports the distribution of each key variable at the appropriate level of analysis. Leadership reciprocity and transitivity varied at the network, or multiteam system, level and so I present the distribution of the 10 multiteam system networks in this study. Shared mental models and leadership ties varied at the dyadic level and were aggregated to the individual level, and so I present the distribution for the 120 individuals in this study.

For leadership and shared mental model ties, possible in-degrees ranged from 0 to 11, meaning that any member of the multiteam system could receive ties from as few as 0 people, up to all 11 other members of the MTS. For reciprocity and transitivity, values ranged from 0 to 1. Reciprocity was a ratio of the number of ties reciprocated to the number of ties in the network. The average reciprocity in this sample was low ($M = .19$), suggesting that about 1 in 5 leadership ties was reciprocated. Transitivity was a ratio of the number of transitive triads (i.e., A relies on B who relies on C, in turn making A rely on C) to all possible triads in the network. Transitivity was also rather low in the current sample ($M = .34$); about 1 in 3 possible transitive triangles were completed. Additionally, Table 3 shows there was meaningful variation on the focal study variables. At the individual level, some members had no shared mental model ties (the minimum possible in-degree for an individual), whereas others had as many as 11. At the network level, reciprocity ranged from 0% to 45%, and transitivity ranged from 8% to 60%.

Figure 3 presents the degree distribution for leadership ties, displaying the number of incoming leadership ties each individual received. Examining Figure 3 shows that, on average, individuals had about 1 or 2 followers ($M = 1.56$). Each crew member had an average of 2 or 3 followers ($M = 2.55$), whereas each mission control member had closer to 1 follower on average ($M = 1.25$). This pattern suggests a shared leadership structure emerged, where there were local clusters of influence. There were also individuals with a broader span of influence, as some members had up to 8 followers (out of 11 possible).

Table 4 presents the ERGM analyses testing the six main hypotheses and includes the parameters for the primary analysis of the megamatrix, as well as the supplementary analysis of each individual network. I report the effect estimate and its associated standard error for each focal variable, as well as the three control variables: “edges,” formal leadership, and informal/expertise-based leadership. For ease of interpretation, I have summarized the findings from the megamatrix and individual ERGMs for all variables in Table 5.

Additionally, goodness-of-fit plots for both the megamatrix ERGM and the individual ERGM analyses are in Figure 4. Goodness-of-fit statistics indicate how well the simulated networks produced by the ERGMs match the observed networks; a good-fitting model is more similar to the observed network (O’Brien, Pilny, Atouba, Shumate, Fulk, & Monge, 2019; Shumate & Palazzolo, 2010). The plots in Figure 4 show the comparisons for each term included in each model, and the points should fall closer to the median in each of the boxes, with fewer deviations in the lines at the top and bottom of each boxplot. Overall, the models demonstrate acceptable goodness-of-fit, and terms were removed where the fit was unacceptable (the “mutual” term was removed from MTS 4 and MTS 6).

Beginning with the control variables, we see the edges term was negative and significant in the composite ERGM (*estimate* = -7.11, $p < .001$), meaning the network was less dense and showed fewer leadership ties than would be expected by chance in a randomly generated network. When analyzing the individual networks (i.e., per multiteam system), the edges term was also negative and significant in all 10 multiteam systems. This finding provides strong evidence of homogeneity across the leadership networks, such that fewer leadership ties formed than would be expected by chance in all multiteam systems. Regarding the effect of formal leadership, the term was not significant in the composite ERGM (*estimate* = .25, *ns*), and analyses of individual networks show this term was significant in one multiteam system and marginally significant in an additional multiteam system. However, the direction of estimates for formal leadership was split (5 were positive and 5 were negative), and as such, formal leadership was not a consistent predictor of leadership emergence. The last control variable tested was informal or expertise-based leadership, and the estimate for this was positive and significant in the composite ERGM (*estimate* = 1.03, $p < .001$), suggesting that Geology team members were more likely to be looked to for leadership than other members in the multiteam system. This finding remained consistent when analyzing the individual networks: the estimate was positive and significant in 6 multiteam systems, and marginally significant in another multiteam system. As such, there is moderate support that leadership ties were more likely to form with people who were informal leaders in the MTS.

Turning to the focal variables, Hypothesis 1 posited that individuals would be less likely to form leadership ties with those who relied on them for leadership (i.e., leadership ties would not be reciprocal). Table 4 shows that the parameter estimate was negative and significant (*estimate* = -.78, $p < .05$), meaning that leadership was not reciprocal, in the composite ERGM. In other words, if Member A relied on Member B for leadership, Member B was then less likely to rely on Member A for leadership, compared to a multiteam system member who was not a follower. Analyses of the individual networks show that the direction of this relationship remained negative in 5 systems and was not observed at all in 2 systems. Unfortunately, this does not provide enough evidence to conclude support for Hypothesis 1 and reciprocity was not a consistent predictor of leadership emergence.

Hypothesis 2 posited that leadership formation would be transitive, such that if Member A relied on Member B for leadership and Member B relied on Member C for leadership, then Member A would be likely to rely on Member C for leadership as well. In Table 4, the results of the megamatrix analysis suggest that people were, in fact, more likely to form transitive triads when relying on individuals for leadership (*estimate* = 1.03, $p < .001$). However, this finding did not hold when looking at the effect of transitivity in each MTS individually. Despite the significant estimates both being positive, 4 of the networks produced negative estimates for transitivity. As such, transitivity—although positive when observed—was not a consistent predictor of leadership emergence; there was no support for Hypothesis 2.

Hypothesis 3 posited that an individual would be more likely to be relied upon for leadership once someone else relied on *them* for leadership (i.e., individuals would exercise preferential attachment when relying on others for leadership). However, I could not test Hypothesis 3 due to multicollinearity with informal/expertise-based leadership and formal leadership. Table 6 displays correlations among these three variables for the full megamatrix, as well as the individual matrices. Given the strength of the correlations between popularity and informal and formal leadership, I did not include popularity in the model for testing.

Moving to the effects of social differentiators, Hypothesis 4 posited that individuals would be more likely to form leadership ties with teammates, compared to members of other teams in the MTS. Results in Table 4 confirm this, with a positive and significant parameter estimate for the team membership term in the composite ERGM (*estimate* = 1.60, $p < .001$). Additionally, this relationship tended to hold for individual multiteam systems. Estimates for team membership were positive in all 10 systems and significant in 7, as well as marginally significant in an additional multiteam system. These findings suggest that the effect of team membership on leadership tie formation is typically positive in multiteam systems. Individuals were indeed more likely to rely on their teammates for leadership, as opposed to relying on members of other disciplinary teams in the multiteam system, supporting Hypothesis 4.

Hypothesis 5 posited that individuals would be more likely to form leadership ties with those who were more physically proximal to them. Examining Table 4, we see that individuals were more likely to rely on more proximal MTS members for leadership (*estimate* = 1.52, $p < .001$) when analyzing the megamatrix of multiteam systems. Looking at the individual networks, we also see that this effect was often positive (positive in 9 out of the 10 systems) and significant (significant in half of the systems). Collectively, these findings provide moderate support for the effect of proximity on MTS leadership tie formation, whereby two individuals who were more proximal to one another were more likely to form a leader-follower tie than were two individuals located at a greater distance from one another. Hypothesis 5 was thus partially supported.

Finally, I hypothesized that shared cognition would positively impact the formation of leadership ties in multiteam systems. In particular, Hypothesis 6a posited that individuals would be more likely to form leadership ties with teammates with whom they had greater task mental model similarity. Table 4 indicates that cognitive similarity on task-related elements positively predicted the formation of leadership ties when the networks were analyzed simultaneously (*estimate* = .45, $p = .05$). However, results for cognitive task similarity were mixed in the analyses of individual networks. Of the 10 systems, half produced a positive estimate, consistent with the composite estimate, but the other half produced a negative estimate; of the significant estimates, one was positive, one was marginally positive, and one was negative. As such, cognitive task similarity was not a consistent predictor of leadership emergence. Regarding the effect of cognitive team similarity, Hypothesis 6b posited that individuals would be more likely to form leadership ties with teammates with whom they had greater team mental model similarity. I found a positive and significant estimate (*estimate* = .66, $p < .01$), but there were no significant estimates for the individual networks, and the direction of the likelihood of tie formation varied as well. Therefore, cognitive team similarity was also not a consistent predictor of leadership emergence. Hypotheses 6a and 6b were not supported.

In sum, it appears that social differentiators had the most substantial impact on leadership tie formation in multiteam systems. Team membership and propinquity displayed the strongest parameter estimates in both the composite and individual networks, which were collectively positive. MTS members were likely to be more insular in leadership relationships, looking to those on their team, as well as those physically close to them. Social norms and cognitive factors, on the other hand, either varied in terms of direction or showed statistically weak results when predicting the likelihood of tie formation for leadership in multiteam systems. As such, I could not conclude their effects on MTS leadership tie formation.

Discussion

The changing circumstances around collaboration have forced researchers to reexamine our understanding of teams and leadership, moving towards a more complex and dynamic perspective to include multiteam system work. Additionally, the lens through which we previously viewed leadership has shifted from person-centric to exploring relational leadership-followership dynamics (Avolio et al., 2009). As a result, I have extended research on leadership emergence to understand the factors that affect leadership emergence in the multiteam system setting. In particular, I asked how leadership emerges in multiteam systems and specifically, which social forces explain leadership emergence? Building on the literature by using a social network analysis approach (Carter et al., 2015; Park et al., 2020), I examined the impact of three types of social forces on the formation of leadership ties in multiteam systems: social norms, social differentiators, and shared cognition. I analyzed the effects of these social forces using ERGM, both in a composite megamatrix of all 10 multiteam systems of 12 members each, as well as within the multiteam systems as individual networks in their own right.

The first social force examined was social norms, including reciprocity, transitivity, and popularity. Although the composite ERGM supported prior research with the finding that leadership was not reciprocal (Emery et al., 2011), analysis of the individual networks did not provide enough evidence in support of this hypothesis. Findings showed similar patterns for transitivity. Despite the significant and positive parameter estimate from the composite megamatrix analysis, transitivity was only significant in two of the individual multiteam system networks. Finally, I investigated the effect of popularity; however, due to its multicollinearity with the two control variables (formal and informal leadership), I was not able to examine this effect using ERGM.

Whereas the effects of reciprocity tended to follow the direction of the hypothesis and the estimate in the composite ERGM, the effects of transitivity were notably mixed. There were four multiteam systems where it was less likely for Member A to follow Member C, given that Member A followed Member B and Member B followed Member C. Taking a closer look at these four systems, we can see that they occurred across three of the four crews (there were negative effects in Crew 1, Crew 3, and Crew 4. However, if we look *within* each crew, we see that the likelihood of transitive leadership ties tended to increase over time. The estimate of transitivity in Crew 1 moved from -.08 to -.50 to .11, the estimate of transitivity in Crew 2 moved from .24 to .53 to .72, the estimate of transitivity in Crew 3 moved from -.13 to .59, and the estimate of transitivity in Crew 4 moved from -.27 to .69. Inherent in the concept of leadership emergence is that these relationships form over time. Additionally, the structural balance hypothesis suggests that social networks balance over time (Cartwright & Harary, 1965; Doreian & Krackhardt, 2001). Therefore, it may be the case that transitive leadership triads may require time beyond a 60-minute task to develop, and this may account for the relatively mixed effects we see across the individual MTS networks, which is a bit more organized when examined within each crew over time.

The second category of social forces I examined was social differentiators. In particular, I analyzed the effects of functional team membership and propinquity, both of which are sources of social identification in teams (Festinger et al., 1950; Tajfel et al., 1971). Extending this work to leadership, I found that both team membership and propinquity served as critical factors in determining who relied on whom for leadership. Results indicated that functional membership and propinquity were both important; however, team membership had a stronger effect on the formation of leadership ties than did propinquity. Thus, although MTS members may look to those who are more proximate to them for leadership, they are *more* likely to look to those who are on their team. This finding is particularly important for multiteam systems that may have teams or even team members who are geographically and/or temporally dispersed, making MTS work even more insular, which runs counter to the incremental benefits multiteam systems have over teams (Zaccaro et al., 2001).

Although social differentiators showed the most substantial effects on the likelihood of MTS leadership tie formation, there were some instances where social differentiators either were not significant or ran in the opposite direction of the hypothesis. In particular, MTS 4 exhibited a positive but non-significant effect of team membership on leadership tie formation, as well as a negative effect for propinquity. MTS 4 was also one of the systems where there was no leadership reciprocity observed at all. Additionally, there was one system where team membership produced a positive but non-significant estimate, which was also in Crew 2 (i.e., MTS 6). Of the four crews who participated in Project RED, Crew 2 was the only all-male crew. Prior work on gender and informal leadership emergence has found that certain personality characteristics (i.e., high conscientiousness and emotional stability) as well as team member network centrality (Neubert & Taggar, 2004) predicted leadership emergence for males. Indeed, examining Table 4, we see that the effect of formal leadership was positive and significant in MTS 4, and in Table 5 we see a high correlation between formal leadership and popularity ($r = .99$, $p < .001$) in this system. Thus, the gender of the crew may have confounded the effect of team membership on leadership emergence for this all-male crew.

Additionally, the context of the multiteam system may be important to consider when interpreting the results for social differentiators, as some members were able to communicate more easily and likely frequently with one another than others. For example, mission control members were situated such that functional teams worked out of separate rooms, and the crew worked out of the habitat. This meant that functional team members on mission control were able to communicate verbally and in real-time within the team. Frequent communication may thus have been interpreted by participants as leadership reliance, which could also explain the strong findings for team membership. These members were also more proximal to one another than were other members of the system, who were located in other rooms at mission control or in other buildings entirely, in the case of the crew. Interestingly, the crew also worked in the same room with one another, despite being members of different functional teams, and in this way, they were able to communicate verbally and in real-time with each other. The ease and likely increased frequency of communication within the crew may shed light on the consistently positive results for propinquity's effect on the formation of leadership relationships. Again, frequent communication may have been interpreted as leadership reliance. The link between communication and leadership is supported in prior research, which found that communication styles were related to knowledge sharing behaviors and perceived leader performance (de Vries, Bakker-Pieper, & Oostenveld, 2010) and communication frequency positively moderated the relationship between a leader and follower (Gajendran & Joshi, 2012). Future research would benefit from controlling for the effect of communication when exploring the formation of leadership relationships in multiteam systems.

The third social force I examined was shared cognition. Results from the analysis of the composite ERGM suggested that both task and team mental models increased the likelihood that a leadership tie would form between two people. However, the analysis of individual networks indicated that these relationships might be idiosyncratic to each multiteam system. Given that both task and team mental model parameter estimates were so widely mixed, and thus mental models were not a consistent predictor of leadership emergence in multiteam systems, I took a closer look for potential trends and explanations for this set of findings.

Starting with the effect of task mental models, these findings may have been crew-dependent. Positive estimates occurred in all three sessions for Crew 1 and two of the three sessions for Crew 2; negative estimates occurred in the last session for Crew 2, and in both sessions for Crews 3 and 4, each. Interestingly, Crews 3 and 4 were the mixed-gender crews (in comparison to Crews 1 and 2, which were homogeneous in terms of gender). Here, team demographic diversity may account for the mixed effects seen across individual multiteam systems when considering the effect of task mental models and their ability to predict the formation of MTS leadership ties. Although gender is typically not related to or predictive of the formation of shared mental models (Fisher, Bell, Dierdorff, & Belohlav, 2012; Marks, Zaccaro, & Mathieu, 2001; Webber, Chen, Payne, Marsh, & Zaccaro, 2000), gender does affect leadership emergence. It may be the case that here, gender moderated the likelihood of leadership tie formation, such that members of multiteam systems with same-gender crews were more likely to develop leadership ties with those with whom they shared task mental models with. Conversely, members of multiteam systems with mixed-gender crews were less likely to develop leadership ties with those with whom they shared task mental models. However, future research is required to tease apart and test this relationship more explicitly.

Moving to team mental models, there were fewer potential indicators to suggest why parameter estimates varied so widely across different multiteam systems. Estimates did not consistently trend upward or downward within or across crews. Additionally, other team constructs such as identity and viability, or outcomes such as performance, did not vary meaningfully across crews with positive vs. negative team mental model estimates. It may be the case that although vital for teamwork, team mental models are not as relevant to the MTS as the task (and the mental model concerning the task), and as such, are not as influential when members are seeking leadership in the name of collaboration. This may account for the lack of effects seen across all multiteam systems for team mental models, particularly when compared to the effect seen across all multiteam systems for task mental models.

Overall, the analysis of the composite versus the individual matrices begs the question: Are leadership networks universal or idiosyncratic to a particular team or MTS? Given that nearly all of the antecedents were supported in the composite ERGM, but almost none exhibited uniformity when looking at individual MTS networks, this study leans more toward the conclusion that leadership networks are idiosyncratic. Some leadership signatures were consistently observed across multiteam systems, and hence seem to be more universal—these include edges, team membership, and propinquity. Across MTSs, leadership ties were unlikely (edges), they were more likely to form among members of the same functional team (team membership), and among those who were geographically proximate (propinquity). In contrast, the degree to which social norms (reciprocity and transitivity) as well as social cognition predicted leadership emergence was more idiosyncratic. Collectively, these findings lend further support to the notion that context is a critical component of understanding multiteam systems (Mathieu et al., 2017; Mathieu et al., 2001; Shuffler et al., 2015).

A related question concerns the choice of analytic approach to use - testing individual networks or testing a hypothesis across a sample of networks. One consideration is the nature of the hypothesis being tested and the orientation toward understanding either an overall tendency that is expected to be similar across networks, or an orientation toward identifying variation in tendencies across networks. The latter approach, focusing on variance, allows the researcher to then associate differences in network tendencies with other outcomes. In this case, examples would be between-team process or multiteam performance. Even if one's interest is in universals, rather than variance across networks, it is nonetheless important to examine the degree to which the networks are homogenous. This is a requirement for interpreting the mega-matrix ERGM which inherently assumes homogeneity. When examining universal hypotheses, researchers should report *both* sets of findings (i.e., composite and individual ERGMs) as they collectively demonstrate the power of context in the MTS setting. In this way, the present study thus makes a unique contribution to the MTS literature by providing quantitative evidence for the uniqueness of multiteam systems—not only in terms of the overall space context, but by the context created by the different compositions of individuals forming each unique multiteam system.

Contributions

Collectively, these findings provide insight regarding how and why leadership relations form in complex multiteam systems, making several contributions to the science and practice of multiteam systems. First, this study advances the literature on teams and multiteam systems by using social network analysis to understand how leadership emerges in the course of collaboration (Park et al., 2020). Social networks have been identified as a key next step in the analysis of teams and multiteam systems, given their ability to model a series of complex and dynamic relationships (Carter et al., 2015; Park et al., 2020). Here, social networks provided more accurate patterns of formal and informal leadership (Crawford & LePine, 2013), as well as the ability to simultaneously model both intra- and inter-group relationships (Wölfer et al., 2015).

A second contribution made by this study is the inclusion of MTS social context in the study design. Multiteam systems are applied phenomena, strongly driven by their surrounding environment (Mathieu et al., 2001). Yet the vast majority of research in this area is conducted in the laboratory, which inherently ignores the multiteam system environment. Several reviews of the literature on multiteam systems have recognized this trend and called for more work that accounts for the environment (Mathieu et al., 2017; Shuffler et al., 2015). The current study answers these calls by employing a quasi-experimental design where four members of the multiteam system operated under high-fidelity circumstances, including isolation, confinement, and communication delay.

In addition to these contributions to science, findings from this study also provide contributions to the practice of multiteam systems. Results indicated that social forces were indeed influential in the formation of leadership ties, as each of the focal variables was an indicator of the likelihood of leadership ties forming across the composite and individual networks. However, the most influential social forces were social differentiators. I found that members demonstrated particularly insular tendencies when identifying leadership in the multiteam system, looking most to those on their team and those physically close to them. Although beneficial to team processes and outcomes, this tendency will likely inhibit the broader MTS. As such, multiteam systems should account for this natural proclivity and work to ensure that cross-team relationships form.

Additionally, these findings shed light on the complexities of MTS leadership relationships, which may be useful in an applied setting. Results indicated which antecedent conditions were more influential in predicting leadership across *all* multiteam systems, versus those that were more idiosyncratic to a few specific MTS experiences. Whereas social differentiators affected the majority of multiteam systems, other antecedents, such as transitivity and shared cognition, were more dependent on the specific conditions of a given multiteam system. Future research would benefit from a stronger understanding of how these antecedents play out in different multiteam systems.

Limitations and Directions for Future Research

While the results of this study help to uncover the antecedent social forces that lead to the formation of leadership relations in multiteam systems, there are several limitations to note. First, while some participants were potential astronaut candidates, the majority of participants were students enrolled in scientific courses. Thus, while they are likely comparable to the target population—albeit younger—there may be key differences in the current sample and the populations found in professional settings. For example, scientists build off of one another's work, and as such, poor work may be detrimental to the field. However, the work that students produced did not influence the work of others; instead, it remained contained in the group. Another limitation was that HERA crew members engaged in the task three separate times, whereas the mission control members were new to the task each time. Therefore, HERA crew members may have had an additional level of knowledge and/or comfort with the task and the members' roles, enabling them to assert leadership easier than those who were engaging with the task for the very first time.

Third, there were limitations to the analytic approach used to explore the antecedent conditions of MTS leadership relationships. I analyzed both the composite network and the individual networks (cf. An, 2016), which ultimately provided two sets of findings. Although the composite ERGM has greater statistical power, and is beneficial in understanding the trends across many multiteam systems at once, it misses different effects present in individual multiteam systems. This would have been a critical oversight in understanding how the different social forces operate in the emergence of MTS leadership relationships. To account for this, I also analyzed each multiteam system as a network. However, each multiteam system included only 12 people, which is quite small for this type of network analysis, and likely caused complications—for example, there were no reciprocal leadership ties in two of the multiteam systems. Both approaches thus had their merits, but neither was solely qualified to most accurately capture the patterns influencing leadership relationships in multiteam systems.

Lastly, the analysis was nested, such that I conducted comparisons of the exponential random graph model on each individual network. Given this comparison, I maintained the term for each variable (i.e., "mutual" to test reciprocity, "dgwesp" to test transitivity, and so on) despite the lack of fit for the "mutual" term in multiteam systems 4 and 6. In a non-nested design, I would instead model the idiosyncrasies of the networks to find a better fit for the reciprocal term. Finally, although formal and informal leadership were based on separate aspects of the task and MTS structure, there was one member represented in both leadership categories. The habcom role (formal leadership) was also a member of the Geology team (informal leadership). As such, the effect of formal and informal/expertise-based leadership should be interpreted with caution.

In the subsequent studies of this dissertation, I aim to address several of these concerns. In particular, it would be beneficial to understand how social forces impact the formation of leadership ties in more traditional teams, such as project management teams or research and development teams. Future research should aim to address the issue of changing team members and understanding how leadership ties form for members "on the same playing field," so to speak, is a good start. In Chapter 3, I detail my efforts to address these limitations with the development and test of the Project RED tabletop intervention in a classroom setting where members remain consistent throughout the task. Additionally, as it would be impactful for future research to conduct such studies in the appropriate field (i.e., investigating how leadership ties form in real astronaut crews on space missions), I study archival interviews from a range of participants embedded in some of the most cutting-edge space multiteam systems currently operating.

Conclusion

The results of this study indicate that social forces—social norms, social differentiators, and shared cognition—impact the formation of leadership ties in multiteam systems. Team membership and proximity exhibited the strongest signal and are in support of leadership tie formation. However, the effects of reciprocity, transitivity, preferential attachment, and shared cognition were mixed when examining the effects across each multiteam system network. This study aligns with the shift to a more dynamic view on collaboration and leadership and opens the door for work in this area to take a dynamic and more in-depth approach.

CHAPTER 3

DEVELOPING LEADERSHIP CAPACITY IN MULTITEAM SYSTEMS

Multiteam systems are changing the way people collaborate, bridging teams together to tackle previously insurmountable issues. The science of multiteam systems has significantly matured over the last two decades and uncovered the inputs and processes that make multiteam systems so effective in achieving their outcomes (Luciano et al., 2018; Shuffler et al., 2015; Zaccaro et al., 2012). However, MTSs operate under challenging circumstances and tend to be quite complicated in their practical applications (Mathieu et al., 2001). Therefore, although the literature suggests leadership as a mechanism to address the challenges of MTS work and bolster team and system performance (Davison et al., 2012; DeChurch & Zaccaro, 2010; Mathieu et al., 2007; Marks et al., 2005), this set of findings may be limited to the lab context.

Similarly, findings on multiteam system leadership are also bound. We know little beyond the notion that leadership tends to be well-positioned (i.e., in the space between teams) and thus serves to integrate ideas and connect members toward the achievement of superordinate goals (Mathieu et al., 2001). We lack a hands-on understanding of the critical skills that leaders (or any other members, informally speaking) can leverage to strengthen inter-group relationships and thus address the challenges of multiteam system work. With this in mind, and in line with recent calls by several researchers for a more applied examination of MTSs (Mathieu et al., 2017; Shuffler et al., 2015), my colleague and I developed an experiential training activity to foster leadership skills aimed at developing effective inter-group relationships in the multiteam system context (DeChurch & Niler, 2019). Specifically, this intervention targets skills that help address the three most pressing challenges in multiteam system work: coordination, goal hierarchy, and inter-team dynamics; I outline these mechanisms and their accompanying behaviors in the following section.

Developing Leadership Capacity to Address Multiteam System Challenges

As seen in Table 1, there are three main challenges of working in a multiteam system. The first is coordination. Multiteam systems require input, process, and output interdependence amongst component teams (Mathieu et al., 2001), and this creates friction in the form of behaviors, as members attempt to reconcile differences between teams in the course of accomplishing tasks. The second is goal hierarchy, which often challenges MTS members cognitively, necessitating that they understand not only how their team fits into the larger system, but also how to work together with (and sometimes despite) other teams to accomplish the superordinate goal(s). Sometimes the component team goal is clearly and directly linked to the MTS goal, while other times, the processes and outcomes of the component team may not be readily apparent in contributing to the system goal. Finally, inter-team dynamics offer an affective challenge in multiteam system work as members collaborate across the component team boundaries to reach their goals, meaning they must navigate the countervailing forces that emerge as a result of inter-team social processes.

Additionally, findings from Study 1 lend support to the notion that multiteam system work is challenging in these three ways. Findings from ERGM analyses identified that social differentiators are the strongest indicator of the formation of leadership relationships in multiteam systems, and more specifically, MTS members tend to be insular; that is, they were most likely look to those on their team and those most proximal to them for leadership. Other factors, like social norms (i.e., reciprocity, transitivity, and popularity), as well as shared mental models, did not seem to affect the likelihood that leadership relationships would emerge in the MTS setting. These findings, in conjunction with prior work looking at the effects of coordination, goal interdependence, and inter-team dynamics, indicate that leadership may be particularly useful in countering these challenges by focusing on boundary spanning behavior.

In multiteam systems, *boundary spanning* is when members cross team boundaries to work in concert with members of other teams in the MTS towards the superordinate goal (Davison & Hollenbeck, 2012), and both team (Ancona, 1990; Ancona & Caldwell, 1992) and multiteam system research (Bienefield & Grote, 2014; Davison et al., 2012; Marks et al., 2005) support this skill in its ability to drive performance. However, practically speaking, boundary spanning is a difficult and fragile process. There are many considerations enmeshed in this act (i.e., type of boundary spanned, purpose served by boundary spanning, degree of interdependence between the teams in questions, and the degree to which boundary spanning is an acceptable action; Davison & Hollenbeck, 2012), and furthermore, between-team interactions occur on the faultlines of the multiteam system. Faultlines exist where there are apparent differences between group members (e.g., race, gender, age) that would lead to the creation of subgroups (Lau & Murnighan, 1998) and in multiteam systems, these differences are rooted in component team membership. As a result, faultlines may form and become a problem when team goals, processes, etc. are incompatible with one another (DeChurch & Mathieu, 2009)—circumstances that are not uncommon in this setting (Luciano et al., 2018). Considering both the criticality and complexity of boundary spanning in multiteam systems, I outline three specific types of boundary spanning behaviors that members can use to promote effective multiteam relationships, and ultimately, address the three main challenges of MTS work. Table 7 summarizes these challenges and their respective behaviors.

First, members can attend to coordination in their boundary spanning efforts. In order to attenuate the challenge of coordination, members can both seek and provide information (Luciano et al., 2018; Mathieu et al., 2001; Shuffler et al., 2015). For example, members may reach out to other teams to provide a status update, outlining their team's progress on the team and superordinate goals and answering any questions this update conjures for other teams, and explain potential task constraints, as well as solicit input from other teams. Moreover, by leading with these types of behaviors, members may encourage one another to feel safe in proactively seeking and sharing information across team boundaries. This process of information sharing will likely serve to increase transparency and ease between-team tensions related to the task. Indeed, prior research on information sharing and psychological safety in teams has suggested that the two are strongly and positively correlated with one another (Bunderson & Boumgarden, 2010), and that psychological safety creates a sense of trust and certainty by providing a scaffolding of coordination procedures (Perrow, 1986). Although collaboration across team boundaries is difficult, input, process, and output interdependence are ultimately *required* to achieve the superordinate goal (Luciano et al., 2018; Mathieu et al., 2001). Therefore, members who engage in boundary spanning aimed at coordinating task behaviors may facilitate the inevitable interactions needed for success in an effective manner.

Hypothesis 1: Individuals will exhibit increased awareness of coordination needs in multiteam systems after completing the training intervention, as compared to before the intervention.

The next area members can focus on concerning boundary spanning is the cognitive challenge of goal hierarchy and the interdependent nature of inter-team goals. To combat this obstacle, members can promote effective multiteam system relationships by creating and fostering shared conditions across the system. This sense of sharedness may come in the form of setting and focusing on the shared superordinate goal (Kanfer & Kerry, 2012; Luciano et al., 2018), or in the form of creating a shared understanding of both task and social processes across the system (Murase, Carter, DeChurch, & Marks, 2014; Rentsch & Staniewicz, 2012). Additionally, in their review of the literature surrounding multiteam systems, Luciano and her colleagues (2018) noted that feedback is an integral part of mitigating the challenges that arise from discoradancy within the goal hierarchy. Overall, boundary spanners working against the challenge of interdependent inter-team goals can use or even generate similarities across the system to unite MTS members, rather than give in to the differences that may exist between the teams.

Hypothesis 2: Individuals will exhibit a more accurate understanding of inter-team goal interdependence after completing the training intervention, as compared to before the intervention.

Finally, the third potential focus of boundary spanning relates to the multiteam system challenge of inter-team dynamics. To overcome this hindrance in multiteamwork, members can engage in boundary spanning behaviors, such as cooperation, by promoting inter-group social processes—identity in particular. Much of the multiteam system research on inter-team dynamics has focused on the impact of identity, a countervailing force, on the system, and findings suggest that higher-level identities promote positive inter-team dynamics (Connaughton, Williams, &

Shuffler, 2012; Hogg et al., 2012; Mell et al., 2018; Shuffler et al., 2015). For example, cooperative conflict management styles correlate with higher levels of team identity (Somech, Desivilya, & Lidogoster, 2009). It follows then that higher levels of MTS identity may help de-escalate the potentially tricky social inter-team interactions demanded in the MTS context. Importantly, researchers suggest that identity can be built through more contact, and so members who boundary span to promote cooperation between teams may simply just spend time working with each of the other teams in the system.

Hypothesis 3: Individuals will exhibit a stronger appreciation for cooperation across teams in the multiteam system after completing the training intervention, as compared to before the intervention.

Methodology

Sample and Setting

I tested a training intervention and its ability to develop the requisite skills of effective leadership processes in multiteam systems in a classroom setting (cf. Waller et al., 2014). Northwestern's School of Communication offers a class on collaborative leadership, where students engage in various activities designed to educate them on the most critical aspects of teamwork and leadership. Thus, Study 2 employed a two-group pre-test/post-test design. Students first participated in a cross-functional team activity serving as the control (called Towers Market; Beggs, Brett, & Weingart, 2000), and five weeks later, they engaged in the cross-functional multiteam system intervention (Project Red planet Exploration and Development, or Project RED, tabletop; DeChurch & Niler, 2019; see Appendix B).

Tasks and Procedures

One of the most utilized methods for evaluating training programs is Kirkpatrick's (1959; 1976) four-dimensional measurement typology. According to Kirkpatrick, a training program is successful to the extent that participants feel the training was valuable (reaction), it develops participants' skills (learning) and changes their behaviors (behavior), and demonstrates a return on the investment (results). Importantly, "learning is measured during training and refers to attitudinal, cognitive, and behavioral learning. Behavior refers to on-the-job performance and, thus, is measured after training" (Alvarez, Salas, & Garofano, 2004, p. 388). Therefore, evaluation of the multiteam task occurred in two stages. The first stage was a control task, and the second stage was the intervention task. To ensure that students were learning, they were surveyed before and after both the control and intervention activities. Additionally, a reflection followed each task to capture participants' reactions and behavior. Next, I outline each of the tasks in greater detail and then discuss the measures used for learning, reaction, and behavior assessment. Figure 5 presents an overview of the final tasks and measures at each time point in the study.

Towers Market control task. Before the task began, students reported their perceptions of coordination, goal interdependence, and intra-team dynamics. After the survey was complete, they began the Towers Market activity (Beggs et al., 2000). Towers Market is a cross-functional team task where students work in teams of four as they enter into a new joint business venture. Each student assumes the role of owning a small business—Parducci's Grocery, Donovan's Liquors, Jacqui's Bakery, or Jardin Florist—and works with the other "vendors" to find the best arrangement on a set of parameters, from advertising to clerks and maintenance to the position of departments. Once the task was complete, students took the post-task survey, reporting their perceptions of coordination, goal interdependence, intra-team dynamics, and leadership relationships as they pertained to their experiences in the Towers Market activity. Participants also reported individual differences at this point. Students then completed a short reflection. The first question in the reflection asked them what they learned about leadership after managing the team in the Towers Market activity, and the second question prompted them to report behaviors that either helped or hindered coordination, navigation of the goal hierarchy, and management of intra-team dynamics in the course of the task. This activity was an ideal control task to accompany the Project RED tabletop intervention because it is similarly structured (i.e., multi-party and cross-functional with an objectively correct answer) but focused at the team level. As such, comparisons between the two should allow me to parse out the degree to which the training intervention, which requires collaboration both within a team *and* between two teams, impacts the targeted multiteam system leadership behaviors.

Project RED tabletop intervention: Pilot. Project RED tabletop was piloted in an undergraduate course on collaborative leadership offered in Northwestern's School of Communication in Spring 2019. The task requires four disciplinary teams—Planetary Geology, Extraterrestrial Engineering, Space Robotics, and Space Human Factors—to work together to achieve the multiteam system goal of building a well that could sustain human life on Mars. In this task, participants receive four possible locations where the well could be built and choose the best location. A successful well is located in a place where it produces the highest, cleanest water output to the most people at the lowest cost. Participants progressed through individual and team phases before meeting with the multiteam system to discuss the best location to build the well. More information on the original Project RED tabletop task is in Appendix E.

Table 8 displays the results from the pilot session of the control and intervention tasks. There was a significant increase in coordination after the control task compared to before the control task [$t(80.82) = -2.77$, $p < .01$], as well as a significant *decrease* in goal hierarchy after the control task as compared to before the control task [$t(70.33) = 2.15$, $p < .05$], but there were no significant differences in intra-team dynamics. Additionally, there were no significant differences in any of the focal variables after the intervention as compared to before the intervention.

The pilot results suggested that the original Project RED tabletop task was not well-structured, and I took a critical second look at its component parts. One issue with the original task was the relatively broad nature of the background information participants received. For example, the biochemical engineer was told the following about a key variable for the role, water efficiency: “You want a filtration system that is efficient in this process of removing contaminants from the water.” To balance the broad nature of the information provided, participants received a point system to guide their choices. However, the point system also proved to be problematic, as participants found it to be confusing and likely distracted them from engaging in the necessary behaviors of coordination, navigation of the goal hierarchy, and management of inter-team dynamics. Given this, I sought to redesign the Project RED tabletop task to heighten the need for coordination, reinforce goal interdependence, and create a better environment to foster inter-team dynamics.

Project RED tabletop intervention task: Validation. The resulting task (described below; DeChurch & Niler, 2019) used more specific details about each location to help encourage coordination through discussions, with deliberately-placed pieces of information within and between teams to make the goal hierarchy very clear, and a richer background story to get participants more invested and thus increase the likelihood for inter-team dynamics. We began to redesign the task by generating a map of potential locations and team preferences. The teams would consider 4 candidate locations: Location A would be the best for Team 1 but the worst for Team 2, Location B would be the best for Team 2 but the worst for Team 1, Location C would be a compromise that worked for both teams but was not the best for the MTS, and Location D would be the best for the MTS. Table 9 displays how each piece of information was distributed throughout the multiteam system to create these preferences.

After mapping out preferences, we crafted the backstory using key information from NASA's latest reference for a Mars mission, Design Reference Architecture 5.0 (Drake, 2009; Drake & Watts, 2014). In reading about missions to Mars, it became apparent that matters of habitation and scientific development are important goals for the actual upcoming mission. Therefore, we used these elements to create a high-fidelity scenario for 2 teams of 3 members each: the Human Habitation team, with an atmospheric specialist, water specialist, and terrain specialist; and the Scientific Discovery team, with a life scientist, climate scientist, and geology scientist. Together, their MTS goal would be to find the best site to land and establish the home base for a crew to live and conduct scientific work on Mars.

We then used the titles of these roles to generate facts for each member's information packet. All facts and the configuration of this information across the multiteam system were validated using TurkPrime participants, and a summary of the validation sessions is in Table 10. First, we generated and validated individual facts on two parameters: (1) correctly identified as pertaining to either Human Habitation or Scientific Discovery, and (2) correctly identified as supporting or undermining landing in a given location. To avoid survey fatigue in validating the 107 total facts, we split the facts up across four surveys, and each survey was taken by 40 individuals. A fact was considered validated if more than 60% of the respondents correctly identified the team affiliation and valence of the fact. There were a handful of facts (8) that required editing to strengthen either the team affiliation or valence, which were validated in a set of 38 individuals with the same cutoff criterion for validation (i.e., greater than 60%).

After validating each fact, we disseminated the information across each role's set of background profiles and validated them on several levels. The first level was the team profiles. For this, we gave participants the full set of information for a given team and considered the profile to be validated if the person correctly identified the best location for that team. The Human Habitation profile was tweaked after the initial validation (N = 39 individuals) to account for a redistribution of a few key pieces of information, and validated again (N = 39 individuals) with 95% correctly identified the best option, 88% correctly identified the worst two options, and 38% correctly identified the worst option.

Next, we validated each set of role information. Roles were validated if the person chose the best location for a given role if provided only the information for that specific role. Each profile was validated by between 38 and 40 individuals, and required that approximately 60% of respondents correctly identified the best option and 60% correctly identified the worst option. In cases where identification of the worst option was a bit low (i.e., Water Specialist and Geology

Scientist), identification of the best option was relatively high and as such, these profiles were accepted. Additionally, the Climate Scientist role came in just under the 60% threshold at 59% correctly identifying the best option and 59% correctly identifying the worst option, and was also accepted.

Finally, we validated the entire MTS profile, meaning: If an individual was given all of the information for Human Habitation *and* Scientific Discovery, would this person correctly identify the best landing site? We surveyed 124 individuals and found that 62% correctly identified the best option and 62% correctly identified the worst two options when provided the full profile of information for all MTS members. After the team, role, and full MTS profiles were fully validated, the task was ready to be used for data collection in the Fall 2019 Master of Science in Communication course on collaborative leadership.

Project RED tabletop intervention task. Before beginning the intervention task, students reported their perceptions of coordination, goal interdependence, and inter-team dynamics. Next, students began the Project RED tabletop intervention. Project RED tabletop (detailed in Appendix B) requires two disciplinary teams, Human Habitation and Scientific Discovery, to work together towards the multiteam system goal of choosing the best location to land on Mars and establish the home base for a human crew. Participants receive information about four possible locations, which is specific to their functional role in the task. The task requires an atmospheric specialist, water specialist, and terrain specialist on the Human Habitation team and a life scientist, climate scientist, and geology scientist on the Scientific Discovery team. Of the four locations, Argyre is the best for Human Habitation but the worst for Scientific Discovery, Casius is the best for Scientific Discovery but the worst for Human

Habitation, Eridania is a compromise between the two teams but not the best location for the MTS, and Diacria is the best location for the MTS. This task is structured such that each individual has unique information, meaning it is essential for members to coordinate both within *and* across teams to find the best landing site.

Project RED tabletop began with an individual phase, where participants received an informational packet outlining the task and their specific role. Once familiar with their role, team, the multiteam system, and the task, they decided where to land as an individual. Next, they met and discussed their information as a team. After making a team decision about where to land, they moved to the final stage where they met and discussed which site would be best for landing as a multiteam system. To conclude the task, members made a final choice of where to land and the debrief was administered. Once the task was complete, students took the post-task survey, where they reported their experiences of coordination, goal interdependence, inter-team dynamics, and leadership relationships as they pertained to their experiences in the intervention. Students also wrote a reflection detailing what they learned from leading the team(s) in the Project RED tabletop activity, as well as highlighting behaviors that either helped or hindered coordination, navigation of the goal hierarchy, and management of inter-team dynamics.

Measures

Coordination. Coordination was measured using an adapted version of Fisher, Bell, Dierdorff, and Belohlav's (2012) coordination scale and respondents reported their perceptions of coordination on a scale of 1 "strongly disagree" to 7 "strongly agree." An example item reads: "It is important for functional team members to provide one another with task-related information without being asked," and a full version of the scale can be found in Appendices C and D (for the control and intervention activities, respectively). I measured coordination behaviors via written assignments administered at the end of each activity, and counted the number of times participants referenced coordination behaviors.

Goal interdependence. Goal interdependence was measured using an adapted scale from previous research on perceptions of goal interdependence in groups (Tjosvold, 1984; van der Vegt & Janssen, 2003). Respondents reported their perceptions of goal interdependence on a scale of 1 "strongly disagree" to 7 "strongly agree" and an example item reads: "If my functional team members attain their goals, it facilitates my goal attainment." A full version of this scale is presented in Appendices C and D. I coded participants' written assignments at the end of the control and intervention tasks for references to inter-team goal interdependence behaviors.

Cooperation. Cooperation was measured using an adaptation of Chatman and Flynn's (2001) measure. Respondents rated items on a scale of 1 "strongly disagree" to 7 "strongly agree" and an example item includes: "Functional team members generally cooperate with one another." The full cooperation scales are presented in Appendices C and D. Additionally, I coded participants' written assignments after each task for instances of cooperative behaviors.

Leadership relationships. Leadership was measured by asking participants to identify "Who did you rely on for leadership?" in a sociometric survey administered after the control and intervention activities. Participants used a roster listing the 3 other team members' roles after the control task and a roster listing the 5 other multiteam system members' roles after the intervention task to identify leadership. This round-robin method (Carson et al., 2007; Kenny & La Voie, 1984) is intended to capture directed leadership ties among the team and multiteam system members.

Controls. Research on leadership emergence suggests several consistent indicators that predict who will naturally emerge as a leader (e.g., intelligence, self-efficacy, self-monitoring; Foti & Hauenstein, 2007; Taggar et al., 1999) and as such, I wanted to control for these factors in assessing the validity of this intervention. The factor is general intelligence. I used a brief problem-solving task to measure this because, as Duncan and colleagues (2000) note, problem-solving is one of the tasks most correlated with general intelligence. Participants solved a survival task where they were stranded in a remote area (here, the moon) and provided a list of items to rank in importance to their survival. Their scores were then computed against experts' rankings of this survival scenario.

Additionally, I used the Core Self-Evaluation Scale to measure the other individual differences that may lead to inherent leadership emergence, including self-esteem, generalized self-efficacy, neuroticism, and locus of control (Judge, Erez, Bono, & Thoresen, 2003). Students indicated the degree to which they felt each item reflected them, responding on a scale of 1 "strongly disagree" to 7 "strongly agree." An example item reads: "I am confident I get the success I deserve in life," and the full scale is presented in Appendix C.

Finally, because this intervention assessment takes place in the classroom, I also controlled for engagement in the task. Engagement was measured using a peer evaluation tool that was part of the class curriculum. For a selection of class activities (including the control and intervention tasks), students logged on to a peer evaluation tool where they provided feedback to their teammates for their participation in a given activity. I coded feedback for action words (i.e., provided, encouraged, asked) as well as for words around participation (i.e., took the initiative, led our group, negotiation, and compromise). This measurement of action and participatory words for engagement is similar to the behaviors outlined in Morgeson, DeRue, and Karam's (2010) Action Phase Leadership Functions. Each piece of feedback that contained an action word received a score of 1. Because the amount of feedback varied from person to person, scores were taken as a percent (i.e., the amount of feedback containing an action out of total feedback provided to the participant) and dichotomized. Scores less than the mean represented "not engaged" and coded as 0, and scores above the mean represented "engaged" and coded as 1.

Results

Descriptive statistics for the focal variables are reported in Table 11, followed by correlations among focal variables for the Towers Market activity in Table 12 and correlations among focal variables in the Project RED intervention in Table 13. Examining the average scores for the focal variables before and after each task in Table 11, we see that there were increases in perceptions of coordination (pre-Towers Market $M = 5.15$ and post-Towers Market $M = 5.71$; pre-Project RED $M = 5.45$ and post-Project RED $M = 5.83$) and intra/inter-team dynamics (pre-Towers Market $M = 5.37$ and post-Towers Market $M = 5.61$; pre-Project RED $M = 5.41$ and post-Project RED $M = 5.92$) after each task when compared to before each task. However, we see that there was a decrease in perceptions of goal hierarchy after both tasks compared to before both tasks (pre-Towers Market $M = 5.22$ and post-Towers Market $M = 5.01$; pre-Project RED $M = 5.52$ and post-Project RED $M = 5.49$).

Moving to Tables 12 and 13, we see that the control variables, including intelligence, engagement in the activity, Core Self-Evaluations, and leadership, tended to be unrelated to the focal study variables for Towers Market and Project RED. Leadership was moderately correlated with post-Towers Market intra-team dynamics ($r = .29$, $p < .05$), intelligence ($r = .28$, $p < .05$)

and task engagement ($r = .36$, $p < .01$) were moderately correlated with post-Project RED team dynamics, and Core Self-Evaluation was moderately correlated with post-Project RED goal hierarchy ($r = .30$, $p < .05$). Because the control variables showed moderate correlations with only a few of the focal variables, they were not included as covariates in the model predicting differences in the control and intervention tasks across MTS leadership challenges.

The data were thus analyzed using ANOVAs, where coded vectors were created for each individual. A vector contained two sets of scores (i.e., before and after the control and intervention, respectively) and I compared scores across the three focal variables in separate ANOVAs; Tables 14-16 present the results for coordination, goal hierarchy, and inter-team dynamics, respectively.

Hypothesis 1 posited that individuals would exhibit increased awareness of coordination needs in multiteam systems after completing the training intervention, as compared to before the intervention. As seen in Table 14, there are two effects analyzed: around each task and across the two tasks. The effect of Time, which examined whether there was a difference between the pre and post scores around either task, was significant [$F(1, 136) = 39.22$, $p < .001$], meaning there was a significant increase in perceptions of coordination in the post-task scores compared to their respective pre-task scores. We can see in Figure 6a that although scores around Project RED tabletop were higher overall, scores increased more after Towers Market compared to before Towers Market. Looking at the Time*Task effect, which assessed whether there was a difference in these scores across tasks, we see this was not significant [$F(1, 136) = 1.47$, *ns*]. Thus, there was not a significant difference in Towers Market and Project RED tabletop scores, and Hypothesis 1 was not supported.

Hypothesis 2 stated that individuals would exhibit a more accurate understanding of inter-team goal interdependence after completing the training intervention, as compared to before the intervention. Looking at Table 15, we see the effect of Time was not significant [$F(1, 136) = 1.19$, *ns*], nor was there a significant effect across time [$F(1, 136) = .59$, *ns*], meaning there were no significant differences in goal hierarchy either around the individual tasks or between the two tasks. Figure 6b displays the plots of these scores. Overall, Hypothesis 2 was not supported.

Finally, Hypothesis 3 predicted that individuals would exhibit a stronger appreciation for cooperation across teams in the multiteam system after completing the training intervention, as compared to before the intervention. Table 16 presents the results of this analysis. The effect of Time was significant [$F(1, 136) = 14.17$, $p < .001$], meaning there was a significant increase in perceptions of intra/inter-team dynamics in the post-task scores compared to their respective pre-task scores. Looking at Figure 6c, we can see that this effect can be attributed to the increase around Project RED tabletop, which a higher and much steeper increase in post-task scores compared to pre-task scores. However, the Time*Task effect was not significant [$F(1,136) = 1.92$, *ns*], meaning there was not a significant difference in Towers Market and Project RED tabletop scores. Hypothesis 3 was not supported.

Supplemental Analyses

Although Hypotheses 1-3 were not supported, the plots in figure 6 show the average scores for coordination and intra/inter-team dynamics *did* improve after each task compared to before each task. To understand if these improvements were significant, I conducted *t*-tests; these results are in Table 17. Looking at this table, we can see that there was only a significant increase in coordination after Towers Market when compared to before Towers Market [$t(68) = -5.14$, $p <$

.001], whereas there were significant increases in *both* coordination [$t(68) = -3.68$, $p < .001$] and inter-team dynamics [$t(68) = -3.92$, $p < .001$] after Project RED tabletop when compared to before Project RED tabletop. Therefore, although not significantly better than Towers Market, Project RED did improve perceptions of coordination and demonstrated a unique overall improvement in inter-team dynamics where Towers Market did not.

Furthermore, in addition to testing the learning dimension of Kirkpatrick's (1959; 1976) four-dimensional measurement typology, I also wanted to examine the remaining dimensions of the model: reaction, or the extent to which participants feel the training was valuable, and changes in behavior. The Kirkpatrick (1959; 1976) model also includes the dimension "results," which refers to whether the intervention demonstrated a return on the investment; however, this was outside the scope of classroom participation and thus could not be measured for inclusion in this study.

To measure reactions, I coded the valence of the freeform short response question (i.e., What did you learn about leadership after managing the team(s) in the Towers Market and Project RED tabletop activities). Responses were coded as either negative, indicating that the participant did not feel the training was valuable, or positive, indicating that the participant felt the training was valuable. In total, 5 students had negative responses after Towers Market, and only 1 student had a negative response after Project RED tabletop; all other responses were positive. These results indicate that, in the context of the Kirkpatrick (1959; 1976) measurement typology, students felt the intervention was valuable and had a positive reaction to the Project RED tabletop task.

I measured behavior by coding the content of the same freeform short response question concerning what participants learned about leadership after each activity. Similar to the method for coding engagement (cf. Morgeson et al., 2010), I coded responses for action words that signaled behaviors participants learned about in the course of participating in each of the tasks, respectively. For example, one participant learned after Project RED tabletop that: "It's important for everyone to have a role and clearly defined goals. The communication was very important and we needed to make sure we were only sharing relevant information. We stayed organized and respected everyone's opinions." The first sentence of this response signaled a behavior relating to goal hierarchy—the terms "sharing relevant information" and "organized" indicated two separate coordination behaviors, and "respected everyone's opinions" suggested a behavior related to inter-team dynamics. I coded all responses in this way, and Table 18 displays these results.

As we can see in this table, the overall trends match the quantitative reports of coordination, goal hierarchy, and intra/inter-team dynamics. There were increased reports of behaviors around coordination, although not significant (χ^2 = 1.43, *ns*), and intra/inter-team dynamics, only marginally significant (χ^2 = 2.88, p < .10), after Project RED tabletop compared to after Towers Market. On the other hand, reports of behaviors around goal hierarchy after Project RED tabletop compared to after Towers Market decreased, but not significantly (χ^2 = .74, *ns*). Despite this relative decrease, behaviors relating to goal hierarchy were still the most frequently reported behaviors for both the control and intervention tasks. This finding stands in opposition to previous results, which indicated that there were no significant relationships, including goal hierarchy, for either Towers Market or Project RED tabletop. Additionally, goal hierarchy did not demonstrate the highest averages pre or post Towers Market, or post Project RED, and often exhibited the *lowest* scores of the MTS leadership challenges reported. Given the mismatch between the quantitative and qualitative reporting of goal hierarchy, there may be a systematic difference between how multiteam systems are conceptualized scientifically versus how MTS members actively experience these collaborative settings.

In addition to counting the behaviors mentioned in the post-task reflections, I also conducted a Linguistic Inquiry and Word Count (LIWC) analysis to understand how participant behaviors were affected by the tasks. LIWC is a text analysis application that uses a predetermined dictionary to detect words and calculate the percentage of words that fall into specific categories (Pennebaker, Booth, Boyd, & Francis, 2015). Categories range from linguistic dimensions, such as pronouns and articles, to more complex psychological processes, including anxiety, insight, and achievement, among others. I first obtained the percentages of each category that resulted from the reflection responses after the Towers Market and Project RED tabletop activities, respectively. I then compared these percentages across the two tasks. Table 19 presents these results.

Looking at the results for the pronouns category, we see a decrease in first-person singular language after Project RED tabletop compared to Towers Market [$t(68) = 3.13$, $p < .01$], accompanied by an increase in first-person plural language [$t(68) = -2.15$, $p < .05$]. In other words: Participants talked significantly more about "we" and less about "I" after Project RED tabletop compared to after Towers Market when discussing what the activity taught them about leadership. Furthermore, there was a marginally lower mention of power-related terms after Project RED tabletop compared to Towers Market [$t(68) = 1.94$, $p < .10$], and participants were also less tentative after Project RED tabletop compared to Towers Market [$t(68) = 2.96$, $p < .01$]. If we view students' discussion of leadership as a behavior in and of itself, these results suggest that their behaviors became more collective, less power-driven, and more self-assured after Project RED tabletop compared to after Towers Market. In the context of Kirkpatrick's (1959; 1976) measurement typology model, this indicates behavior became more collective and collaborative and offers support for positive behavior change due to the introduction of the intervention.

To summarize, the Kirkpatrick (1959; 1976) measurement typology assesses the efficacy of training interventions on four dimensions. The first dimension is reaction, which was measured by the valence of the short response reflection question asked after the control and intervention tasks. Given that only one student provided a negatively-valenced response to Project RED tabletop, I concluded that participants felt the training was, indeed, valuable. The next dimension was learning, which I captured in participants' survey responses. Although this dimension was not supported in the ANOVAs of MTS leadership challenges, subsequent *t*-tests indicated that both coordination and inter-team dynamics improved after Project RED tabletop compared to before Project RED tabletop, whereas Towers Market only led to an increase in coordination after the task compared to before the task. The third dimension is behavior, captured via content coding and LIWC analysis of the short response reflections that participants provided at the end of each task. Behaviors related to inter-team dynamics were reported marginally more frequently after Project RED when compared to after Towers Market, and participants used significantly more "we" language and less "I" language when discussing what they learned about leadership after Project RED compared to after Towers Market. Together, this indicates a positive change in behavior and specifically a shift towards more collaborative behavior after the intervention. The fourth and final dimension of the Kirkpatrick typology is results. This dimension refers to whether the intervention demonstrated a return on the investment, but could not be measured as it fell outside the scope of classroom participation.

Discussion

The notion of a multiteam system has shifted the landscape of collaboration to focus on how distinct teams work as systems in order to pursue complex goals (Mathieu et al., 2001; Zaccaro et al., 2012). However, our understanding of MTS inputs and processes has been overwhelmingly scientific (as opposed to practical; Mathieu et al., 2017; Shuffler et al. 2015;) and thus, limited. Using the current understanding of leadership as a critical lever for MTS success (Mathieu et al., 2001; Carter & DeChurch, 2014; DeChurch & Marks, 2006; Murase et al., 2014), we developed an experiential MTS training intervention. This intervention, called Project RED tabletop (DeChurch & Niler, 2019), helps prepare individuals to successfully navigate three of the most pressing challenges in MTS work—coordination, goal hierarchy, and inter-team dynamics—building members' MTS leadership skills in the process.

I tested the efficacy of Project RED tabletop in the classroom setting (cf. Waller et al., 2014) using a two-group pre-test/post-test design. The control task used for comparison with Project RED tabletop was the cross-functional team task, called Towers Market (Beggs et al., 2000). The efficacy of Project RED was evaluated using Kirkpatrick's (1959; 1976) four-dimensional measurement typology: learning, reaction, behavior, and results. I tested learning via ANOVAs, comparing the survey responses across the two tasks on each of the three MTS challenges. Although results of the ANOVAs were not significant for the effects across the tasks, coordination and intra/inter-team dynamics showed significant differences from pre to post task. Supplemental analyses found that when isolating the effects of each task separately, Project RED tabletop aided in the training of coordination and inter-team dynamics skills. I also evaluated the reaction and behavior components of the Kirkpatrick (1959; 1976) model (the ability to capture the results dimension fell outside the scope of classroom participation and thus could not be measured in this study). Analysis of the post-task reflection responses indicated both a positive reaction to Project RED tabletop, as well as a marginal increase in references to behaviors related to inter-team dynamics and a shift to more collective language after Project RED tabletop compared to after Towers Market. Additionally, I found that behavior references to goal hierarchy were the most frequently mentioned of any of the MTS challenges, which is interesting, as it stands in contrast to the quantitative reports of this challenge.

Indeed, goal hierarchy not only produced insignificant relationships, but it was also the only challenge that showed decreases—when measured both quantitatively and qualitatively. However, it was the *most* referenced behavior when participants elaborated on their experiences regarding what they learned about leadership after participating in each of the activities. This finding indicates a potential aperture in the scientific operationalization of multiteam systems and the experience of multiteam systems. It may be the case that researchers have not been using terminology and measurements that reflect the true MTS experience. As a result, our understanding of multiteam systems may be bound by the lab context in which it has been studied (Mathieu et al., 2017; Shuffler et al., 2015). Future research should continue to delve into the qualitative investigation of the MTS experience to gain a better understanding of how individuals perceive multiteam system work, challenges, and leadership opportunities.

Contributions

This study makes several important contributions to research on multiteam systems. The first contribution is to MTS theory. Although inherently practical, training interventions are a key mechanism by which theory is shaped, as they uncover and strengthen our understanding of leader and team member skills/knowledge (Cooke & Hilton, 2015). As such, training interventions are a critical component in the development of team, multiteam, and organizational theory (Cooke & Hilton, 2015). Project RED tabletop goes beyond interventions at the team level (Day, Gronn, & Salas, 2004; Salas, DiazGranados, Klein, Burke, Stagl, Goodwin, & Halpin, 2008) to specifically account for the cross-team collaboration required for multiteam system leadership and is the first to do so. Moreover, the multiteam nature of Project RED tabletop is important, given that team principles do not transfer linearly to the multiteam system context (Shuffler & Carter, 2018). In this way, Project RED tabletop fills a critical role in the multiteam systems literature.

More to this point, this study contributes to the practice of multiteam systems with the Project RED tabletop tool. Project RED tabletop can be used in a variety of settings to help prepare leaders for the challenges of MTS work and potential pitfalls (as the results of Study 1 demonstrated). Although the hypotheses testing the learning dimension of the Kirkpatrick typology (1959; 1976) were not supported when comparing Project RED to a team task, Project RED remains a unique tool given its multiteam system focus. Project RED did improve perceptions of coordination and inter-team dynamics nonetheless, and scores for goal hierarchy were still much higher and did not show as steep of a decrease from pre- to post-task as they did for Towers Market. As such, Project RED remains a validated and efficacious MTS leadership training tool that offers a specifically *multi*team experience, going beyond the traditional team training tools currently offered by others. In this way, Project RED speaks to organizations like NASA, who is actively seeking a countermeasure to support multiteam systems via training. Moreover, there is no space-specific knowledge required by the intervention and so any multiteam system can use and benefit from Project RED tabletop. Leaders, directors of centers, and other high-level administrators of multiteam cross-disciplinary efforts may find great value in this exercise.

Limitations and Directions for Future Research

Although this study takes a critical step toward developing a multiteam system leadership training intervention, there are several limitations to note. The first set of limitations stems from the setting. This study was conducted in a classroom setting and so despite measuring and controlling for task engagement, it is possible that participants were not as invested in the tasks and training as teams in a real-world setting might be. Related to this, the particulars of the learning objectives taught in the class may have confounded the effects detected in either Towers Market or Project RED tabletop. The week before Towers Market, students completed a cross-functional team hidden profile task, and in the weeks between Towers Market and Project RED, students engaged in a creative thinking task, a team formation task, another cross-functional team execution task, and a shared leadership task. Therefore, students may have learned critical collaboration skills related to coordination, goal hierarchy, or intra/inter-team dynamics outside the context of these two tasks in particular.

This study was also limited in terms of its measurements. First, given the findings from the qualitative study that followed this examination, there were several additional measures I would have included if given the opportunity to improve and reevaluate Project RED tabletop. The three main challenges studied here were coordination, goal hierarchy, and intra/inter-team dynamics, which hail from just one theme of challenges of MTS work. I would have instead created new measures that capture each theme of challenges, including a composite of coordination, goal hierarchy, and inter-team dynamics to capture Integration challenges, as well as a measure for Structure challenges and Climate challenges. Another limitation in measurement was the error in the items used to capture intra-team dynamics. The phrasing of the questions was similar, but not a one-to-one match to the post-Project RED items. For example, the first item measuring intra-team dynamics after Towers Market read, “There was little collaboration among functional team members” and the corresponding item after Project RED tabletop read, “Functional teams did not collaborate with one another.” As such, the comparison across tasks may not be completely accurate.

Future research will be helpful in addressing these limitations. In particular, researchers should further validate Project RED tabletop as a training intervention in an applied context with managers who work in MTSs. Rather than distribute the control and intervention tasks throughout a course, administer the tasks immediately and consecutively (ideally in Weeks 2 and 3 of the course, respectively) to decrease the chance for outside class material to influence the results. It may also be beneficial to test the effects of administering Project RED before Towers Market to control for any learning effects from one task to the next. Additionally, testing the efficacy of Project RED tabletop in a real-world setting would be helpful in understanding its effects, as there may be systematic biases in the way students think about and execute collaboration as compared to professional teams.

Moreover, the departure between the quantitative and qualitative reporting of goal hierarchy should be explored more deeply by future research. Researchers have recently called for a more applied investigation of MTSs (Mathieu et al., 2017; Shuffler et al., 2015), and results from this study suggest that this may be the *most* critical next step in MTS research. We must have a correct understanding of the experience if we are to advance the science and practice of multiteam systems. As such, I conduct a qualitative analysis of multiteam systems in the following study of this dissertation. Following the backdrop of space exploration utilized in Studies 1 and 2, I use a grounded theory approach to analyze interviews conducted with members from some of the most important space multiteam systems currently operating. In this way, I hope to generate a new framework by which we think about multiteam systems and characterize their challenges and opportunities for leadership.

Conclusion

Multiteam systems provide a way for different teams to come together and solve complex problems. However, our understanding of their inputs and processes is necessarily bound by the academic context in which we have studied them, including the notion that leadership can be a crucial lever for success. Here, I tested an experiential MTS training activity aimed at developing the skills necessary to navigate the three core MTS challenges effectively. Results suggested initial support for the training intervention, but more importantly, identified a potential gap in the scientific understanding of multiteam systems versus the true MTS experience. In this way, this study takes an important first step in examining the more practical processes of multiteam systems, and also paves the way for even richer work to be conducted in this area.

CHAPTER 4

HOUSTON, WE HAVE A PROBLEM:

A QUALITATIVE ANALYSIS OF THE CHALLENGES AND RESPONSES OF MTS WORK

A relatively novel concept in the literature on organizational collaboration, multiteam systems (MTS) research has spent the last two decades uncovering the key processes and outcomes of these "teams of teams" (Mathieu et al., 2001). Indeed, prior work has established that multiteam systems are particularly useful when there is a complex issue which one team alone cannot solve (Marks et al., 2005; Mathieu et al., 2001; Shuffler & Carter, 2018), but the inherently complicated nature of multiteam systems makes them ripe for challenges. Furthermore, although leadership is a potential solution to an array of MTS challenges (Carter & DeChurch, 2014; DeChurch & Marks, 2006; Mathieu et al., 2001), there is little work explicating how leadership, or the actions that contribute to the needs of the team (McGrath, 1962), develops and operates in this setting.

Furthermore, consideration of context or environment is lacking in MTS research more broadly. Most of the work dictating our understanding of multiteam systems was conducted in a laboratory setting and now, several researchers are calling for examinations of multiteam systems in their natural environments (Mathieu et al., 2017; Shuffler et al., 2015). This shift in the study of multiteam systems will be critical for the field, as the environment plays a vital role in creating and shaping a multiteam system (i.e., "MTSs are open systems whose particular configuration stems from the performance requirements of [the] environment that they confront and the technologies that they adopt; Mathieu et al., 2001, p. 291). Among other objectives, this dissertation aims to answer this call by studying multiteam systems in increasingly natural environments.

The first study presented here dove deeper into multiteam system leadership to examine the antecedent conditions promoting the development of MTS leadership relationships. I found that multiteam system members tended to form leadership relationships in direct opposition to the patterns that would be most helpful, looking inward for leadership as opposed to bridging team boundaries. The second study then used this information, in conjunction with the review of literature on multiteam systems and MTS leadership, to craft a training intervention aimed at developing the necessary skills to promote leadership relationships in multiteam systems. Importantly, findings from this study highlighted a potentially crucial discrepancy: Participants' quantitative reporting of the importance of goal hierarchy did not match their qualitative descriptions. This incongruity suggests the experience of working in and leading a multiteam system is potentially not captured in the constructs that previously guided multiteam systems research; as such, there may be additional challenges that have not yet been offered and uncovering them (or improving our understanding of existing challenges) may better inform MTS leadership.

The current study thus takes a qualitative approach to multiteam systems research to build on both of the previous studies in this dissertation by probing into the experience of MTS work. I analyze interviews conducted with individuals working in some of the most critical presently operating space multiteam systems across NASA with employees on the ground, astronauts who have worked on the International Space Station, and crew members participating in an extensive multinational long-distance spaceflight simulation. Through this investigation, I hope to not only gain a better understanding of how the challenges of MTS work unfold in an applied setting but also capture the intricacies and complexities of multiteam system work that were potentially overlooked or not replicated in the traditional lab setting.

Multiteam System Challenges

Multiteam systems are complex units of collaboration. They consist of two or more teams; are typically larger than the average team, but smaller than an organization; are formed to meet the needs of their environment; their “component” teams have both team-level goals that integrate towards the superordinate system-level goal(s); and exhibit input, process, and output interdependence with one another (Mathieu et al., 2001). Given this configuration and the challenging circumstances under which multiteam systems form (Luciano et al., 2018; Mathieu et al., 2001), it comes as no surprise to find that they are complicated. In fact, the challenging nature of MTS work has guided the field of research concerning these unique entities, and a review of the research on multiteam systems reveals two key patterns in this literature.

The first pattern in the MTS literature is that researchers have investigated three focal challenges of multiteamwork. Table 1 presents a review of the MTS research, outlining each study and its accompanying challenge(s). The first and most prevalent challenge seen in the literature is that of coordination (Bienefeld & Grote, 2013; Davison et al., 2012; DeChurch & Marks, 2006; DeChurch et al., 2011; Marks et al., 2005; Mell, DeChurch, Contractor & Leenders, in press; Olabisi & Lewis, 2018; Wijnmaalen, Voordijk, Rietjens, & Dewulf, 2019). In other words: How do MTS members work together across team boundaries? The second challenge is the goal hierarchy, which is a fundamental tenet of multiteam systems. The goal hierarchy refers to the fact that component teams have both proximal team-level goals *and* distal

MTS-level goals, and although team goals must all serve the system goal, they may be in direct conflict with one another (Mathieu et al., 2001). Several studies have attempted to understand how members reconcile these different goals to work with other teams in the system effectively (Bienefeld & Grote, 2014; Lanaj, Foulk, & Hollenbeck, 2018; Rico, Hinsz, Burke, & Salas, 2017). There is also the third challenge of inter-team dynamics, concerned with the consequences of having both team-level and system-level social processes (Carter, 2014; Huggins & Scheepers, 2019; Porck, Matta, Hollenbeck, Oh, Lanaj, & Lee, 2019; Rico, Hinsz, Davison, & Salas, 2018; Wijnmaalen et al., 2019).

However, after examining the efficacy of the Project RED training intervention (DeChurch & Niler, 2019) in developing skills around these three challenges, I found a discrepancy. Whereas there was no change in perceptions of goal hierarchy after the intervention compared to before the intervention (this was also the case after the control task compared to before the control task), goal hierarchy was the most frequently cited learning in the post-task reflection. Thus, participants' quantitative and qualitative perceptions of relative importance of the goal hierarchy did not match. One potential explanation for this gap is a disconnect between the scientific conceptualization of goal hierarchy and the *true* experience of working in a multiteam system.

Indeed, the second pattern uncovered in my review of the literature is that the vast majority of MTS research is conducted in the laboratory. Researchers often bring participants in and simulate the conditions of a multiteam system experience. There is little work representing the multiteam system experience as measured in the field (Mathieu et al., 2017; Shuffler et al., 2015). This imbalance between lab and field research on multiteam systems is particularly problematic because a defining characteristic of multiteam systems is their environment (Mathieu et al., 2001). Without accounting for the unique and dynamic environment of a multiteam system, MTS research is likely missing a critical component in their understanding of multiteam systems. Accounting for the environment may explain the gap found in the previous study and also open the door to other challenges that have not yet been explored or uncovered in the lab. Therefore, I take a step back from the current literature and reexamine the challenges of multiteam system work from the perspective its members, asking:

Research Question 1a: How prevalent are different types of challenges in multiteam systems?

Extreme Multiteam Systems

We now face complex issues, and as a result, multiteam systems are omnipresent. Teams of emergency medical technicians work with firefighters and doctors to save victims of car crashes, teams across the government and non-profit sectors come together in response to natural disasters, and more recently, there are teams of scientists and engineers, among many others, who are working to achieve interplanetary travel (NASA, 2015). Spaceflight is both an exciting and appropriate context for understanding multiteam systems, given the need for multiteam interdisciplinary collaboration. However, the space context is also an extreme team context (Bell et al., 2018; Driskell et al., 2018; Mesmer-Magnus, Carter, Asencio, & DeChurch, 2016) and although many principles of space MTS work are mirrored in other MTS contexts, there are some aspects of this environment that may not be applicable in other more traditional multiteam systems.

Research on extreme team and multiteam settings cites that extreme environments are those with "unconventional performance environments and have serious consequences associated with failure" (Bell, Fisher, Brown, & Mann, 2018, p. 2740). Performance environments usually include heightened elements, such as intense time pressure, confinement, and danger (Bell et al., 2018). The work done in these environments is also typically characterized by specialized training (Bishop, 2004; Power, 2018; Smith-Jentsch et al., 2015) and a strong chain of command (Driskell, Salas, & Driskell, 2018; Foushee & Helmreich, 1988; Klein et al., 2006). Given that space and astronaut crews are often identified as an extreme environment/team (Bell et al., 2018; Driskell et al., 2018; Mesmer-Magnus et al., 2016), I account for extreme nature of the space context by posing the following question:

Research Question 1b: What are challenges that are unique to multiteam systems in extreme contexts?

Multiteam System Leadership

In addition to the challenges outlined by the literature on multiteam systems, research offers a few solutions as well. One tool that has the potential to combat all of these challenges is leadership. Leadership is a critical component in capitalizing on multiteam systems' uniquely capable structure (Mathieu et al., 2001), and it is positively related to team (Bienefeld & Grote, 2014) and MTS performance (Bienefeld & Grote, 2014; Davison et al., 2012; DeChurch & Marks, 2006). However, MTS leadership is just as complex as the multiteam system itself. Multiteam system leaders must operate at both the team and system levels, and as a result, they are continually moving between their component team and the larger system (Mathieu et al., 2001; Morgeson et al., 2010). This complexity often creates the need for informal leadership to fill in any gaps left by these shifts across levels of interdependence (Carter & DeChurch, 2014), in addition to formal leadership in multiteam systems, adding further complexity to this process.

Despite the long history of leadership research, we know relatively little about leadership in the MTS setting. We primarily lack an understanding of how it emerges in multiteam systems, and this information is critical to be able to effectively navigate the informal leadership that arises in this setting (Carter & DeChurch, 2014). Furthermore, there is no guide for what members can do to build leadership relationships. Unlike the teams leadership literature, which has matured to be able to proffer effective behaviors (cf. Fleishman, Mumford, Zaccaro, Levin, Korotkin, & Hein, 1991; Zaccaro et al., 2001), multiteam systems are unique to teams, and so their principles cannot be directly transferred (Shuffler & Carter, 2018). As such, understanding the inner workings of multiteam systems (i.e., challenges) will help provide leadership guidance for members working both within *and* across team boundaries, and I ask:

Research Question 2: What leadership behaviors are enacted in an attempt to resolve challenges?

Methodology

Sample and Setting

I used three sets of archival interviews to answer these research questions. The first set (*N* = 9) included interviews conducted with NASA employees in 2014, the second set (*N* = 5) included interviews with astronauts who were active on the ISS from 2018 to 2019, and the third set (*N* = 6) included interviews with astronaut candidates who participated in the four-month SIRIUS 2019 analog mission in Moscow, Russia. Figure 7 presents the ISS and SIRIUS analog in Figures 6b and 6c, respectively. Interviews with NASA employees lasted approximately 60 minutes each, and interviews with ISS astronauts and SIRIUS crew members lasted approximately 30 minutes each; all were semi-structured. The interview questions for each set of participants can be found in Appendices F-H, respectively.

NASA. The National Aeronautics and Space Administration is an interdisciplinary agency, independent of the U.S. government, responsible for the science and technology related to air and space (NASA, 2018), including the civilian spaceflight program. There are a variety of experts that work at NASA "to discover and expand knowledge for the benefit of humanity" (NASA, 2019), including astronauts, engineers, psychologists, and flight directors, among others. I had access to interviews conducted with 9 of these individuals conducted by Leslie DeChurch, Jessica Mesmer-Magnus, and Steve Fiore. Interviews captured the work done by these individuals, which allowed them to provide unique and detailed insight regarding the benefits, drawbacks, and challenges of working in a multiteam system environment.

International Space Station. The International Space Station is a collaboration between the space agencies of the United States, Russia, Europe (Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom), Japan, and Canada (NASA, 2018). Importantly, there are teams of people within each agency working to support crews through their expeditions, as well as the research taking place on this spacecraft every day. This work requires collaboration between the agencies' flight crews; multiple launch vehicles; globally distributed launch, operations, training, engineering, and development facilities; communications networks; and the international scientific research community (NASA, 2018). The ISS may operate with up to seven crew members at any given time, and there are three American crewmembers aboard the ISS at this moment. The interviews were conducted by Daniel Newton, Leslie DeChurch, and Noshir Contractor. A total of five astronauts from the United States consented to this study and agreed to speak about their time working in a multiteam system on the ISS.

Scientific International Research In a Unique terrestrial Station. SIRIUS is a habitat located in Moscow, Russia, as part of the American-Russian space research initiative, where simulated missions are executed to understand and prepare for the effects of long-distance space exploration. A total of six crewmembers ingressed into the habitat in mid-March 2019 and remained there for 120 days as they carried out experiments by an international group of researchers. A critical aspect of this setup is that the module has been designed to recreate the conditions of long-distance space exploration, and so just as on the ISS, crewmembers in SIRIUS experienced conditions of isolation, confinement, communication delay, and working with a multinational crew. Therefore, SIRIUS crewmembers were also uniquely positioned to provide rich detail regarding the complexities of working in a space multiteam system. Leslie DeChurch and Noshir Contractor conducted interviews with all 6 crew members the week following the mission conclusion via phone call.

Analytic Approach

I used thematic analysis (Braun & Clarke, 2006) to analyze the interviews with crew members' and construct a complete picture of MTS challenges and leadership responses. As outlined by Braun and Clarke (2006), there are several stages of performing thematic analysis. The first is to familiarize oneself with the data, which entails reading and re-reading the data, and noting any initial ideas. The second stage is to generate initial codes, meaning features of the data are coded systematically across the entire dataset. Third, the researcher collates the codes generated into potential themes and fourth, reviews those themes. In the fourth stage of review, the researcher is checking whether the themes map onto the coded extracts and the entire dataset. The fifth stage is to define and name the themes. Finally, the sixth stage is to produce a report. This stage is the final opportunity for analysis, where the researcher may select vivid examples and relate the data back to the research question and the literature.

Establishing the analytic lens. In addition to the six steps outlined by Braun and Clarke (2006), the authors also advise researchers to make a series of decisions first to establish the analytic lens through which the text will be coded and analyzed. For the purposes of this study, where my goal was to understand the ubiquitous multiteam system experience, I chose to widen my scope to include a detailed description of the entire dataset. It was essential to capture the challenges experienced in all multiteam systems. I utilized an inductive approach to account for changing or new terminology around challenges and leadership responses not previously discussed in the multiteam systems literature.

Regarding the level of coding and the epistemology, I employed a contextualist approach, using latent coding to identify challenges and responses, and semantically coding the content of those challenges and responses. This approach allowed me to include as much information as possible in the identification of challenges and responses (particularly given the nature of questions asked) while also capturing the true nature of challenges and responses as close to participants' descriptions as possible.

Data extraction and synthesis. After becoming familiar with the interviews and noting initial ideas, I extracted relevant data in two stages. First, I extracted all text relevant to multiteam system work, and within those pieces of text, I identified challenges and responses. A challenge was defined as a task or situation that tested someone's abilities, and the text was coded as a challenge if it described a challenge (e.g., a fire onboard), an off-nominal/emergency event, or if it contained negatively-phrased language (e.g., "We don't like when…"). A response was defined as aiding in response to (potential) challenges, and identified with a description of success (e.g., "That worked really well" and, "It helped to…"), positively-phrased language (e.g., "It is important to…", "You need to…"), or signals of a final decision.

Once identified, I coded the content of challenges and responses, respectively. For both challenges and responses, I used one interview per set (i.e., one interview of a NASA employee, one interview of an astronaut on the ISS, and one interview of a SIRIUS crew member) to establish the initial codes. I then proceeded to code the rest of the interviews from that initial set of codes. Both as coding progressed and again when it concluded, I evaluated each code to ensure that it was non-redundant; redundant codes were collapsed into other existing codes. In total, 20 unique codes presented from the challenges and organized into 4 core themes, and 20 unique codes presented from responses and organized into 5 core themes.

Multiteam System Challenges and Responses

Challenges

After identifying and analyzing the content of multiteam system challenges as described by participants, 4 core themes emerged, and each theme included several subthemes. A complete summary of the thematic analysis of the challenges of multiteam system work is presented in Table 20. Overall, I found that multiteam systems are challenging in that they are structurally complex, create dynamic climates, and require integration; there were also challenges unique to the space context that emerged in this analysis.

Challenges of *Structure* included factors imposed on members (i.e., derived from the external environment) and had two subthemes: (1) Process, which captured the challenges of timing, engagement, myriad resources, and dynamic circumstances; and (2) Outcomes, which captured the technical challenges of the work and challenges related to performance.

Participants also described challenges of multiteam system work around the theme of *Climate*, which referred to factors members imposed on their environment, or elements that were derived by members internally, the effects of which manifested at three levels: (1) Individual, including challenges of unmet expectations and management of emotions; (2) Team, including boundaries; and (3) MTS, including unique perspectives and lack of awareness.

The third theme of challenges was *Integration*, described as the reconciliation of factors imposed on and by members of the multiteam system, as these challenges required members to work together in some capacity and as a result, individuals' internal and external environments integrated. Integration challenges were behavioral (coordination and priorities), informational (communication and disconnect), and relational (relationships) in nature.

Lastly, participants described challenges of *Space Context*, representing factors that were distinct to the space exploration setting in which these multiteam system members operated, and included working with international partners, control, training, and confinement. Next, I discuss the challenges in greater detail, providing definitions, along with select excerpts, as well as variations of each. Select quotes for all challenges are in Appendix I.

Structure. Of the challenges that were derived externally by factors imposed on members, there were four related to process. One such challenge was timing. Participants described timing in the context of creating or maintaining the schedule, and references were often made to task timing and waiting for information or resources. For example, one member recalled low points in the mission, saying:

> Low times would be… I guess when the schedule is packed with things, or we had all sorts of blood draws to do, uh, followed by a lot of, uh, experiments that required a great deal of, um, set up and tear down… (SIRIUS crew member #5)

A related challenge was that of engagement. Engagement was inherently difficult for participants, given the complexity of their tasks and the rigorous nature of their schedules. Tasks ranged from providing crew members with familial experiences, like "…seeing [a] kid's game…involved in a funeral, talking to aunt/uncle," (NASA employee #1) to working on a $10 billion piece of equipment (ISS crew member #4), often in rapid succession. One participant identified this as being the source of mistakes:

> I think that's when mistakes happen—is you because you're not fully engaged, and you've been working from one thing, you move from one thing to the next to the next. It's hard to keep your head in one game after the other after the other. (ISS crew member #1)

Finally, as expected with the complexity of multiteam system work (Luciano et al., 2018; Mathieu et al., 2001), members struggled with being overwhelmed at times (i.e., the challenge of myriad resources) and operating in dynamic circumstances.

Beyond the Structure challenges related to process, there were two Structure challenges related to outcomes, one of which was technical challenges. These challenges included anything describing a technical issue or failure—for example, one participant described a fire onboard, and another recalled a time when a spacesuit malfunctioned:

> A year ago, there was a problem with a suit… training for an EVA, the helmet began filling up with water, [the astronaut] could have drowned! A fan pump separator was causing problems, [we] had to replace it… (NASA employee #4)

Additionally, a key outcome in many team contexts, there was also discussion of performance challenges. Performance was described as an ideal to which members felt they were accountable. These standards, which were not codified but rather a collective notion, felt like a challenge in the midst of completing multiteam system work. One participant commented on this ideal, saying:

> [There is a] pressure to perform and be one of those "steely-eyed" NASA flight directors like you've heard about since you were a kid… flight director is barking at you… pressure to look good and be good… (NASA employee #3)

The challenges in the Structure category reflect prior research on task engagement. A meta-analysis conducted by Crawford, LePine, and Rich (2010) on the effect of job demands and resources on employee engagement and burnout outlined that there are two types of stressors when considering engagement, one of which is challenges. Challenge stressors "tend to be appraised as stressful demands that have the potential to promote mastery, personal growth, or future gains" (p. 836), and examples include job demands like high workload, time pressure, and high levels of job responsibility. Thus, the structure of the work itself—and in the case of myriad resources and dynamic circumstances, the structure of the multiteam system itself (Luciano et al., 2018)—presents challenges for members engaging in multiteam system work. Furthermore, research on team and organizational leadership has suggested that task-oriented aspects of work are an "initiation of structure" (Halpin, 1957). As such, I consider the challenges in this category, rooted in the task engagement literature, to be structural.

Climate. Participants also described challenges of multiteam system work around the theme of Climate, or factors members derived internally and imposed on their environment. Starting with factors that manifested at the individual level, participants described situations when their expectations were not met as challenging. Especially when working with a diverse group of people or a set of teams, understanding the strengths and constraints of other multiteam system members is difficult. Furthermore, in-group bias (Tajfel, 1978) negatively predisposes members of different teams towards one another, and collectively, this may result in inaccurate expectations of members and incremental frustration when expectations go unmet. For example, one participant spoke of managing the response on the ground from interactions with the crew, saying: "Occasionally in some cases, a particular discipline would roll their eyes like, 'I thought they were supposed to be smart people?'" (NASA employee #4). This quote exemplifies how unmet expectations made the immediate environment for the ground challenging, as they felt they had to do more work to compensate for the (perceived) lack of crew members' capability.

In a similar way, emotions were another challenge of Climate that manifested at the individual level. Typically referenced by way of managing negative emotions, participants struggled with regulation; although crew members' entire lives are onboard, members of ground teams found emotion management to be challenging as well: "…even on a good day, you can feel 'beat up'…" (NASA employee #3). Yet regardless of the context or impetus for the emotional challenge, the outcome of emotional management (or not) affected the direct environment of the member facing this challenge: "I mean, if you were having a bad day, I mean, it could make the whole day less enjoyable if something happened in the morning. That could make the whole day less enjoyable" (ISS crew member #1).

Moving to Climate challenges that affected the team level of the MTS, participants described boundaries as being challenging to navigate. Whereas multiteam systems have natural boundaries around component teams, boundaries referred to *within*-team divides in the context of these interview responses. In this way, boundaries were derived from the individual members and imposed on the work environment. A key example provided was the multicultural composition of the astronaut crews and how members from different cultures had a difficult time interacting. Another interesting example of these self-imposed boundaries was in the turnover of crew members from increment to increment:

> And so from a… from a psychology perspective…you know, I'm thinking about a whole different set of priorities than those guys are thinking about. I'm in a whole different place mentally and, and looking at the mission and reflecting on what's going on and preparing mentally to come home. And those guys are full speed ahead. (ISS crew member #5)

Similar to the transition between increments, the other major boundary described was between the "front-room" and "back-room" teams on the ground. Still, all cases indicated boundaries imposed among members typically considered to be an intact component team, solidifying boundaries as a challenge of Climate.

Finally, there were two Climate challenges expressed at the multiteam system level. Unique perspectives seemed to plague members of different teams, which was usually attributed to working at a distance. The canonical example provided by both members on the ground and in-flight (either real or simulated) was planning for task execution, versus actual task execution. One participant lamented:

> Will always be a “we vs. them”… because the ground people are not there, so they don’t have a true understanding… 30 minutes to do this task with [a] drawer and panel… may not have gotten the drawer open because of microgravity, so couldn’t even do the task because the ground doesn’t understand what is happening in space flight… (NASA employee #9)

As seen in this example, one member of the system on the ground generated his/her perspective on task execution, but it differed from the perspective of the member working in the focal environment where the task would be executed. This difference ultimately affected the environment of a member of a different team in the system, creating a challenge. The second challenge that emerged in this category was that of awareness—often lack thereof. As was the case with unique perspectives, lack of awareness on the part of one member of the multiteam system would translate into a challenge for members of a different team. One participant recalled:

> But there are some sensational things they see that the ground control can’t see—for example a fire situation or a depressurization situation. These are good examples of things the ground control team wouldn’t know unless the space crew tells them…depressurization makes the space crews’ ears pop, so they call down to mission control and tell them… (NASA employee #3)

When considered together as a theme, the challenges of Climate may be informed by the literature on team and organizational climate. Team climate is, “team members’ collective perceptions of task-related behaviors, practices, and procedures" (Açıkgöz, Günsel, Bayyurt, & Kuzey, 2014, p. 1147) and organizational climate is, "the shared perceptions of and the meaning attached to the policies, practices, and procedures employees experience and the behaviors they observe getting rewarded and that are supported and expected" (Schneider, Ehrhart, & Macey, 2013, p. 362). Thus, climate refers to the awareness and perspectives of the team (or in this case, the multiteam system) members. Boundaries are then also pertinent to climate since the boundaries described were not the typically placed boundaries around a component team, but rather within-team divides imposed by members based on their perceptions of where boundaries existed. Additional research on team climate has indicated that it includes both expectations and feelings as well (Pirola-Merloa, Härtel, Mann, & Hirst, 2002; Schneider, 1990).

Integration. Integration challenges captured the reconciliation of factors imposed on and by members. Indeed, integration is a hallmark of multiteam systems and arguably the key element that makes them so uniquely useful (Marks et al., 2005; Mathieu et al., 2001; Shuffler & Carter, 2018). As such, this category of challenges has confirmed much of the prior research on multiteam systems; however, we are now getting a thorough picture of what integration looks like for multiteam system members in action.

One form of integration participants described was the integration of actions, or coordination. Coordination reflected anytime members' actions happened either simultaneously, in relatively rapid succession, or were dependent on one another. The space context is a very active one, and so there were many instances of coordination detailed by participants. After the Progress ship hit the Mir space station, one participant said: "The crew may need to take over, and lots of training comes into play… lots of integrated activities that cross across a lot of disciplines…" (NASA employee #6). A SIRIUS crew member also recalled a coordination challenge—when speaking of the impact that training had on acting as one team, the participant said: "We only spend about two months together…" (SIRIUS crew member #4). Beyond the challenges that stemmed from integrating actions more broadly, participants also cited challenges specifically concerned the integration of behaviors around members' different priorities. A determining factor in multiteam systems is goal hierarchy, whereby different teams have both proximal team-level goals and distal system-level goals, and team-level goals may or may not be in conflict with one another (Mathieu et al., 2001). As such, it was not surprising that the reconciliation of priorities presented a challenge to these multiteam system members, which manifested in the form of behaviors. One participant provided an example of how different priorities affected the workflow:

> If the president wants to talk to the crew on a specific day, you won't have a choice, so you'll have to move stuff around with all these constraints like maintenance and number of payloads, battery, power, requirements… managing the activities across these constraints takes a lot of coordination across all these disciplines… (NASA employee #6)

Participants also cited challenges that stemmed from the integration of information, known in this context as communication. There were more general communication challenges whereby members had a difficult time exchanging information with one another, as well as a more specific communication challenge, called disconnection. Disconnect refers to a misunderstanding or miscommunication where information was exchanged, but not received as the sender had anticipated. It occurred not only for members who spoke different languages (i.e., an English-speaker trying to converse with a Russian-speaker) but also for members on different teams or with different functional backgrounds. For example:

> Um…the downside, I mean it was so close. Um, there were some moments when there was, um, uh, misunderstanding although we speak the same language but when we say that we have, uh, issues with some, uh, experiments and, uh, I don't know why, but the answer came back totally not related. (SIRIUS crew member #2)

The final integration challenge participants discussed was the integration of members themselves, or relationships. When members managed emotions between one another, they were managing their relationship, and this was a key step in the process of collaboration. Although relationships could be challenging within teams, there were far more instances of relationship challenges between teams. For example, one participant spoke of the relationship between the crew and a principal investigator:

> [Crew member] does [an experiment] three times, and then all of a sudden, I do it the fourth time—that can actually lead to problems. That's actually kind of a biggie. I'm glad this just came up because you know if [crew member's] done it three times, then he knows all the little "isms" of that procedure, he's talked to the PD—either on a first-name basis, you know they have the history to it… (ISS crew member #3)

It was not surprising to find that participants spoke of coordination, communication, and relationships as challenges in MTS work, as these are well-represented in the literature on multiteam systems. As seen in Table 1, coordination is a cornerstone of multiteam system work (Davison et al., 2012; DeChurch & Marks, 2006; Firth et al., 2015; Lanaj et al., 2013; Marks et al., 2005; Mathieu et al., 2001), but it was curious that the integration of priorities fell under the subcategory of behavior. I expected that priorities would fall under the subcategory of information because a goal hierarchy is characterized as, "shared objectives and their relative importance" (Firth et al., 2015, p. 816), and shared objectives are built through the exchange of information (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). However, the complexity of multiteam systems and diversity of teams' specialized knowledge sets (Luciano et al., 2018; Mathieu et al., 2001) may result in more "showing" as opposed to "telling" when it comes to managing the goal hierarchy. Therefore, as I saw in the interviews, priorities may be managed in practice via behaviors (which may implicitly communicate priorities) and not by communication, strictly.

The integration of information is also a considerable contingent of the multiteam systems literature (Cianciolo & DeCostanza, 2012; DeChurch, Doty, Murase, & Jiménez, 2012; Bienefeld & Grote, 2013). Indeed, miscommunication is a significant challenge of collaboration, particularly for team members who are working at a distance (Cramton, 2001) and for functionally diverse members (Bunderson & Sutcliffe, 2002)—both of which are features of multiteam systems (Mathieu et al., 2001).

Finally, relationships were discussed relatively frequently in these interviews, yet the focus on relationships and inter-team dynamics has only recently become a point of consideration in the MTS literature (Carter, 2014; Cuijpers et al., 2016; Porck, Matta, Hollenbeck, Oh, Lanaj, & Lee, 2019; Rico et al., 2017; Wijnmaalen et al., 2019). For the first 10 years multiteam systems were studied, there was no empirical work on inter-team dynamics; the vast majority of research on this topic has been produced over just the last few years (Carter, 2014; Cianciolo & DeCostanza, 2012; Cuijpers et al., 2016; DeChurch et al., 2012; Huggins &

Scheepers, 2019; Mell et al., in press; Porck et al., 2019; Rico et al., 2017; Rico et al., 2018; Wijnmaalen et al., 2019). This study not only provides further evidence for the role of inter-team dynamics in the MTS experience but also suggests that researchers continue their recent trend of explicating this aspect of multiteamwork. More to this point, inter-team dynamics/relationships may be a key area for MTS leaders to focus on, as leadership is, at its foundation, a relational process (Avolio et al., 2009; Carter et al., 2015; DeRue & Ashford, 2010) and strong relationships may help them address a wider variety of issues across the multiteam system.

Space context. As was expected, participants also outlined several challenges that were unique to the space context. Certainly, some of these challenges may be present in more "traditional" multiteam systems; however, challenges in this theme were considered unique to the space context given how they were discussed and executed in these systems in particular. For example, although many multiteam system members are on-boarded to their team or position, this is not the same as the rigorous training experienced in the context of spaceflight. Therefore, all of these challenges are unique to the space context but also applicable to all extreme multiteam system contexts, such as military operations and hospitals, among others.

There were four Space Context challenges, one of which was working with international partners. The space station and many of the operations on the ground are a close collaboration between several countries led primarily by the United States and Russia. As a result, many of the processes require working across state lines, which can present both physical and cognitive challenges. Simply put, one participant stated, "Russian, U.S., and Japanese [members are] very different" (NASA employee #4). Others cited processes they would have liked to be put into place, but that likely would not happen because they would require the involvement of international partners. The exercise of control was another challenge unique to the space context. NASA is particularly well-known for its regimented and hierarchical procedures, and both the ground and crew were acutely aware of this dynamic. Participants referred to the ground as the "operator" and the crew the "worker bees" (NASA employee #9). Furthermore, despite the "train, trust, and turn loose" motto that several participants mentioned regarding the challenge of control, training was yet another challenge cited in the discussion of multiteam system work. Members most commonly said that the current training was inadequate in some way—not enough training together for crew members, did not teach crew members the right sets of skills, etc. Lastly, participants talked about how the confinement of the space context presented challenges. One participant (a non-astronaut) commented: "No matter how well you get along with people, but if you are closed up with them for a year, there will be problems…" (NASA employee #7).

Collectively, these challenges align with the broader literature on extreme teams. Indeed, confinement and isolation are typical challenges for teams in extreme settings (Bell et al., 2018; Bishop, 2004; Driskell et al., 2018), and although intended to alleviate friction, specialized training also presents issues as it mirrors the work of extreme collaborative settings and there are many faults in complicated training programs (Power, 2018). Control is also quite a common issue for teams in extreme settings, and some research has suggested that sharing leadership with more junior team members may help (Klein, Ziegert, Knight, & Xiao, 2006). Additionally, although the move towards globalization has introduced team members of all nationalities and origins to each other (Brett, Behfar, & Kern, 2006; Halverson & Tirmizi, 2008), the ways in which these MTS members interacted with their international partners was idiosyncratic. The space program is a unique collaboration where nations are working together across state lines, and the type and criticality of information exchanged happens very infrequently, if at all, outside the space program.

Prevalence of multiteam system challenges. Beyond understanding what the landscape of challenges looks like for multiteam system members, I also wanted to identify the prevalence of the different types of challenges. After analyzing the content of each challenge, I counted and summed the number of novel challenges mentioned per theme. A challenge was novel if mentioned for the first time—if a participant mentioned several communication challenges, but the examples provided for the communication challenges were distinct, they were each coded as a novel communication challenge. For instance, if a participant described a time when there were too many controlling documents from the ground and also a time when they had difficulty talking with a crew member of a different nationality, each would be a distinct communication challenge.

In Table 20, we can see that challenges occurred with relatively the same frequency. Challenges of Integration were the most prevalent at 150 instances across all 20 participants, with challenges of Structure and Climate falling closely behind at 136 and 135 instances, respectively. The challenges least frequently mentioned were those unique to the Space Context, which were mentioned 47 times across participant responses, which further supports the notion that challenges of Structure, Climate, and Integration may have more a general application across multiteam systems in various contexts. Additionally, I analyzed the challenges that were mentioned more than once (i.e., redundant mentions). Whereas communication was the novel challenge most frequently cited at 46 instances, timing was cited most redundantly at 22 redundant mentions. Timing was thus the most frequently cited challenge overall at 63 total mentions, followed by unique perspectives at 57 mentions and communication at 56 mentions. In terms of the number of participants who mentioned challenges, 18 unique participants mentioned relationship challenges, making it the most cited throughout the entire sample, followed by timing, perspectives, and communication, which were each mentioned by 17 unique participants.

Responses

In addition to the challenges of multiteam system work, I also identified and analyzed responses to understand leadership behaviors members use to resolve challenges. A complete summary of the thematic analysis of responses to the challenges of multiteam system work is in Table 21. I found multiteam system members responded to challenges by working through structural complexity, managing their contribution to the climate, and utilizing communication; they also employed responses unique to the space context and discussed a few elements not considered to be leadership behaviors.

Although themes of the responses were nominally similar to the themes of challenges, how participants described the responses demonstrated a distinct application from their challenge counterparts. Responses of *Structure* represented how participants pushed through factors imposed on them, such as timing, engagement, and problem-solving. Responses of *Climate* included factors that members contributed, often detailing the positive ways in which they participated in the collaboration, and included awareness, emotions, and expertise. Responses of *Communication* captured the methods by which members integrated behaviors, information, and people, and in this way served as the counterpart response for Integration challenges. These responses were communication, coordination, cooperation, expectation setting, collective perspective, relationship building, boundary spanning, goal management, and parsimony. Responses pertaining to the *Space Context* identified elements that were particularly unique to the space context of these multiteam systems, like independence and training. Finally, whereas all responses in the previously mentioned themes entailed some type of leadership behavior, there were several responses—leadership, performance, and expectations met—that were not leadership behaviors in and of themselves and thus fell into the theme of *Non-Leadership Behaviors*. Next, I discuss the responses in greater detail, providing definitions and select excerpts to demonstrate each, as well as variations in responses. Select quotes for all responses are in Appendix J.

Structure. Whereas challenges of Structure represented factors imposed on members, responses of Structure represented how participants pushed through external impositions. Timing is an example of this. As a response, *timing* captured having enough time and creating or following a timeline; in other words, it pertained to how participants worked with/around time to move through or mitigate a challenge. One participant highlighted a relatively simple timing response, saying: "A lesson learned out of this is the requirement that there are no meetings between noon and 1:30-2 PM, so people can actually eat…" (NASA employee #2). Onboard, one astronaut cited the following strategy: "…I'd take the time. I'd finish my other tasks early so I could start at this one early" (ISS crew member #3). Participants also talked about engagement as a response, moving through challenges by plainly doing the work required. Similarly, problem-solving was a response whereby participants worked through a range of (often technical) challenges. One participant described the response to a failure scenario: "…carbon dioxide scrubber on station… had to replace… maintenance activity that failed…" (NASA employee #4). As was the case with challenges of Structure, responses of Structure are also informed by the literature on task engagement. Both timing and engagement are well-documented aspects of task engagement (Crawford et al., 2010), and such challenge demands trigger a problem-solving response (Crawford et al., 2010).

Climate. Similar to their challenge counterparts, Climate responses represented elements that members imparted on the environment, but this time, participants took ownership of these processes in positive ways. Awareness signified when a member exhibited recognition of the broader context. When asked if any specific personal characteristics made one participant's crew so successful, he mentioned a few characteristics but ended his thought by saying: "So just, you know, being aware of each other's, uh, ups and downs. That's very important too. I've noticed that as well" (SIRIUS crew member #1). Emotions played a role in Climate responses as well. Emotions referred to either the recognition or incorporation of positive emotions or the management of negative emotions. For example, one participant noted the need to "overcome emotional obstacles and be nimble enough to make it work… and not get personal… going to have to be that way… almost turning off emotions" (NASA employee #7). There were also cases where participants discussed how positive emotions factored into their responses. Speaking of autonomy, one participant said that not only was it efficient, but "…the most pleasant way; it's the most rewarding way" to work (ISS crew member #4). Finally, expertise was something MTS members contributed in response to challenges. Expertise captured instances where members either volunteered or were asked to contribute specific/specialized knowledge. When describing how certain people acted as liaisons across the control centers, one participant recounted how a member's "knowledge of their respective systems" helped prevent miscommunication (NASA employee #6). Given that Climate responses were similar to Climate challenges, it follows that the literature on team and organizational climate helps inform this theme as well. Team and organizational climate encompass the awareness and perspectives of team and multiteam system members (Açıkgöz et al., 2014; Schneider et al., 2013), as well as members' feelings and emotions (Pirola-Merloa et al., 2002). Moreover, provided that climate forms from the social processes around members' expertise (i.e., "the policies, practices, and procedures they experience"; Schneider et al., 2013, p. 362), expertise also serves as a component of team/organizational climate.

Communication. Of all the response themes, Communication was the only one that did not take on the name of its challenge counterpart. Responses in this theme served to integrate behaviors, information, and people but were ultimately predicated on the exchange of information. As such, I found that Communication was the response that corresponded to Integration challenges, but was explicitly named as Communication to account for the true nature of these responses. Communication (as a response) captured the exchange of information via talking, emailing, documentation, and conferences. One flight director noted that "for any given day, there are 5-10 flight notes" for his review (NASA employee #3).

However, there were many specific forms of communication or processes that communication served. One process was that of coordination, or working together on a task. Whereas coordination challenges referred to the difficulties of working together, coordination responses captured the process of information exchange that allowed members to move through the challenges to work together. Speaking of joint work, one participant said that he was always following orders: "So sometimes it's more obvious, but the… you never do anything completely out of your own- on your own, at the very least, you're reading a procedure written by mission control" (ISS crew member #4). Participants also employed cooperation in response to challenges. Cooperation was characterized as members helping or supporting one another, and any references to "working as a team." Whereas coordination captured working together on a task, cooperation captured working together in a more friendly or social manner. One example of cooperation was when a participant said: "Work as a team and work with the larger team… knowing that that team …. close-by on the ground can help…" (NASA employee #7). Here, the "work" being referred to is more social and supportive, and the participant even notes that the ground is available for "help," making it a prime example of cooperation.

Participants also utilized expectation setting as a response to challenges. This response included preparing or setting procedures or a timeline. Although expectation setting can be structural (i.e., team and MTS charters; Asencio, Carter, DeChurch, Zaccaro, & Fiore, 2012; DeChurch & Zaccaro, 2013; Mathieu & Rapp, 2009), this was often an informal process whereby participants used prior lessons to improve in future situations. One crew member learned that the crew should be proactive about what mission control might ask to improve communication efficiency (SIRIUS crew member #5). Another crew member described a norm where if someone were having a bad day, they would make that known to the other crew members, which then helped the others adjust their behaviors accordingly (ISS crew member #2). A similar element of Communication responses was collective perspective. Collective perspective was when members created or, in some cases, used a shared understanding. The creation of collective perspectives often occurred over open "flight loops" where all members could hear the conversation; this was a major player for the ground teams. Additionally, one member reflected on how she attempted to create a collective perspective:

> Sometimes it took them several times, you know, three or four drafts, basically re-reading and reviewing their own, uh, radiograms, and changing them, and making sure they're basically putting them in the shoes of the MCC [mission control center] to kind of test for understanding on the other side, to make sure that, you know, they answer it adequately. (SIRIUS crew member #6)

Other Communication responses were more explicitly social. Relationship building, which was similar to, but distinct from cooperation, was focused *solely* on the social bond between two or more people and did not pertain to work in any way. Speaking of working at a distance, one participant discussed prefacing the work by building relationships:

> You need to develop a social relationship with these people so that once you are remote, you will be able to manage your relationships with them… develop a reservoir of social interactions with these folks so that you can draw on them when you are distant. (NASA employee #1)

Boundary spanning was yet another process employed in response to challenges and required or was aided by communication. Boundary spanning included instances when a member of one team would reach out to a member or members of another team. Most often, the role of CAPCOM, or Capsule Communication, filled this position, although there were additional instances of representatives who would reach out and manage communications across team boundaries. Speaking of the CAPCOM role, one participant remarked: "[That's where] the

CAPCOM can be very helpful to the flight crew and ground crew… and this is what the crew is thinking… can be the liaison between the crew and the ground…" (NASA employee #8).

Participants also exchanged information as a means by which to manage the different goals of members and teams. Goal management was thus indicated when members set goals or outcomes. Although similar to expectation setting, goal management referred specifically to situations where the conversation focused on goals or outcomes. Goal management also included any references to differing goals/priorities. One astronaut recalled a particular instance when there was not enough time in the schedule, and the response was to identify and reconcile the priorities:

> Then I would just call the ground and say, "Hey, it doesn't look like, you know- we need some help with the timeline because I have my exercise coming up, and I don't want to be late for it, so tell me what your priority is, and see if we can find some time for the activities that are not going to fit in." (ISS crew member #1)

The last Communication response was parsimony, or the simplification of information, resources, or procedures. This response included paring down the number of attendees to a meeting or the plain statement: "So the easier instructions, the simplest forms, uh, of explanation are the best" (SIRIUS crew member #1).

Although communication is considered in the research on multiteam systems, the literature on organizational communication may better reflect the responses included in the category of Communication. Myers and Myers (1982) suggested that organizational communication serves three primary functions: (1) coordination and regulation of production activities, (2) socialization, and (3) innovation; these three functions correspond to the

Communication responses. Indeed, participants cited discussions around the task (coordination, expectation setting, goal management, and parsimony), social conversations (relationship building), as well as communication that included a mix of both task and social elements (cooperation, collective perspective, and boundary spanning). Furthermore, the distinction between task and social elements of collaborative work has a long history in the team/organizational leadership literature. Bales (1950) first introduced this duality, citing task and social as the two types of leadership behaviors, a concept furthered in the Ohio State leadership studies (Halpin, 1957; Halpin & Winer, 1957; Hemphill & Coons, 1957; Stogdill, 1963) and has since created the foundation upon which the field of leadership has grown (Lord et al., 2017; Schriesheim & Bird, 1979). This distinction is particularly meaningful for leadership in the MTS setting where there is increased complexity (Luciano et al., 2018; Mathieu et al., 2001), high demand placed on formal leaders (Jonassen, 2015; Mathieu et al., 2001; Morgeson et al., 2010), and a subsequent need for informal leadership (Carter & DeChurch, 2014). Having several leaders who focus on certain facets of communication may help resolve the various integration challenges posed to multiteam system members.

Space context. There were two Space Context responses that emerged throughout the interviews. Independence, or being granted the ability to or acting on one's behalf, was one such response. Although there is a pervasive culture of control and dependence at NASA, independence remained a consistent element throughout the interview responses. There were ways that crew members in particular either negotiated or took control, and there were several references to the need to revert to the "train, trust, and turn loose" model from the earlier days of the spaceflight program. Training was the second Space Context response, and here, training referred simply to the training programs. Whereas training was often referenced in a negative way for challenges, references to training were more neutral when participants discussed responses: “Training for these scenarios is to be aware of these issues and communicate them as soon as possible” (NASA employee #3).

Due to the extreme nature of the context in which this study took place, it follows that some of the responses provided by participants were unique to the space context and align with the literature on extreme teams (similar to Space Context challenges). Training is often a means by which challenges are mitigated, especially for teams working in extreme settings (Bishop, 2004; Power, 2018; Smith-Jentsch et al., 2015). Additionally, whereas control is common a challenge for space, military, medical, and other teams of the like (Foushee & Helmreich, 1988; Klein et al., 2006), research has suggested that independence and autonomy help alleviate this and other strains of working in extreme settings (Britt, Jennings, Goguen, & Sytine, 2016).

Non-leadership behaviors. Whereas the previous themes included responses that entailed some type of leadership behavior, there were three factors discussed among these responses that were not leadership behaviors themselves. The first of these responses was leadership. Leadership referenced an individual acting as a leader, either preceded or followed by the specific actions taken by that leader. For example, one member recalled: “Our, um, the head of, yeah, the [PI] of medical, um, the medical support, he was, uh, very good” (SIRIUS crew member #2). This statement was followed by: “He was caring a lot and, um, you could communicate with him, uh, anytime and, uh, he would give you great advice,” and components of this statement were coded as different leadership behaviors. There were also a small number of cases (2) where leadership referenced informal leadership. However, given the focus of formal leadership in the interviews (as well as in NASA as an organization), these instances were considered outliers. Performance was another element in the discussion of responses that was not a leadership behavior per se. Participants would describe the actions taken, and if tied to a performance outcome, they would then discuss the outcome/completion/final decision. Lastly, participants included situations when they had their expectations met in their discussion of responses. Expectations met captured when situations or people were familiar or when participants specifically had an expectation met. Speaking of the process of becoming more experienced onboard, one participant said eventually you get to a point where "'Oh, I know what happens when this happens…'" (ISS crew member #4). Rather than denoting an individual or outcome, expectations met often served as punctuation between processes, informing processes to come.

Success of responses. This study examined the challenges and responses in multiteam system work; however, simply because a response was mounted against a challenge does not mean the challenge was successfully resolved. Because leadership assumes an effective response that resolves a challenge in some way (McGrath, 1962; Zaccaro et al., 2001), I also wanted to analyze the responses participants noted as being successful. Success was identified as anything that "works," was at some point or is needed for success, was "very" or "extremely important," or was identified as being "best." Success was also noted anytime a participant described how they successfully addressed a challenge (i.e., described the challenge and also how they moved through it towards the desired outcome). Once coded, I then cross-referenced these codes with each response and these results are in Table 22. Communication responses were the most-cited successful response: Cooperation was the most frequently cited response in successful situations with 32 overlapping pieces of text, followed by communication with 23 pieces of overlapping text, and coordination with 21 pieces of overlapping text. Both expectations set and awareness followed with 16 pieces of overlapping text each. These findings suggest that Communication responses—particularly those which support/help others and those which pertain to the task—are the most successful responses to employ when leading in a multiteam system.

Discussion

Multiteam systems are uniquely capable of addressing complex issues (Mathieu et al., 2001), and our understanding of their critical processes and outcomes has matured substantially over the last two decades (as seen in Table 1). However, critical gaps in our knowledge of multiteam system work remain. First, researchers have focused on three challenges of multiteamwork: coordination, goal hierarchy, and inter-team dynamics. Second, although leadership has been offered as a solution to multiteam system challenges more broadly (Carter & DeChurch, 2014; DeChurch & Marks, 2006; Mathieu et al., 2001), there is little in the way of how to enact leadership. Questions such as how it develops and what are the key behaviors to foster these relationships remain. Moreover, much of the existing research on multiteam systems is based in a lab setting, which neglects the vital role the MTS environment plays in its processes and outcomes (Mathieu et al., 2017; Mathieu et al., 2001; Shuffler et al., 2015). Therefore, this study provided a novel qualitative examination of multiteam system work, the aims of which were twofold: (1) to construct a more accurate picture of multiteam system functioning, which could inform (2) where and how members should focus their behaviors to build effective leadership relationships, thus addressing these challenges.

I conducted a thematic analysis of 20 interviews across 3 sets of participants, including NASA employees, astronauts on the ISS, and members of the SIRIUS analog habitat in Moscow, Russia. This analysis yielded 4 themes from a total of 20 unique challenges and 5 themes from a total of 20 unique responses. It is worthy to note that the themes across challenges and responses were quite similar. Challenges included Structure, Climate, Integration, and Space Context and responses included Structure, Climate, Communication, Space Context, and Non-Leadership Behaviors. This similarity is likely due to the fact that parsing out challenges from responses of multiteam system work was tricky; they were tightly linked. It was sometimes difficult to determine whether the participant intended for a given instance to be a challenge or response. For example, one participant described the following:

> On [a] long-distance flight, you need to have more autonomy with real-time decisions… mission control will have to understand that with communication, timelines, etc… I'm not saying they don't trust us, but they are going to have to trust the training that people will know what to do… they will have to be more tuned-in to being individuals who are working together as a team, and specialists can take care of things by themselves and then report to mission control… (NASA employee #7)

Although phrased as a response, this concept was derived from challenges the participant experienced or witnessed. Therefore, I found that in practice, challenges and responses were two sides of the same coin in practice.

There were also similarities evident at the level of challenges/responses and each response corresponded to a particular challenge, as seen in Table 23. In some cases, the challenge and responses were of the same name, but the interpretation was slightly different—

take awareness as an example. The challenge and response are both labeled "awareness," but the meaning of awareness in the context of challenges pertained to a lack of awareness, whereas the meaning of awareness in the context of responses often cited members having awareness. There were also instances where challenges and responses were two ends of a spectrum, like the challenge of control and the response of independence.

However, despite these nominal similarities, challenges unfolded in the multiteam system experience differently than did responses. For example, Structure was challenging in that difficult elements were imposed on members; responses of Structure included members powering through external elements. In terms of Climate, members either contributed factors that made the situation difficult (challenges) or made the situation better (responses). Communication was the only response that did not take on the same name as its challenge counterpart, Integration. Nevertheless, this is quite telling, as it suggests that communication is the response to the challenges of integration, which is a hallmark for multiteam system work (Davison et al., 2012; DeChurch & Marks, 2006; Firth, Hollenbeck, Miles, Ilgen, & Barnes, 2015; Lanaj, Hollenbeck, Ilgen, Barnes, & Harmon, 2015; Marks et al., 2005; Mathieu et al., 2001). It was also informative to see which challenges and responses were unique to the Space Context, as well as which elements in the discussion of responses did not include leadership behaviors.

Additionally, some responses did not fall under the same theme as they did for challenges. One example of this was expectations. There was one challenge around expectations, which was when participants' expectations were unmet, and this fell under the theme of Climate. There were two responses around expectations, including when expectations went unmet and when they were set; expectations met fell under Climate, matching its challenge counterpart, but expectations set fell under Communication. Another example of this discrepancy was performance, which was a challenge of Structure but a Non-Leadership Behavior response.

I also found that challenges and responses were complex in and of themselves, typically covering multiple themes within one challenge/response. An example of a challenge that covered multiple themes is this participant's discussion of meeting coordination (the challenges are italicized in brackets):

> What was happening there was a race between the next flow control valve troubleshooting team and the EVA team [*timing, Structure*]… EVA wanted to plan because the troubleshooting team couldn't sustain over long time… the flow control team wanted to get to that configuration to control long time [*perspectives, Climate*]… troubleshooting team couldn't prove it was fixed, but they were thinking it a risk to wait… we might be able to work the valve, it's labor-intensive to limp along to bring the new suits up [*priorities, Integration*]… (NASA employee #2)

The same was true in many of the responses: "I mean eventually you get experienced enough that you know, 'Oh I know what happens when this happens [*expertise, Climate*], this is what you do [*problem-solving, Structure*],' and I'll just call them [*communication, Communication*] and tell them I fixed it [*independence*]" (ISS crew member #4). That challenges and responses crossed multiple themes is not particularly surprising, given the complex nature of multiteam systems (Luciano et al., 2018; Mathieu et al., 2000), but may suggest that training interventions for multiteam systems specialize in covering several types of challenges simultaneously, rather than isolating a particular training objective as most training programs do. Although this will pose a challenge to those creating and administering the multiteam system training, it will likely be a key component in the success of future training programs aiming to improve this kind of collaboration.

Furthermore, results of this thematic analysis found that certain subsamples of the data did not discuss a number of challenges and responses at all. These factors were thus excluded from the final themes because they were not ubiquitous of the multiteam system experience. The three challenges that were not mentioned in at least one subset of the data were leadership (i.e., mentions of formal or informal leadership, or hierarchy), individual (i.e., challenges facing an individual or resulting from working as an individual), and dependence (i.e., a requirement to rely on others). There was only one response not mentioned in at least one subset of the data, which was privacy. Privacy represented either private communications or was in the context of privacy in confinement. Although it was not common to have an entire subset not discuss one of the challenges or responses, it appears that responses were relatively more of a shared experience than were challenges since there was only one (versus three of the challenges) that did not appear across a set of participants. This finding may allude to responses being a more shared experience across multiteam systems, whereas challenges may be more idiosyncratic to the multiteam system. Future research would benefit from continuing this exploration to determine which, if any, of the challenges are not universal across all multiteam systems.

Finally, after analyzing the interviews and looking at each theme, both within and across challenges, I noticed one key pattern: multiteam system work is paradoxical. Although prior work has recognized the paradoxical nature of multiteam system work, it has been in the context of integrating different teams for one shared purpose (Shuffler & Carter, 2018; Luciano et al., 2018) or in the context of countervailing forces (DeChurch & Zaccaro, 2013). However, this study uncovered several more specific paradoxes of multiteam system work, which may have contributed to prior confusion or mixed findings in the literature. For example, there was a Structure paradox whereby participants described task engagement as being highly individualized, but also never doing anything alone because the crew was always working with the ground. With Climate, many speak of everyone being a member of the team and not discerning where the team boundaries fall, and yet participants often imposed boundaries in places where MTS scholars would not objectively place them. Integration challenges also demonstrated paradoxes—participants reported daily communication between the crew and ground, and still so many reported instances of a disconnect between these two “teams.” Even those challenges unique to the space context were paradoxical, as crew members expressed times when they felt challenged because there was too much participation on behalf of the ground, but also felt challenged when the ground did not pay adequate attention or provide enough participation. Moreover, there were instances of paradoxes within a theme or subtheme—for example, the paradox of MTS Climate challenges. Although both stemmed from different sets of knowledge available to members, they exhibited one crucial difference: Perspectives created challenges by members imposing their views on others, whereas awareness created challenges by *not* considering others’ views. With this in mind, it may be the case that paradoxes constitute at least one part of the black box of multiteam system “complexity.”

Given the findings of this study, effective multiteam system leadership may lie in recognizing and resolving the paradoxes of multiteam system work. This finding supports and provides further insight to the work in this area, which has suggested the need for informal leadership in addition to formal leadership (Carter & DeChurch, 2014). However, whether this finding explains the need for leaders to move between the team and MTS levels (Mathieu et al. 2001; Morgeson et al., 2010) such that these challenges capture the more specific transition between the levels, or adds a pillar to our understanding of MTS leadership remains to be seen. Future research would benefit from exploring the relationship between these challenges and the movement of leaders between the team and system levels to understand how the challenges of MTS work relate to the previously identified challenges of MTS leadership.

Contributions

This study makes several contributions that span both the science and practice of multiteam systems. Concerning its contribution to science, this study is one of the first qualitative examinations of multiteam systems via interviews with members. Although prior quantitative work has been critical for forging our initial understanding of multiteam systems, this study adds depth to this understanding and, in this way, has expanded our understanding of the challenges of working in multiteam systems in the field. For example, most studies have focused on the challenges of coordination, goal hierarchy, or inter-team dynamics. This study found these represent only *one* theme in the challenges of multiteam system work (Integration); there are at least two other themes of challenges that multiteam system members face. Furthermore, because members do not seem to be experiencing these challenges in isolation, it is likely the case that prior studies may not have captured a full picture of coordination, goal hierarchy, or inter-team dynamics. Future research may build on this by examining the compound or moderating effects of multiteam system challenges, similar to the work of Davison et al. (2012) who found that between-team coordination had adverse effects at the team level but effects at the MTS level only when coordination efforts focused on the most critical team, or

Lanaj et al. (2013) who found that decentralized planning was positive for the multiteam system but that the adverse effects of this type of decentralization created excessive risk-seeking and coordination failures and thus offset any positive effects.

The current study is also one of the first to consider the context or environment of multiteam systems in its analysis, which recent work on multiteam systems has identified as a critical next step in moving the field forward (Mathieu et al., 2017; Shuffler et al., 2015). Consideration of the environment in the analysis of multiteam systems is particularly important, given the role that the environment plays in the formation, processes, and even the outcomes of multiteam systems (Mathieu et al., 2001; Shuffler et al., 2015). Rather than merely stating that "multiteam systems are complex," this study demonstrated precisely how this is true. Therefore, I hope this study serves as a substantive look into the black box of MTS complexity, as well as a springboard for others to further codify the intricacies of multiteam systems towards an understanding that will help leverage the unique capabilities of these systems in meaningful ways.

Additionally, there are important practical contributions of this study. Several findings may help improve the development of interventions focused on training skills for multiteam system work. Indeed, understanding the problems that multiteam system members face as they work across team boundaries toward superordinate goals highlights where training interventions should focus their efforts. For example, timing and task engagement present considerable Structure challenges, more so than having an overload of information or working through a technical issue. Multiteam systems members should also understand how internally derived factors can manifest the individual level, *as well as* at team and multiteam system levels, and something as simple as recognizing other teams/members may help prevent points of friction in the course of collaboration. In terms of Integration challenges, communication and relationships are the most prevalent challenges (not coordination), and so it could be helpful to boost the focus on these elements in MTS training as well.

Moreover, understanding what members naturally do in response to these challenges (and when responses do or do not produce successful results) can serve as vital counterbalances in these training programs (i.e., whereas most people respond to Challenge X with Response Y, research suggests that Response Z is more effective because…) This information is critical as more and more teams are banding together to tackle incredibly complex issues. Surely many, if not all, team members have worked in multiteam systems whether they knew it or not, and the trend towards this type of collaboration shows no signs of stopping: Interplanetary destinations are the next frontier for spaceflight (NASA, 2015), political conflict is now a multifaceted endeavor as was the case with September 11th and the Iraq War (McChrystal et al., 2015), natural disasters increasingly plague the southeast United States prompting more emergency response multiteam systems (DeChurch & Mathieu, 2009; Emrich & Cutter, 2011), and the complications of worldwide pandemics can ravage even the most developed countries (Tufekci, 2020). Therefore, being able to provide accurate information and effective training on multiteam system challenges and leadership behaviors will likely benefit a wide-reaching audience—anywhere from NASA's mission to Mars to a local community fundraiser.

Limitations and Directions for Future Research

This study presents an examination of multiteam systems through qualitative analysis of interviews with some of the most cutting-edge space multiteam systems, and in this way, provides a substantial contribution to our understanding of multiteam systems; however, there are several limitations of the current study. First, all interviews were archival and as such, specific interview questions pointed at multiteam system challenges and responses could not be included in this analysis. Although discussion of multiteam system work and switching between tasks and levels of the multiteam system (i.e., individual, team, and MTS) naturally addressed challenges of this work, the interview protocol could be made stronger with questions derived explicitly from the research questions. On a related note, the interviews with NASA employees were conducted several years before this analysis and did not include audio recordings; only notes from the interviewers were available. I used the history of the shared files where researchers recorded their notes to reconstruct the interviews as accurately as possible, combining the notes of several researchers for each response where available. Still, I had to rely only on what was captured in the notes, so it is possible that some data was either not captured or removed due to uncertainty in the reconstruction process. Finally, members of the SIRIUS crew did participate in an active multiteam system simulation, but there was a critical manipulation of this mission: autonomy. There were several instances over the 120-day simulation where the crew and mission control acted together, but cross-team collaboration was less frequent than would be expected for an average space mission. Regardless, this manipulation adds a noteworthy layer to the analysis of multiteam system work, as globalization (in more traditional forms of team- and multiteamwork) becomes more prevalent in collaborative settings. Future research may benefit from exploring the role of autonomy in multiteam work—qualitative or otherwise—as the trend of globalization continues.

Still, there are several paths of research that stem from the current study. The first is concerned with refining the scope of the investigation. Future research would benefit from the thematic analysis of multiteam work using interview protocol more tailored to the challenges and responses of multiteam system work. Again, the general discussion of multiteam system work, as well as the challenges of switching between tasks and levels of the multiteam system unearthed 20 unique challenges and 20 unique responses. However, future research should confirm that the archival nature of the dataset did not suppress additional challenges or responses. Additionally, future research should conduct thematic analysis of challenges and responses with different types of multiteam systems. Space is just one context for multiteam work, but many other multiteam systems can inform our understanding of the challenges and leadership responses in this setting. Emergency and disaster response efforts, airline crews, and technological innovators would all serve as informative contexts under which researchers could examine the challenges and responses of multiteam system work.

Second, future research would benefit from a more robust understanding of successful responses in multiteam systems. This study analyzed the interviews of different members of the multiteam system who may or may not have worked together. As such, the analysis of successful responses was limited compared to the total number of responses. To better triangulate legitimately successful responses, future research may consider interviewing entire intact multiteam systems as a way of understanding where responses are viewed collectively as successful. This would provide further evidence for multiteam system experiences that are ubiquitous, versus more idiosyncratic ones. Future research may also consider conferring the challenges of multiteam system work in this way to understand which challenges are more or less important, if the importance varies based on context, and so on.

The third path forward from this research is to use the findings to improve the Project RED training intervention (DeChurch & Niler, 2019). Indeed, the Project RED intervention was designed to teach participants the skills needed to build effective relationships to combat three challenges of multiteam system work: coordination, goal hierarchy, and inter-team dynamics. However, results from this analysis suggest that those are not the only challenges faced by multiteam system members. Not only are there more unique challenges, but the challenges derive from different themes. It would therefore be fruitful to redesign the Project RED training intervention to help participants navigate some of the most pressing challenges from each theme: timing and engagement (Structure), unique perspectives and unmet expectations (Climate), and communication and relationships/inter-team dynamics (Integration). NASA may also consider including working with international partners and control to address challenges unique to the space context. Improvements may include slight modifications to the task and its instructions to reinforce certain elements, such as engagement or unique perspectives, and use prompts that ask participants to reflect on factors like timing or their expectations as they move through the task (mainly from the team to the multiteam system phase, or even in the middle of the MTS phase).

Finally, future multiteam systems research would benefit from both diversification of challenges explored, as well as a continuation of qualitative analysis to understand other processes and outcomes more deeply. Whereas prior work—primarily quantitative and based in the laboratory—has worked to understand factors like coordination, goal hierarchy, and inter-team dynamics, findings here indicate that these are but a small portion of challenges multiteam systems face. Future research may start to investigate other challenges, such as timing or awareness, or disconnection more thoroughly in both quantitative and qualitative forms. The field would also benefit from taking a deeper dive into the previously examined team and multiteam phenomenon to better understand how they unfold. For example, there has been some work on countervailing forces in multiteam systems, where the dynamics that benefit the team hinder the system, and vice versa (Asencio et al., 2016; DeChurch & Zaccaro, 2013). It would be helpful to understand the intricacies of this relationship, which may not be apparent from quantitative analysis alone. We may ask: How do these forces develop, are they more common for certain processes than others, how does this affect the experience of working in a multiteam system, and are there particular ways to address these forces that we have not yet uncovered?

Conclusion

Multiteam systems, although a relatively new facet of the collaborative landscape, have come to be both common and critical in addressing some of the most pressing issues of our time. Research on multiteam systems had previously focused on quantitative analysis of three core challenges, including coordination, goal hierarchy, and inter-team dynamics; however, qualitative analysis suggests that there are 20 unique challenges, in addition to 20 unique responses employed in reaction to these challenges. As such, this study opens up an entirely new path for researchers to explore multiteam system processes and outcomes more deeply. This kind of analysis is arguably a requisite for the field, given multiteam systems' tight coupling with their environment and their level of complexity. An understanding characterized by numbers has served as a strong foundation for this line of work, but a richer examination of multiteam systems is the natural next step for the field in order to reach the next frontier of advances.

CHAPTER 5

CONCLUSION

Multiteam systems enable critical collaboration across teams with various expertise (Mathieu et al., 2001). MTSs are prevalent in acute situations, like the task forces currently in action due to the worldwide pandemic; MTSs are also prevalent in more traditional organizations that combine teams working across functions or geographic locations. Research over the last two decades has illuminated the core features of multiteam systems, as well as some of their most pressing challenges and potential solutions (Mathieu et al., 2017; Mathieu et al., 2001; Shuffler et al., 2015). Indeed, coordination, goal hierarchy, and inter-team dynamics are challenges that multiteam system members face as they work together across team boundaries (Cuijpers et al., 2016; DeChurch et al., 2012; Lanaj et al., 2018; Marks et al., 2005; Mathieu et al., 2001; Porck et al., 2019; Rico et al., 2017), and leadership holds great potential for mitigating those problem areas of MTS work (Bienefeld & Grote, 2014; Carter, 2014; DeChurch & Marks, 2006; Mathieu et al., 2001; Murase et al., 2014). However, these findings have only scratched the surface of a very rich and complex set of collaborative interactions. This dissertation sought to dig through the complexity and explicate MTS leadership as it occurs in the true environment to strengthen our understanding of how to create effective inter-group relationships to improve multiteam system processes, and ultimately, success.

First, multiteam systems are complex and Mathieu, Marks, and Zaccaro (2001) identified leadership as a critical lever for MTS success, but there is no indication of what these terms mean for multiteam system functioning. In this way, complexity has become a bit of a black box for multiteam system researchers, and though some have started to clarify the processes and procedures of MTS work (as seen in Table 1), findings may either be incomplete or mixed. In terms of leadership, the lack of specificity around who leaders are or are not, what they should or could do, etc. has led to a murky concept of leadership that is often unactionable. Furthermore, this lack of specificity is particularly problematic since multiteam systems are quite active and evolve based on their surrounding environment (Luciano et al., 2018; Mathieu et al., 2001).

More to this point, the second significant gap in multiteam systems research is that despite being a product of their unique environment, the majority of research on these systems took place in a laboratory setting. In fact, several reviews of multiteam system research over the last five years highlighted the lack of field studies and suggested that not only should future research move in this direction, but also that it will be a critical next step in the progression of this line of work (Mathieu et al., 2017; Shuffler et al., 2015). Therefore, this dissertation asked how multiteam system members can create conditions that support the emergence of effective inter-group relationships; in the course of three studies, which employed progressively richer analytic approaches, I sought to answer this question.

The first study investigated the emergence of informal leadership relationships in multiteam systems. Informal leadership is particularly important to understand in multiteam systems because it becomes necessary as formal leaders are preoccupied moving between the team and system levels, and thus micro and macro functions (Jonassen, 2015; Mathieu et al., 2001; Morgeson et al., 2010). Therefore, using a mixed lab-field design, I tested the link between three categories of social forces and the formation of informal leadership relationships in multiteam systems: (1) social norms, including reciprocity, closure, and popularity; (2) social differentiators, including disciplinary team membership and propinquity; and (3) cognitive factors, including task- and team-related shared mental models. There were 10, 12-member multiteam systems; 4 of the MTS members were astronaut candidates in a space analog in Houston, Texas (i.e., HERA; Cromwell & Neigut, 2014), and the other 8 members were student participants at a southeastern university. Results of the ERGM analyses suggested that all three types of social forces affected the development of MTS leadership ties, but social differentiators had the strongest and most positive influence on the formation of these relationships. Thus, I found that members have more insular tendencies when looking for leadership in a multiteam system environment, and these findings run counter to what the research suggests is the purpose of multiteam system leadership: To bridge the gap *between* teams (DeChurch & Marks, 2006; Mathieu et al., 2001; Murase et al., 2014).

With this information, it became clear that multiteam system members likely need training and guidance if they want to develop effective inter-group relationships in the MTS setting. Therefore, I created an intervention called Project RED tabletop to help train members on how to develop the skills necessary to create these MTS leadership relationships (DeChurch & Niler, 2019). The intervention poses the scenario that for the upcoming mission to Mars in 2030, there needs to be a proper landing site selected. Members either have expertise in Human Habitation (i.e., atmosphere, water, or terrain) or Scientific Discovery (i.e., human life, climate, or geology). After selecting the best location (of the four possible) as an individual and then with their team, participants meet with the other team to come to a multiteam system decision regarding where to land. As with any multiteam system, each individual has some shared and some unique information about each of the four locations. Moreover, different teams have different team-level goals, but they are united in their shared system-level goal. I tested the intervention’s ability to improve skills around the three core MTS challenges identified in the conceptual review: coordination, goal hierarchy, and inter-team dynamics. After conducting a series of tasks in a two-group pre-test/post-test design, I found some evidence for the efficacy of this task. Although the ANOVA results for coordination, goal hierarchy, and inter-team dynamics showed no significant differences, post hoc *t*-tests suggested that students did learn from Project RED tabletop: There were significant increases in coordination and inter-team dynamics after Project RED when compared to before Project RED. Additionally, linguistic analysis of the open-ended responses after the control and intervention tasks indicated the reaction to the Project RED intervention was overwhelmingly positive, and there was a shift towards more plural and collective language after Project RED as well. However, there was one curious finding from this study, which was the relative gap between participants’ quantitative and qualitative reporting of goal hierarchy. There were no significant changes in goal hierarchy between the pre- and post-tests of either the control or intervention tasks, but goal hierarchy was talked about most frequently in the responses that followed both tasks.

The discrepancy between the quantitative and qualitative reporting of goal hierarchy led me to reconsider our broader understanding of multiteam systems: does our academic laboratory-based concept of multiteam systems match the field experience of this type of work? I was particularly interested in the challenges of MTS work and responses to those challenges, so I conducted a thematic analysis of interviews from a sample of 20 members from across the NASA organization, astronauts who recently flew on the ISS, and members of the SIRIUS analog crew from the 2019 4-month mission. I found evidence not only of the previously identified challenges, but 17 additional challenges for a total of 20 unique challenges that spanned four themes: Structure, Climate, Integration, and Space Context. I also found 20 unique responses to challenges across similar themes: Structure, Climate, Integration, Space Context, and Non-Leadership Behaviors. Taking a more in-depth look at the challenges and responses across these themes, I found that the typical challenges the multiteam systems literature has focused on are bound in one theme, Integration; however, there are three other types of challenges that MTS members face. Additionally, I found that challenges and responses were often tightly coupled and shared many properties—awareness presented a challenge when members lacked it, but awareness offered a response when members possessed it. It was also the case that challenges and responses were complex in and of themselves. Oftentimes a focal challenge or response would contain several component parts across different themes. Finally, I found several paradoxes with and across themes that may account for the mixed findings of prior MTS research and suggest that multiteam system leadership may lie in recognizing and resolving these paradoxes. These findings, along with other aspects of this dissertation have implications for the science and practice of multiteam systems—particularly for MTS leadership.

Contributions

Scientifically, there are several contributions offered by this dissertation. First, the conceptual review in Chapter 1 provides a review of the multiteam systems literature organized by the core challenges of multiteam system work. Organizing the literature in this way clarifies where empirical work on multiteam systems has been concentrated thus far. Not only does this summarize the prior work of the field, but it allows future researchers to test these three challenges and identify their limits. Within the bounds of this dissertation alone, I have shown that coordination, goal hierarchy, and inter-team dynamics *are* just a snapshot of all challenges that multiteam system members face and derive from only one of the three ubiquitous themes presented in my analysis (or four themes, if we consider an extreme multiteam system). Therefore, I have summarized the body of work in this area, and also shown the limited scope of research on the challenges of multiteam system work.

Beyond extending the scope of our understanding of the challenges of multiteam system work, this dissertation contributes to the science of multiteam systems by studying them with increasingly deep methodologies and rich contexts. I began my work analyzing multiteam systems in a mixed lab-field setting, moved to a classroom setting for the training intervention, and concluded by studying the interviews of real multiteam system members. I thus answered the call put forth by several reviews to consider the environment in MTS research (Mathieu et al., 2017; Shuffler et al., 2015) and provided one of the first interview-based qualitative analyses of multiteam systems. Not only is this important for moving the field forward by gaining a more complete understanding of multiteam systems, but it is especially critical given the role the environment plays in shaping multiteam system formation, processes, and outcomes (Mathieu et al., 2001).

Finally, the work in this dissertation also contributes to the science of multiteam systems by developing a leadership intervention to shape their processes and effectiveness. As Cooke and Hilton (2015) acknowledged, “leader and team member skills and knowledge are essential to foster effective team science” (Leadership Development For Team Science Leaders, para. 1); one way to further skills and knowledge is through training interventions. Although there are established interventions at the team level (Day, Gronn, & Salas, 2004; Salas, DiazGranados, Klein, Burke, Stagl, Goodwin, & Halpin, 2008), team principles do not transfer linearly to multiteam systems. This dissertation thus contributes to the literature on multiteam systems by providing the first intervention explicitly tailored to multiteam system leadership.

The Project RED tabletop tool also serves as a practical contribution of this dissertation. NASA is aware of the importance of multiteam systems and the prevalence of these systems in the work they do, and Project RED tabletop speaks directly to NASA's objective for countermeasures to support multiteam systems and multiteamwork via training. Indeed, Project RED tabletop may be administered to any member of the organization (or any space organization throughout the world) to help members learn how to work together and develop effective inter-group relationships with their fellow multiteam system members. Additionally, although situated in a specific context, Project RED tabletop can be used in a variety of environments, as the second study showed by using the classroom context to test the efficacy of the intervention. The intervention is inclusive in that there is no expertise required to participate (space or otherwise), so any multiteam system could use and benefit from it. Directors of centers and other high-level administrators—particularly those heading interdisciplinary efforts, like disaster response, community organizations, and technology innovation—may find great value in this exercise.

Limitations

This dissertation certainly makes contributions to both the science and practice of multiteam systems; however, it is essential to acknowledge that there are also some limitations of these studies. In the first study, which used ERGMs to examine potential antecedent social forces of MTS leadership relationships, the majority of the sample was student participants enrolled in scientific curriculum. Although they were likely comparable to the target population, there may be important differences in this sample when compared to those in the target population. For example, there were minimal consequences for shoddy work by one member for other members of the MTS in the context of this study, which is not the case in the target population where mistakes may mean life or death for fellow members. It was also the case that HERA crew members participated in the task up to three times, whereas the mission control members only participated in the task once. Therefore, despite controlling for other formal leadership roles like the crew commander and the mission control habcom role, the HERA crew's familiarity with the task may have provided those members with an advantage to asserting leadership. Related to this, there was one member in each system who represented both formal *and* informal leadership: The habcom role (formal leadership) was also a member of the Geology team (informal leadership). As such, interpretations of the effect of formal and informal/expertise-based leadership should be interpreted with caution. Finally, given the nesting of the analytic approach used in this study, with comparisons of the ERGM and each MTS network, I maintained the reciprocal term ("mutual") in the model despite its lack of fit in multiteam systems 4 and 6. In a non-nested design, I would instead model the idiosyncrasies of the networks to find a better fit for the reciprocal term.

In the second study, although the classroom setting was a useful context in which to test this intervention, it may have also been a limitation. The students may not have been as invested in the task as a real team would be when participating in a training intervention (although I did measure and control for task engagement to help mitigate this). It is also possible that other activities or learning objectives of the broader course confounded the effects found in either the Towers Market or Project RED tasks. Given that the course was on "Leading Collaboration," students may have developed critical collaboration skills related to coordination, goal hierarchy, and intra/inter-team dynamics outside the context of Towers Market and Project RED. Lastly, there were two main limitations of measurement. The first was a lack of consideration for challenges beyond those of integration. With the knowledge gained from the qualitative analysis in Chapter 4, I would recommend the design of new measures to capture the themes of challenges (i.e., Structure, Climate, and Integration). Additionally, the phrasing of the intra-team dynamics measures before and after the Towers Market activity were similar, but not identical, and so the comparison across tasks may not be completely accurate.

Finally, there were a few limitations of the thematic analysis of interviews—namely that the interviews were entirely archival. Therefore, the interview protocols could not be crafted (or revised in real time with participants) to probe about the challenges and responses of multiteam system work. Although these topics were certainly discussed in the course of each interview by way of covering multiteam system work generally, as well as the switches between tasks and levels of the multiteam system (i.e., individual, team, and MTS), the protocol may have been stronger if it were an ongoing study, rather than archival. A second limitation of this study was that the interviews with NASA employees were conducted several years prior with only researcher notes and no audio recording. This meant that I was able to reconstruct the timeline and combine researchers' notes for each response. Still, it is possible that some data was either not captured originally by researchers, or that questions and accompanying responses were removed if they could not be verified in the reconstruction of the interviews. Third, whereas typical multiteam system work requires interdependence of teams on one another, the SIRIUS mission was conducted as part of a broader research objective, which included autonomy for the 2019 mission. Particular tasks did require multiteam work with mission control and the faculty who conducted the research, but interdependence was not salient for these crew members. Therefore, their reporting of multiteam system experience was less extensive than would typically be expected.

Directions for Future Research

Looking ahead, future research will be helpful in, and benefit from, addressing these limitations. There are three main areas for future research to focus on that stem from the findings in this dissertation. The first is to continue to improve the Project RED tabletop training intervention. Currently, the training intervention centers on three core challenges of MTS work: coordination, goal hierarchy, and inter-team dynamics. Although these three challenges were confirmed in the qualitative analysis that followed, they represented just 3 of 20 total challenges in just 1 of 4 themes, faced by multiteam system members in the course of collaboration. Especially considering that several themes contributed to each challenge, it would be beneficial to emphasize additional challenges from other themes in the intervention. For example, task instructions may be adjusted to reinforce the elements of engagement or unique perspectives. The intervention may also use additional prompts asking participants to reflect on things like timing or how their expectations influence their interactions with fellow MTS members across different teams.

Furthermore, it would be helpful to validate Project RED tabletop in an environment where there are fewer potential confounds. Future research may administer the control and intervention tasks in consecutive weeks to decrease the chances for outside class material to impact the results, as well as counterbalancing and administering Project RED tabletop before Towers Market in a comparison sample. Finally, future research would benefit from validating the task in a real-world setting, to parse out the effects that are specific to the classroom setting (i.e., systematic biases in the way students approach multiteamwork versus the way professional teams approach multiteam work).

Future research would also benefit from continuing to improve the Project RED tabletop training tool (DeChurch & Niler 2019). The intervention showed promising results in Chapter 3; however, results from Chapter 4 suggest important areas for further improvement. For example, the current Project RED tabletop focuses on three challenges: coordination, goal hierarchy, and inter-team dynamics, which are all challenges of integration. In contrast, Chapter 4 uncovered 13 additional challenges (17 when counting those unique to the space context) from at least 2 new themes. As such, it would be helpful to update Project RED tabletop to reflect challenges from additional themes. Adding reminders to press timing, prompts to highlight unique perspectives and expectations, and a post-task exercise to consider task engagement would all be fruitful avenues for improving the training intervention.

The second main area where future research should focus is the continued qualitative analysis of multiteam systems. It would be helpful to conduct additional studies of multiteam system challenges and responses with a more pointed interview protocol to be able to verify the challenges/responses uncovered in this dissertation. Participants all described challenges and responses through a broader discussion of multiteam system work, as well as shared cognition and task switching, but interview protocol tailored to the research questions and the ability to conduct live follow-up questions to key points raised would certainly strengthen these findings. Similarly, it would be helpful to interview fully intact multiteam systems to gain a better understanding of responses to challenges of multiteam system work. The analysis in this dissertation could not verify the extent to which responses were successful or even helpful in addressing challenges. Members may or may not have worked together, and simply because a response was mounted and one member thought it was successful does not mean the other members in the system viewed the response the same way. Interviewing complete multiteam systems will allow future research to more accurately triangulate how successful (or not) specific responses were, further clarifying where leaders should focus their behaviors to be successful. This will also provide evidence for multiteam system experiences that are either ubiquitous or idiosyncratic. Related to this point, future research should conduct this analysis in different multiteam systems to understand which, if any, challenges or responses are dependent on the multiteam system context (e.g., space vs. disaster response vs. technology vs. medical).

The third and final area where future research may build on the work in this dissertation is to diversify the challenges explored—both quantitatively and qualitatively. Table 1 demonstrates how the vast majority of multiteam systems research has focused on coordination, goal hierarchy, and inter-team dynamics. Nevertheless, there are a great many more challenges that multiteam system members face that have yet to be explored in this context. Work that explicates the effects of timing, awareness, and disconnection, among others, will help push the field of multiteam systems research forward.

Conclusion

Looking to the future of collaboration, it will be critical to further our understanding of multiteam systems. These systems are uniquely capable of addressing the challenges we now routinely face, and MTS members have been able to accomplish far more than singular teams over the last two decades. However, as this dissertation demonstrated, the field may be at a critical point of growth. Whereas the current research has provided a strong foundation, this area has now matured to a point where field research is likely to yield additional new theory and practical insights.

Table 1

Multiteam System Challenges Identified in Prior Research

Article	Year	MTS Challenge(s) Examined
Marks, Mathieu, Panzer, and Alonso	2005	Coordination processes used to integrate component teams
DeChurch and Marks	2006	Coordination processes used to integrate component teams; leadership
DeChurch, Burke, Shuffler, Lyons, Doty, and Salas	2011	Coordination processes used to integrate component teams; leadership
Cianciolo and DeCostanza	2012	Coordination processes used to integrate component teams; communication and interpersonal relationships
Davison, Hollenbeck, Barnes, Sleesman, and Ilgen	2012	Coordination processes used to integrate component teams; leadership
DeChurch, Doty, Murase, and Jiménez	2012	Coordination processes used to integrate component teams; leadership, communication, and inter-team dynamics
Bienefeld and Grote	2013	Coordination processes used to integrate component teams; communication
de Vries, Hollenbeck, Davison, Walter, and van der Vegt	2013	Coordination processes used to integrate component teams
Lanaj, Hollenbeck, Ilgen, Barnes, and Harmon	2013	Coordination processes used to integrate component teams; leadership/planning
Bienefeld and Grote	2014	Coordination processes used to integrate component teams and goal hierarchy
Carter	2014	Inter-team dynamics; leadership
Murase, Carter, DeChurch and Marks	2014	Coordination processes used to integrate component teams
Firth, Hollenbeck, Miles, Ilgen, and Barnes	2015	Coordination processes used to integrate component teams
Cuijpers, Uitdewilligen, and Guenter	2016	Coordination processes used to integrate component teams and inter-team dynamics
Rico, Hinsz, Burke, and Salas	2017	Goal hierarchy and inter-team dynamics

Lanaj, Foulk, and Hollenbeck	2018	Goal hierarchy; leadership
Olabisi and Lewis	2018	Coordination processes used to integrate component teams
Rico, Hinsz, Davison, and Salas	2018	Coordination processes used to integrate component teams and inter-team dynamics
Huggins and Scheepers	2019	Coordination processes used to integrate component teams and inter-team dynamics; leadership
Porck, Matta, Hollenbeck, Oh, Lanaj, and Lee	2019	Inter-team dynamics
Wijnmaalen, Voordijk, Rietjens, and Dewulf	2019	Coordination processes used to integrate component teams and inter-team dynamics
Mell, DeChurch, Contractor and Leenders	In press	Coordination processes used to integrate component teams and inter-team dynamics

Table 2

Plan of Study and Analysis

	Research Question	Setting	Data Source(s)	Analysis Plan
Study 1	How do multiteam system features/forces impact the formation of leadership relationships?	NASA HERA	Surveys (quantitative responses)	ERGMs (Lusher, Koskinen, & Robins, 2013)
Study 2	Does MTS leadership training lead to improved coordination, understanding of goal hierarchy, and inter-team dynamics?	Classroom	Surveys (quantitative and qualitative responses)	ANOVA
Study 3	What are the challenges/ leadership needs of working in an MTS?	NASA employees, NASA ISS & RKA SIRIUS	Interviews	Thematic Analysis (Braun & Clarke, 2006)

Table 3

Descriptive Statistics of Focal Study Variables

	Unit of Analysis	*Min*	*Max*	*Mean*	*SD*
Leadership ties (in-degree)	120 individuals	0	8	1.56	1.57
Task mental models (in-degree)	120 individuals	0	11	6.82	2.91
Team mental models (in-degree)	120 individuals	0	11	6.58	2.70
Leadership reciprocity	10 MTSs	0	.45	.19	.15
Leadership transitivity	10 MTSs	.08	.60	.34	.16

Table 4

ERGM Predicting Leadership Tie Formation

Predictors	*Full*	*MTS 1*	*MTS 2*	*MTS 3*	*MTS 4*	*MTS 5*	*MTS 6*	*MTS 7*	*MTS 8*	*MTS 9*	*MTS 10*
	—	*Crew 1*			*Crew 2*			*Crew 3*		*Crew 4*	
	Estimate (SE)	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*	*Estimate (SE)*
Edges	-7.11*** (.23)	-4.42*** (1.23)	-6.39*** (1.85)	-5.06** (1.63)	-2.64* (1.09)	-3.81*** (1.03)	-4.04*** (.75)	-4.40*** (1.24)	-4.50*** (1.04)	-2.91** (1.07)	-4.05*** (.94)
Formal Leadership	.25 (.20)	.79 (.68)	1.57† (.84)	-.07 (.68)	3.11*** (.93)	.72 (.60)	-.69 (.73)	.41 (.80)	-.50 (.77)	-.78 (.77)	-.60 (.69)
Expertise-Based Leadership	1.03*** (.17)	2.32** (.90)	2.08* (.96)	1.95** (.62)	-.32 (.99)	1.66** (.57)	.08 (.59)	.76 (.81)	1.61** (.61)	1.85** (.62)	.88† (.49)
Reciprocity	-.78* (.37)	-1.25 (1.39)	-2.03 (1.46)	.18 (.83)	—	-1.54 (1.27)	.59 (.89)	-1.01 (1.43)	—	-.66 (.95)	.13 (.80)
Transitivity	1.03*** (.13)	-.08 (.59)	-.50 (.83)	.11 (.36)	.24 (.81)	.53 (.47)	.72* (.29)	-.13 (.96)	.59 (.41)	-.27 (.46)	.69* (.31)
Team Membership	1.60*** (.19)	2.19** (.84)	4.30*** (1.30)	2.31*** (.60)	.57 (.92)	2.05** (.72)	.61 (.69)	2.51** (.82)	1.31* (.61)	1.20† (.64)	1.57** (.56)
Propinquity	1.52*** (.11)	.12 (.42)	.34 (.46)	.04 (.32)	-.66 (.59)	.10 (.39)	.98** (.31)	.97* (.46)	.87* (.38)	.92* (.39)	.88** (.33)
Cognitive Task Similarity	.45* (.20)	.41 (.81)	.75 (1.02)	2.50† (1.35)	.43 (.90)	1.81* (.76)	-1.73* (.74)	-.40 (.73)	-.29 (.83)	-.88 (.66)	-.89 (.55)
Cognitive Team Similarity	.66** (.21)	.73 (.95)	1.03 (1.03)	-.09 (.62)	-.43 (1.00)	1.03 (.79)	.62 (.57)	-.59 (.78)	-.01 (.77)	-.21 (.56)	.51 (.50)

Note. N = 1,320 dyads.
† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5

Conclusions Based on Composite and Individual ERGM Analyses

	Composite ERGM	Individual ERGMS	Composite vs. individual	Conclusions
Control: Edges	**Direction**: Negative **Significant**: Yes	**Direction**: 10 negative **Significant**: 10 (negative)	Homogeneity is reasonable	**Conclusion:** Leadership ties were generally unlikely to form; less likely than by chance. **Support**: Strong
Control: Formal Leadership	**Direction**: Positive **Significant**: No	**Direction**: 5 positive, 5 negative **Significant**: 1 (positive), 1 marginally (positive)	Heterogeneous	**Conclusion:** Formal leadership was not a consistent predictor of leadership emergence, but was significant in one MTS. **Support**: N/A
Control: Expertise-Based Leadership	**Direction**: Positive **Significant**: Yes	**Direction**: 9 positive, 1 negative **Significant**: 6 (positive), 1 marginally (positive)	Homogeneity is reasonable	**Conclusion:** Leadership ties were more likely to form with people who were expert-based leaders. **Support**: Moderate
Hypothesis 1: Reciprocity	**Direction**: Negative **Significant**: Yes	**Direction**: 3 positive, 5 negative, 2 absent **Significant**: None	Heterogeneous	**Conclusion**: Reciprocity was not a consistent predictor of leadership emergence. **Support**: N/A
Hypothesis 2: Transitivity	**Direction**: Positive **Significant**: Yes	**Direction**: 6 positive, 4 negative **Significant**: 2 (positive)	Heterogeneous	**Conclusion**: Transitivity was not a consistent predictor of leadership emergence, but was positive when observed. **Support**: N/A
Hypothesis 3: Popularity	—	—	—	—
Hypothesis 4: Team Membership	**Direction**: Positive **Significant**: Yes	**Direction**: 10 positive **Significant**: 7 (positive), 1 marginally (positive)	Homogeneity is reasonable	**Conclusion**: Leadership ties were more likely to form between people on the same team, compared to people on different teams. **Support**: Strong
Hypothesis 5: Propinquity	**Direction**: Positive **Significant**: Yes	**Direction**: 9 positive, 1 negative **Significant**: 5 (positive)	Homogeneity is reasonable	**Conclusion**: Leadership ties were more likely to form among people who were proximal to one another, compared to people who were distant from one another. **Support**: Moderate
Hypothesis 6a: Cognitive Task Similarity	**Direction**: Positive **Significant**: Yes	**Direction**: 5 positive, 5 negative **Significant**: 1 (positive), 1 (negative), 1 marginally (positive)	Heterogeneous	**Conclusion**: Cognitive task similarity was not a consistent predictor of leadership emergence. **Support**: N/A
Hypothesis 6b: Cognitive Team Similarity	**Direction**: Positive **Significant**: Yes	**Direction**: 5 positive, 5 negative **Significant**: None	Heterogeneous	**Conclusion**: Cognitive team similarity was not a consistent predictor of leadership emergence. **Support**: N/A

Table 6

Correlations Among Popularity, Formal Leadership, and Expertise-Based Leadership

		1. Popularity	2. Formal leadership	3. Expertise leadership
Composite	1. Popularity	—		
	2. Formal leadership	.34***	—	
	3. Expertise leadership	.66***	.37***	—
MTS 1	1. Popularity	—		
	2. Formal leadership	.89***	—	
	3. Expertise leadership	.92***	.85***	—
MTS 2	1. Popularity	—		
	2. Formal leadership	.81**	—	
	3. Expertise leadership	.62*	.40	—
MTS 3	1. Popularity	—		
	2. Formal leadership	.14	—	
	3. Expertise leadership	.96***	.28	—
MTS 4	1. Popularity	—		
	2. Formal leadership	.99***	—	
	3. Expertise leadership	.67*	.67*	—
MTS 5	1. Popularity	—		
	2. Formal leadership	.74**	—	
	3. Expertise leadership	.93***	.63*	—
MTS 6	1. Popularity	—		
	2. Formal leadership	.14	—	
	3. Expertise leadership	.44	-.06	—

		1. Popularity	2. Formal leadership	3. Expertise leadership
MTS 7	1. Popularity	—		
	2. Formal leadership	.20	—	
	3. Expertise leadership	.68*	.00	—
MTS 8	1. Popularity	—		
	2. Formal leadership	.01	—	
	3. Expertise leadership	.90***	.18	—
MTS 9	1. Popularity	—		
	2. Formal leadership	-.01	—	
	3. Expertise leadership	.84***	.10	—
MTS 10	1. Popularity	—		
	2. Formal leadership	-.11	—	
	3. Expertise leadership	.90***	-.09	—

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 7

Boundary-Spanning Behaviors to Promote Effective MTS Relationships

MTS Challenge	Boundary-Spanning Behaviors
Coordination	• Provide updates on intra-team inputs, processes, and outcomes to other component teams. • Explain intra-team task constraints. • Answer questions from members of other component teams. • Ask for feedback from other component teams regarding intrateam inputs, processes, and outcomes. • Ask questions of other component teams regarding their relevant inputs, processes, and outputs.
Goal Hierarchy	• Discuss intra-team inputs, processes, and outcomes and how they are related to system goals. • Discuss your team's goal with other teams in the system. • Solicit feedback about how to integrate your team's goals directly with members of other teams. • Act as a broker of expertise—when asked for information regarding intra-team inputs, processes, and/or outcomes, directly link members of other teams to your team members with the relevant expertise.
Inter-Team Dynamics	• Promote the superordinate identity, among other social processes (e.g., superordinate cohesion, superordinate trust, etc.) • Highlight similarities between teams, such as terminology or language. • Employ a cooperative (rather than a competitive) approach when managing conflict, particularly outside of your team's boundaries. • Spend time working with other teams to understand their inputs, processes, and outcomes.

Table 8

T-Tests of Towers Market and Original Project RED Tabletop

Task	Pre-Task	Post-Task	*t*
	Mean (SD)	*Mean (SD)*	
		Coordination	
Towers Market	5.41 (1.11)	5.99 (.85)	-2.77**
Project RED	5.37 (1.20)	5.61 (1.14)	-.85
		Goal Hierarchy	
Towers Market	5.46 (1.26)	4.74 (1.59)	2.15*
Project RED	4.98 (1.15)	5.24 (1.14)	-.95
		Intra/Inter-Team Dynamics	
Towers Market	5.75 (.75)	5.73 (1.14)	.13
Project RED	5.22 (.99)	5.42 (.99)	-.85

Note. $N = 39$ individuals Pre-Towers Market and $N = 45$ individuals Post-Towers Market, $N = 34$ for Project RED.
* $p < .05$, ** $p < .01$.

Table 9

Distribution of Information in Updated Project RED Tabletop

		Human Habitation Team			Scientific Discovery Team		
		Atmospheric Specialist	Water Specialist	Terrain Specialist	Life Scientist	Climate Scientist	Geology Scientist
Argrye	Support	S1, S2, S3, S4	S1, S2, S3, S5	S1, S2, S3, S6	S7	S7	S8
	Undermine	U1	U1	U2	U3, U4, U5, U6	U3, U4, U5, U7	U3, U4, U5, U8
Casius	Support	S1	S2	S2	S3, S4, S5, S6	S3, S4, S5, S7	S3, S4, S5, S8
	Undermine	U1, U2, U3, U4	U1, U2, U3, U5	U1, U2, U3, U6	U7	U7	U8
Eridania	Support	S1, S2, S3	S2, S3, S4	S1, S3, S4	S5, S6, S7	S6, S7, S8	S5, S7, S8
	Undermine	U1, U2	U2, U3	U3, U4	U5, U6	U6, U7	U7, U8
Diacria	Support	S1, S2	S3, S4	S5, S6	S7, S8	S9, S10	S11, S12
	Undermine	U1, U2	U1, U2	U1, U2	U3, U4	U3, U4	U3, U4

Note. S = Support, or information that supports landing at a given location, and U = Undermine, or information that undermines landing at a given location. Each number represents a unique piece of information. Thus, S1, S2, and S3 are three pieces of unique but shared information provided to all members of the Human Habitation Team. However, there are also unique distributed pieces of information; for example, only the Atmospheric Specialist can see S4, only the Water Specialist can see S5, and only the Terrain Specialist can see S6.

Table 10

TurkPrime Project RED Tabletop Task Validation

Level	Validation	*N*	Results
Facts	Individual facts (Round 1)	40 per fact	> 75% classified the item correctly on valence and goal
	Individual facts (Round 2)	38	> 75% classified the item correctly on valence and goal
Team	Habitation (Round 1)	39	97% correctly identified the best option; 89% correctly identified the worst two options; 50% correctly identified the worst option
	Habitation (Round 2)	39	95% correctly identified the best option; 88% correctly identified the worst two options; 38% correctly identified the worst option
	Scientific Discovery	40	83% correctly identified the best option; 69% correctly identified the worst option
Role	Atmospheric Specialist	40	68% correctly identified the best option; 60% correctly identified the worst option
	Water Specialist	40	82% correctly identified the best option; 37% correctly identified the worst option
	Terrain Specialist	40	82% correctly identified the best option; 68% correctly identified the worst option
	Life Scientist	39	62% correctly identified the best option; 64% correctly identified the worst option
	Climate Scientist	40	59% correctly identified the best option; 59% correctly identified the worst option
	Geology Scientist	38	78% correctly identified the best option; 39% correctly identified the worst option
MTS	MTS Profile	124	62% correctly identified the best option; 62% correctly identified the worst two options

Table 11

Descriptive Statistics of Focal Study Variables

	Towers Market				Project RED			
	Mean (SD)	*Median*	*Min*	*Max*	*Mean (SD)*	*Median*	*Min*	*Max*
				Coordination				
Pre-Task	5.15 (.90)	5.33	2.67	7.00	5.45 (1.00)	5.67	1.00	7.00
Post-Task	5.71 (.90)	5.67	2.67	7.00	5.83 (1.01)	6.00	1.00	7.00
				Goal Hierarchy				
Pre-Task	5.22 (1.07)	5.33	3.00	7.00	5.52 (1.08)	6.00	1.00	7.00
Post-Task	5.01 (1.29)	5.00	1.00	7.00	5.49 (1.05)	5.50	3.00	7.00
				Intra/Inter-Team Dynamics				
Pre-Task	5.37 (.84)	5.33	2.67	7.00	5.41 (.82)	5.33	3.00	7.00
Post-Task	5.61 (.98)	5.67	3.33	7.00	5.92 (.80)	6.00	4.00	7.00

Note. N = 69 individuals.

Table 12

Correlations Among Focal Study Variables for Towers Market

		1	2	3	4	5	6	7	8	9	10
Pre-Task	1. Coordination	(.29)									
	2. Goal Hierarchy	.05	(.84)								
	3. Dynamics	-.14	.30*	(.61)							
Post-Task	4. Coordination	.51***	.16	-.03	(.42)						
	5. Goal Hierarchy	.02	.41***	.03	.15	(.85)					
	6. Team	-.11	.04	.07	.06	.44**	(.56)				
Controls	7. Intelligence	.19	.16	.14	.03	-.01	-.02	—			
	8. Engagement	-.12	.02	-.13	.01	.10	-.03	.11	—		
	9. CSE	-.14	-.05	-.07	.06	.07	.00	-.06	.15	(.87)	
	10. Leadership	-.06	-.01	.00	.07	.14	.29*	.18	.44***	.28*	—

Note. $N = 69$ Individuals. Cronbach's alphas for each scale are presented on the diagonal in parentheses.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 13

Correlations Among Focal Study Variables for Project RED Tabletop

		1	2	3	4	5	6	7	8	9	10
Pre-Task	1. Coordination	(.67)									
	2. Goal Hierarchy	.31**	(.96)								
	3. Dynamics	.21	.35**	(.32)							
Post-Task	4. Coordination	.65***	.35**	.22	(.51)						
	5. Goal Hierarchy	.13	.22	.13	.12	(.48)					
	6. Team	.02	-.01	.10	.20	.15	(.52)				
Controls	7. Intelligence	-.03	-.07	-.03	.14	.03	.28*	—			
	8. Engagement	.05	.11	.09	.20	.13	.36**	.08	—		
	9. CSE	-.03	-.16	-.11	-.09	.30*	.19	-.06	.22	(.87)	
	10. Leadership	.18	-.01	.00	.01	.14	-.10	-.11	.11	.22	—

Note. $N = 69$ Individuals. Cronbach's alphas for each scale are presented on the diagonal in parentheses.
* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 14

ANOVA Comparing Coordination Across Towers Market and Project RED Tabletop

	Type III SS	*df*	*MS*	*F*	*p*
Time (pre-post)	14.69	1	14.69	39.22	.00
Time (pre-post) * Task	.55	1	.55	1.47	.23
Error (Time)	50.93	136	.37		

Note. N = 69 individuals.

Table 15

ANOVA Comparing Goal Hierarchy Across Towers Market and Project RED Tabletop

	Type III SS	*df*	*MS*	*F*	*p*
Time (pre-post)	1.03	1	1.03	1.19	.28
Time (pre-post) * Task	.51	1	.51	.59	.45
Error (Time)	117.79	136	.87		

Note. N = 69 individuals.

Table 16

ANOVA Comparing Intra/Inter-Team Across Towers Market and Project RED Tabletop

	Type III SS	*df*	*MS*	*F*	*p*
Time (pre-post)	9.67	1	9.67	14.17	.00
Time (pre-post) * Task	1.31	1	1.31	1.92	.17
Error (Time)	92.85	136	.68		

Note. N = 69 individuals.

Table 17

T-Tests Comparing Focal Study Variables Before and After Each Task

Task	Pre-Task	Post-Task	t
	Mean (SD)	*Mean (SD)*	
	Coordination		
Towers Market	5.15 (.90)	5.71 (.90)	-5.14***
Project RED	5.45 (1.00)	5.83 (1.01)	-3.68***
	Goal Hierarchy		
Towers Market	5.22 (1.07)	5.01 (1.92)	1.33
Project RED	5.52 (1.08)	5.49 (1.05)	.23
	Intra/Inter-Team Dynamics		
Towers Market	5.37 (.84)	5.61 (.98)	-1.58
Project RED	5.41 (.82)	5.92 (.80)	-3.92***

Note. N = 69 individuals.
*** $p < .001$.

Table 18

Chi-Square Tests of Behaviors Related to Focal Study Variables

MTS Leadership Challenge	Towers Market	Project RED	χ^2
Coordination	37	48	1.43
Goal Hierarchy	59	50	.74
Intra/Inter-Team Dynamics	5	12	$2.88^{\dagger}$

Note. N = 69 individuals.
† $p < .10$.

Table 19

LIWC Analysis of Post-Task Short Response Reflections

Category	Term	Example	Towers Market	Project RED	*t*
Descriptive	Word Count	—	28.86 (18.99)	26.33 (16.93)	1.06
	Analytical thinking	—	66.63 (32.78)	73.66 (31.52)	-1.44
	Clout	—	69.50 (31.08)	77.56 (24.46)	-1.62
	Authentic	—	37.60 (34.40)	35.71 (35.73)	.34
	Emotional tone	—	83.58 (29.52)	73.91 (33.40)	1.81
	Words per sentence	—	16.48 (7.25)	15.63 (7.22)	.80
	Words > 6	—	28.15 (14.92)	27.21 (15.66)	.41
	Dictionary words	—	93.56 (6.22)	89.15 (17.47)	1.89
Pronouns	1st person singular	I, me, mine	1.80 (3.49)	.51 (1.51)	3.13^{**}
	1st person plural	We, us, our	.80 (2.25)	1.66 (3.17)	-2.15^{*}
	2nd person	You, your, thou	1.13 (2.72)	.45 (1.44)	1.77
	3rd person singular	She, her, him	.18 (1.21)	.07 (.60)	.63
	3rd person plural	They, their, they'd	.94 (2.10)	.45 (1.16)	1.95
Drives	Affiliation	Ally, friend, social	7.75 (12.47)	10.31 (12.63)	-1.26
	Achievement	Win, success, better	8.35 (6.59)	9.72 (6.61)	-1.32
	Power	Superior, bully	6.35 (6.15)	4.59 (503)	$1.94^{\dagger}$
	Reward	Take, prize, benefit	5.48 (5.03)	4.66 (5.50)	.98
	Risk	Danger, doubt	.75 (1.90)	.37 (1.30)	1.50

	Insight	Think, know	4.88 (5.08)	5.96 (5.36)	-1.29
	Causation	Because, effect	2.22 (3.04)	2.62 (3.35)	-.70
	Discrepancy	Should, would	2.20 (3.71)	1.49 (2.62)	1.30
Cognitive processes	Tentative	Maybe, perhaps	3.88 (5.38)	1.82 (3.17)	2.96**
	Certainty	Always, never	2.48 (3.25)	2.38 (3.57)	.19
	Differentiation	Hasn't, but else	3.65 (4.59)	3.04 (3.88)	.85

Note. $N = 69$ individuals.
† $p < .10$, * $p < .05$, ** $p < .01$.

Table 20

Thematic Analysis of Challenges of Multiteam System Work

Theme	Subtheme	Code	Definition	Novel Mentions	Redundant Mentions	Participants	NASA Employees	ISS Astronauts	SIRIUS Crew
Structure *Factors imposed on members; derived externally*	Process	Timing	Schedule/timeline, task timing, waiting	41	22	17	6	5	6
	Process	Engagement	Task engagement, participation	40	11	15	6	5	4
	Process	Myriad	Overload of information or resources	13	0	9	6	2	1
	Process	Dynamic	Changing circumstances	12	4	8	3	2	3
	Outcome	Technical	Describe technical issue or failure	24	4	14	9	3	2
	Outcome	Performance	Performance, outcomes	18	7	12	6	5	1
Climate *Factors members impose; derived internally*	Individual	Expectations	Expectations not met, surprise	29	3	15	7	5	3
	Individual	Emotions	Managing emotions	26	12	13	6	5	2
	Team	Boundaries	Within-team divide, faultlines	17	4	9	6	1	2
	MTS	Perspectives	Unique perspectives	42	15	17	9	5	3
	MTS	Awareness	Knowledge or recognition of others	25	3	16	5	5	6
Integration *Reconciling of factors imposed on and by members*	Behaviors	Coordination	Integrating actions	35	5	15	9	4	2
	Behaviors	Priorities	Priority differences across different parties	25	7	11	6	4	1
	Information	Communication	Exchanging information; often lack thereof	46	10	17	8	4	5
	Information	Disconnect	Misunderstanding, miscommunication	25	10	15	4	5	6
	Members	Relationships	Managing relationships	38	17	18	8	5	5
Space MTS Context *Unique to the space MTS context*	—	International	Working with international partners	18	2	9	6	2	1
	—	Control	Exercising control or lack of autonomy	14	5	8	3	4	1
	—	Training	References to inadequacies of training	10	1	7	5	1	1
	—	Confined	Confined quarters	6	0	4	1	1	2

Note. Novel Mentions refers to the unique challenges discussed across all participants, Redundant Mentions refers to challenges that were discussed more than once across all participants, Participants refers to the number of unique participants who mentioned a given challenge, and NASA Employees, ISS Astronauts, and SIRIUS Crew each refer to the number of participants in the respective subsamples who mentioned a given challenge.

Table 21

Thematic Analysis of Responses to Challenges of Multiteam System Work

Theme	Code	Definition	Mentions	Participants	NASA Employees	ISS Astronauts	SIRIUS Crew
Structure *Factors members work through*	Timing	Having enough time, creating/following timeline	52	17	8	5	4
	Engagement	Task engagement; participation	45	15	8	5	2
	Problem-solving	Working through a technical issue; diagnostic	45	14	8	3	3
Climate *Factors members contribute*	Awareness	Recognition of the larger context	48	14	5	4	5
	Emotions	Positive emotions; management of negative emotions	39	13	4	5	4
	Expertise	Refers to specific and/or specialized knowledge	30	11	8	2	1
Communication *Exchanging information*	Communication	Exchange info; conferences, talking, emailing	141	20	9	5	6
	Coordination	Working together on a task	98	18	9	5	4
	Cooperation	Helping one another; support; working "as a team"	97	17	6	5	6
	Expectations set	Preparing; setting timeline or procedures	71	17	8	4	5
	Collective perspective	Shared/common understanding, open flight loops	62	17	9	4	4
	Relationship building	Fostering social relationship; team dynamics/cohesion	59	15	7	3	5
	Boundary spanning	Cross-team interaction; CAPCOM, representatives	49	13	9	2	2
	Goal management	Setting goals/outcomes	24	11	6	1	4
	Parsimony	Simplifying procedures, information, etc.	6	5	2	2	1
Space MTS Context *Unique to the space context*	Independence	Being granted ability to or acting on one's own behalf	39	13	7	5	1
	Training	References to training	27	10	7	2	1
Non-Leadership Behaviors	Leadership	Formal or informal leadership, hierarchy	38	14	8	1	5
	Performance	Outcomes, completion, final decisions	32	13	5	5	3
	Expectations met	Familiarity; describing when expectations were met	28	9	3	4	2

Note. Mentions refers to the number of instances a response was discussed across all participants, Participants refers to the number of unique participants who mentioned a given response, and NASA Employees, ISS Astronauts, and SIRIUS Crew each refer to the number of participants in the respective subsamples who mentioned a given response.

Table 22

Content of Resolutions

	Response	Overlap with Resolutions
Structure	Timing	12
	Engagement	10
	Problem-Solving	6
Climate	Awareness	16
	Emotions	11
	Expertise	7
	Cooperation	32
Communication	Communication	23
	Coordination	21
	Expectations Set	16
	Relationship Building	15
	Collective Perspective	12
	Boundary Spanning	10
	Goal Management	4
	Parsimony	3
Space Context	Interdependence	9
	Timing	7
Non-Leadership Behaviors	Performance	13
	Leadership	9
	Expectations Met	7

Table 23

Pairing of Responses with Challenges

Theme	Response	Challenge
Structure	Timing	Timing
	Engagement	Engagement
	Problem-Solving	Technical
Climate	Awareness	Awareness
	Emotions	Emotions
	Expertise	Technical
Communication	Communication	Communication
	Coordination	Coordination
	Cooperation	Relationships
	Expectations set	Expectations
	Collective perspective	Unique perspective
	Relationship building	Relationships
	Boundary spanning	Boundaries
	Goal management	Priorities
	Parsimony	Myriad/Dynamic
Space Context	Independence	Control
	Training	Training
Non-Leadership Behaviors	Leadership	Leadership
	Performance	Performance
	Expectations met	Expectations

Figure 1

Three Social Forces Hypothesized to Shape the Formation of Leader-Follower Relationships in Multiteam Systems

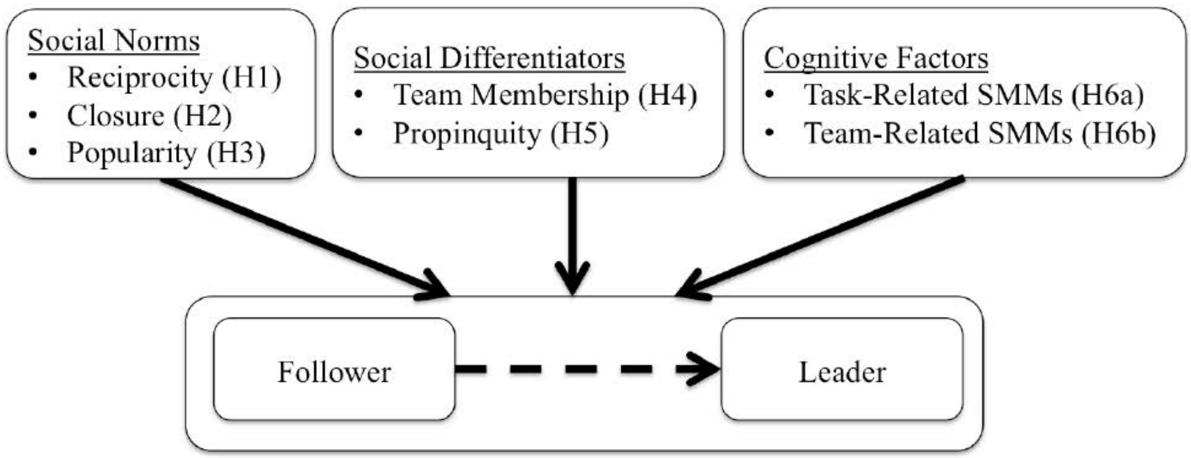
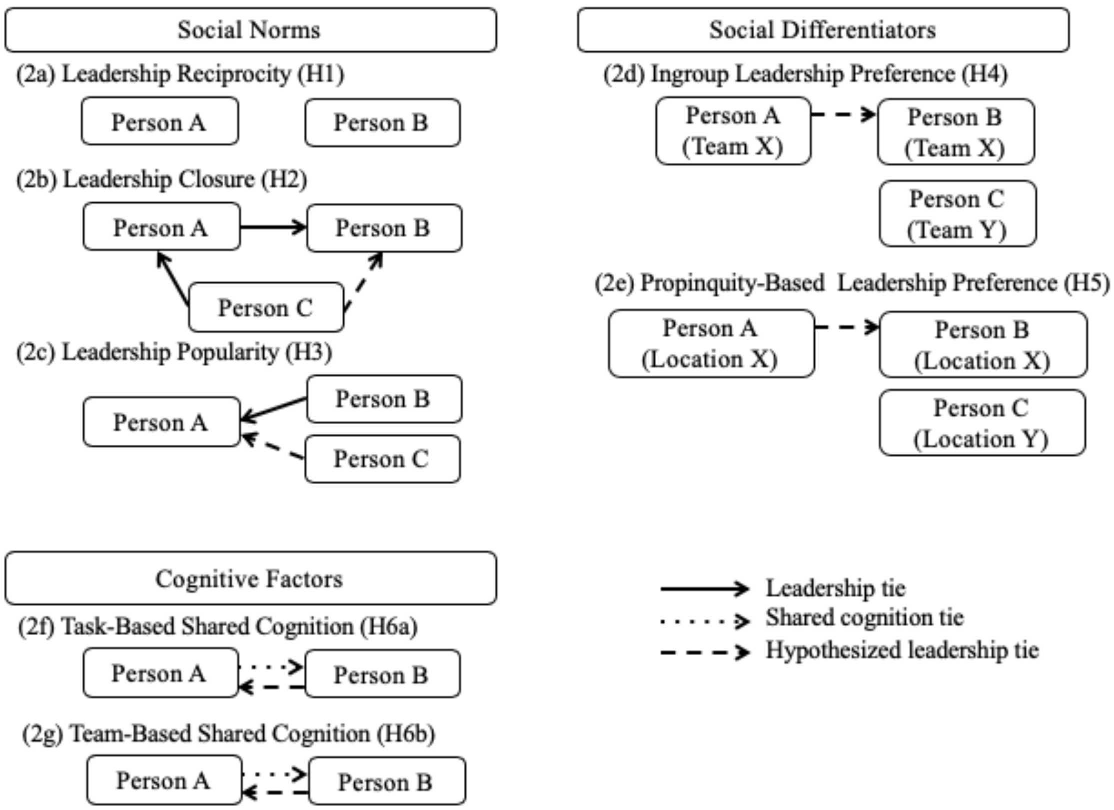


Figure 2

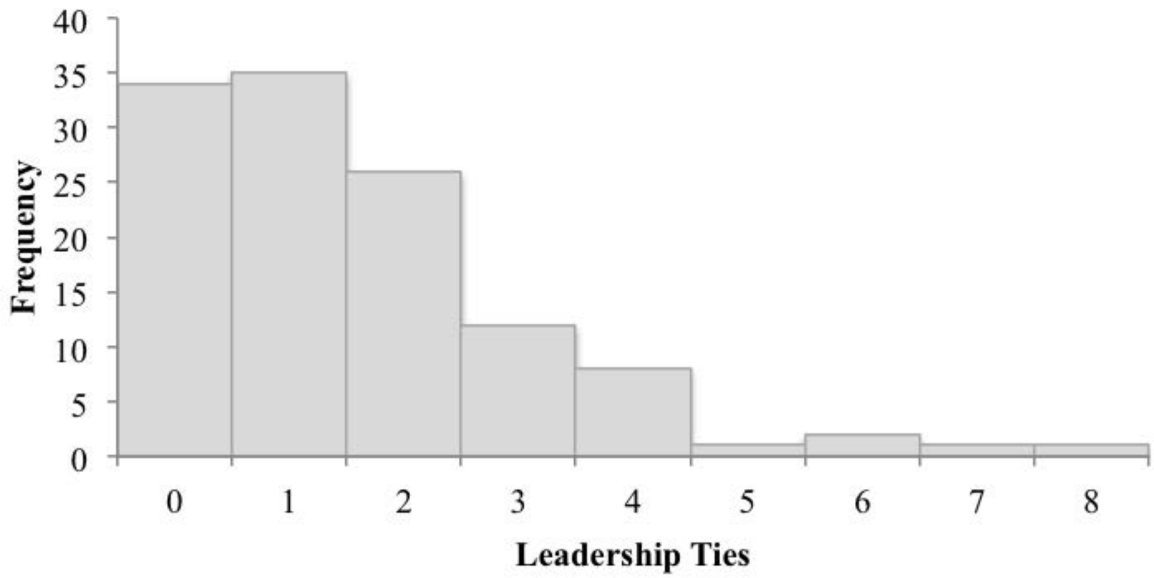
Motifs of Structural Signatures of Hypothesized Social Forces Affecting Leadership Network Tie Formation



Note. Figure 2a displays the network motif of leadership ties forming on the basis of reciprocity. Figure 2b displays the network motive of leadership ties forming on the basis of transitive closure. Figure 2c displays the network motif of leadership ties forming on the basis of popularity. Figure 2d displays the network motif of leadership ties forming on the basis of ingroup preference. Figure 2e displays the network motif of leadership ties forming on the basis of propinquity. Figure 2f displays the network motif of leadership ties forming on the basis of task-based shared cognition. Finally, Figure 2g displays the network motif of leadership ties forming on the basis of team-based shared cognition.

Figure 3

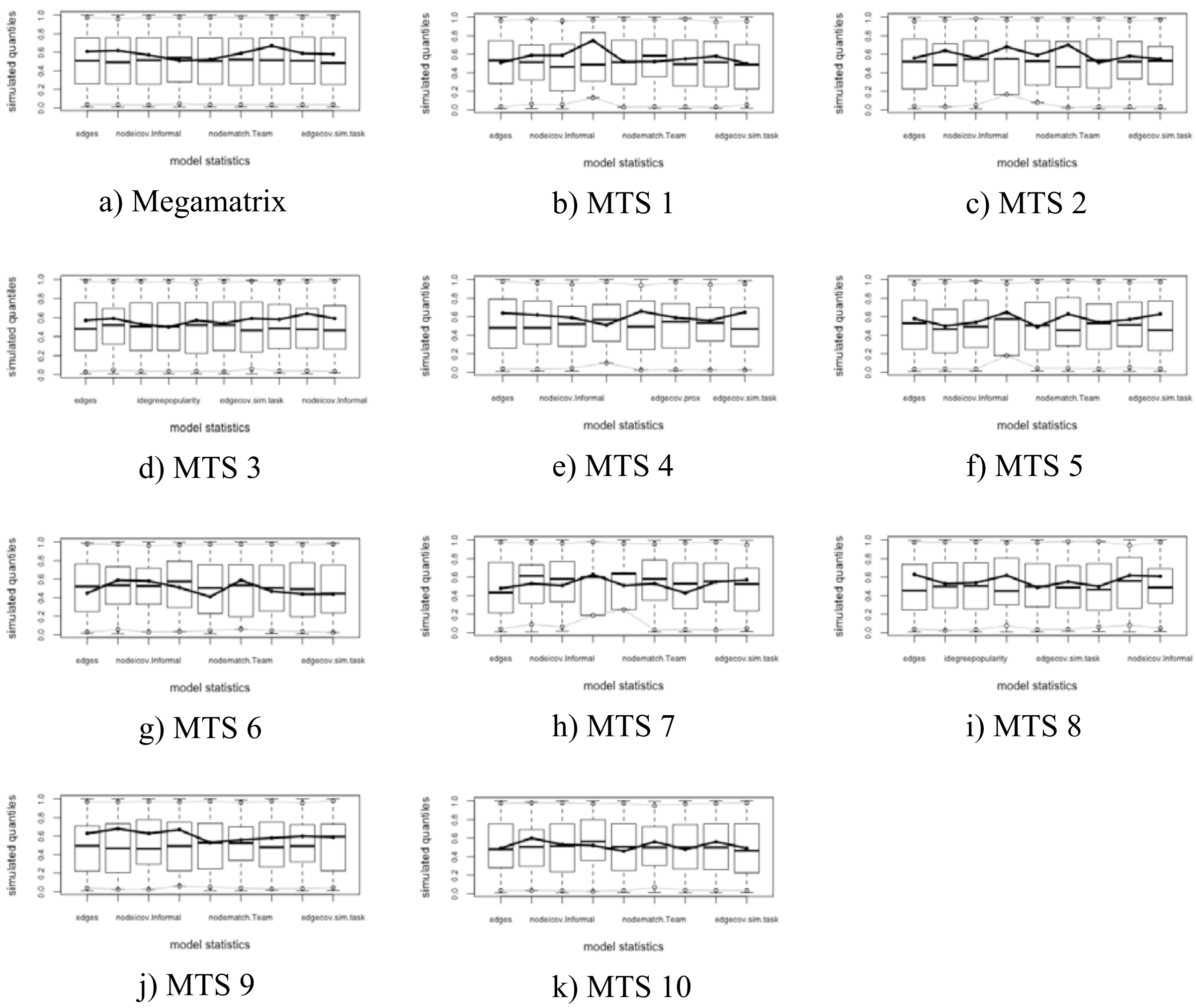
Degree Distribution of Directed Leadership Ties (N = 120 individuals)



Note. The maximum number of ties an individual could report was 11. Observed leadership ties ranged from 0 to 8 per individual.

Figure 4

Goodness-of-Fit Plots



a) Megamatrix b) MTS 1 c) MTS 2

d) MTS 3 e) MTS 4 f) MTS 5

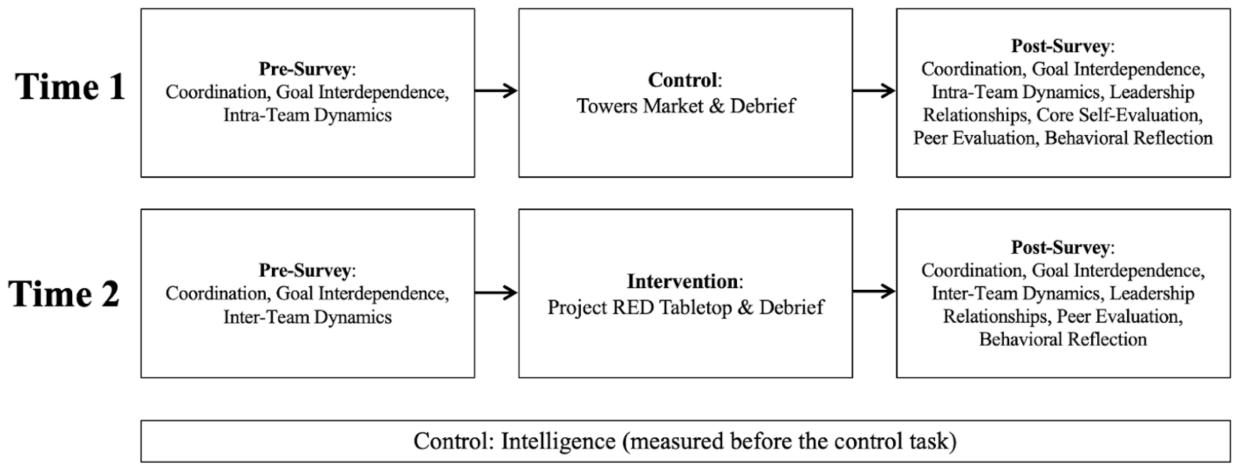
g) MTS 6 h) MTS 7 i) MTS 8

j) MTS 9 k) MTS 10

Note. Figure 4a displays goodness-of-fit for the megamatrix ERGM analysis, and figures 4b-4k display goodness-of-fit for the individual ERGM analyses of MTS 1-10, respectively. MTS 4 and MTS 6 do not include the “mutual” term.

Figure 5

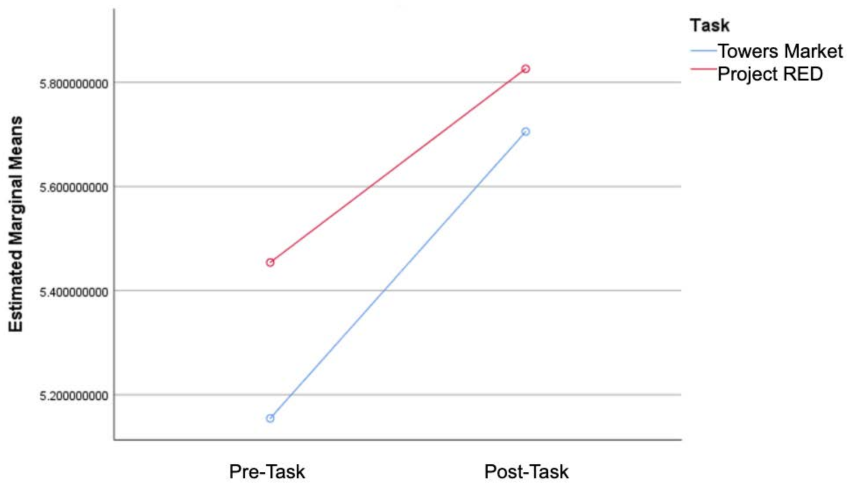
Timeline of Data Collection and Task Administration for Testing Project RED Tabletop



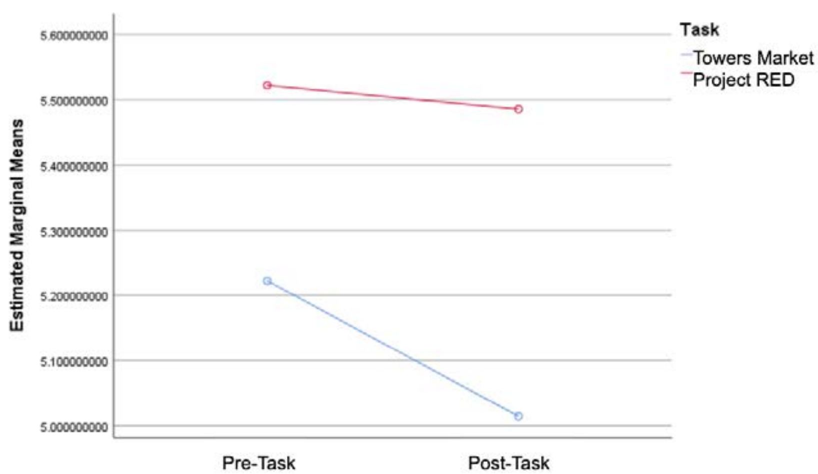
Note. Data were collected in a 10-week course; Time 1 refers to Week 4, and Time 2 refers to Week 9.

Figure 6

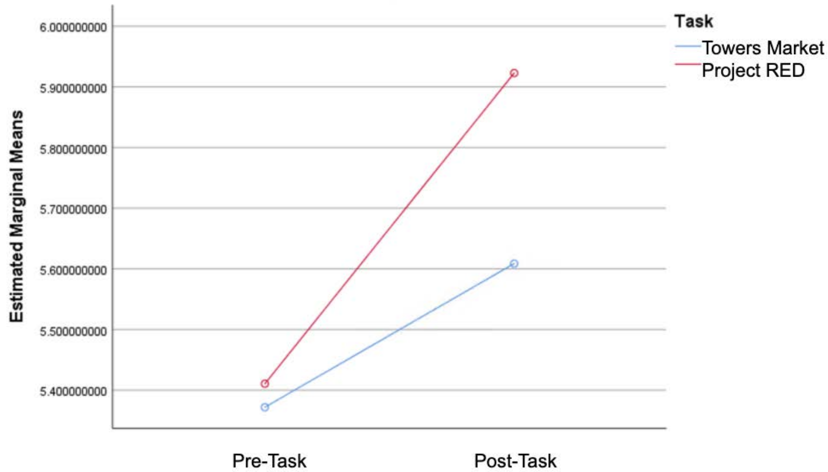
Plots of MTS Leadership Challenges for Towers Market and Project RED Tabletop



a) Coordination



b) Goal Hierarchy



c) Intra/Inter-Team Dynamics

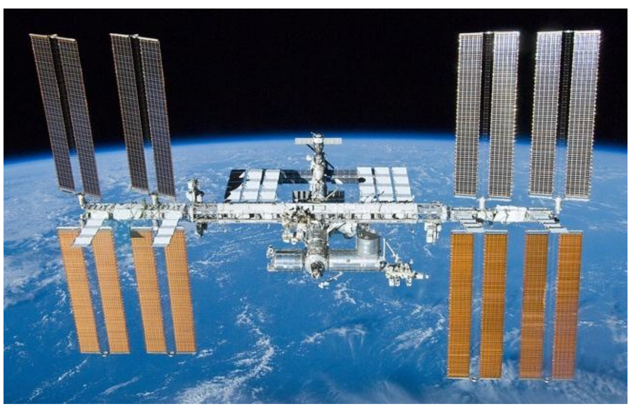
Note. Figure 6a displays coordination scores before and after Towers Market and Project RED tabletop. Figure 6b displays goal hierarchy scores before and after Towers Market and Project RED tabletop. Figure 6c displays intra/inter-team dynamics scores before and after Towers Market and Project RED tabletop.

Figure 7

Operating Environment of Each Space Multiteam System Examined in This Dissertation

a) The Human Exploration Research Analog (HERA); retrieved from:

https://www.planetary.org/blogs/guest-blogs/2017/20170505-hera-crewmember-mission-start.html



b) The International Space Station (ISS); retrieved from:

https://en.wikipedia.org/wiki/International_Space_Station

c) The Scientific International Research In a Unique terrestrial Station (SIRIUS); retrieved from: https://www.nasa.gov/feature/nasa-is-sirius-about-its-analog-missions/

Note. Figure 7a displays NASA's Human Exploration Research Analog, where 4, 4-person crews embarked on 30-day simulated missions, during which they participated in the Project RED activity examined in Study 1. Figure 7b displays the International Space Station, where astronauts interviewed in Study 3 worked. Figure 7c displays the Scientific International Research In a Unique terrestrial Station (SIRIUS) analog, where crewmembers interviewed in Study 3 were isolated for 120 days on a simulated mission.

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Appendix A: Survey Items for Leadership ERGMs

Leadership

- Who did you rely on for leadership (check all that apply)?

Task Shared Mental Model Items

- How related are: “Comparing locations for the well and designing an effective well”?
- How related are: “Comparing locations for the well and minimizing costs to our disciplinary team and/or other disciplinary teams”?
- How related are: “Comparing locations for the well and sending calculations to other disciplinary teams”?
- How related are: “Comparing locations for the well and experimenting with different calculations”?
- How related are: “Designing an effective well and minimizing costs to our disciplinary team and/or other disciplinary teams”?
- How related are: “Designing an effective well and sending calculations to other disciplinary teams”?
- How related are: “Designing an effective well and experimenting with different calculations”?
- How related are: “Minimizing costs to our disciplinary team and/or other disciplinary teams and sending calculations to other disciplinary teams”?
- How related are: “Minimizing costs to our disciplinary team and/or other disciplinary teams and experimenting with different calculations”?
- How related are: “Sending calculations to other disciplinary teams and experimenting with different calculations”?

Team Shared Mental Model Items

- How related are: “Motivating one another and coordinating our work”?
- How related are: “Motivating one another and managing conflict”?
- How related are: “Motivating one another and monitoring our progress”?
- How related are: “Motivating one another and sharing information”?
- How related are: “Coordinating our work and managing conflict”?
- How related are: “Coordinating our work and monitoring our progress”?
- How related are: “Coordinating our work and sharing information”?
- How related are: “Managing conflict and monitoring our progress”?
- How related are: “Managing conflict and sharing information”?
- How related are: “Monitoring our progress and sharing information”?

Appendix B: Project RED Tabletop Protocol (Updated)

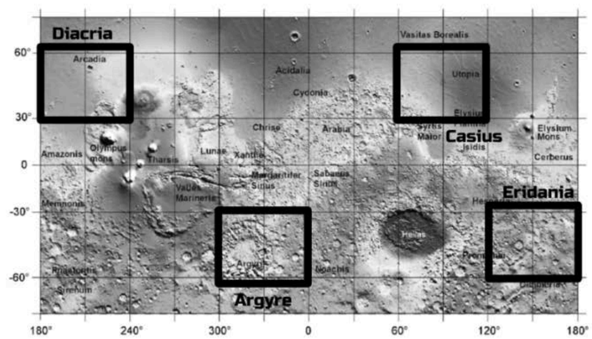
Step 1: Assign Trainees to Disciplinary Teams

Trainees are assigned to one of two disciplinary teams with unique skills & expertise.

Human Habitation team: Concerned with supporting human life on Mars. Expertise in the atmosphere, available water, and properties of the terrain across the entire planet.

Scientific Discovery team: Concerned with advancing science on Mars. Expertise in detecting prior signs of life, climate, and geology across the entire planet.

Step 2: Prepare Trainees for Simulation



All trainees are told that the overarching goal of the simulation is to which location is the best site to land and establish the home base for the crew on Mars. There are four possible locations that have been deemed acceptable for landing by the international space colonization alliance. The MTS must decide on one location.

In addition to these general instructions, the Project RED simulation provides additional instructions that are specific to each team. These instructions are designed to create the types of barriers to inter-team collaboration that are commonly observed in many MTS setting (e.g., differences between teams with regard to norms, goals, priorities, access to knowledge, and areas of expertise).

Step 3: Complete the Project RED Tabletop Simulation

Project RED

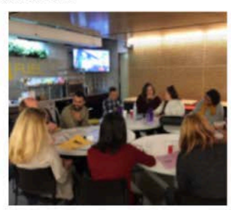
Terrain Specialist

By Leslie DeChurch & Ashley Niler

Synopsis

NASA has its sights set on deep space. In the 2030's, a 6-member international crew will set off to step down on Mars. They will be the first humans to leave Lower Earth Orbit (also known as LEO), and will lay the groundwork needed to establish a human colony on Mars. To quote NASA, "unlike Apollo, we will be going to stay."

However, before we can stay on Mars, we need to land there. The landing site will be absolutely critical to mission success because this is where the crew will set up their base for habitation and exploration. This will also be the hub where pre-positioned supplies will arrive, and where future re-supply missions and crews will land. Importantly, it is not feasible to land in one location and move to another, meaning that wherever the crew lands, they will need to quickly assemble their habitat and live at that location. Additionally, it takes nearly 8 months to



3a. Introduction: Trainer provides a brief overview of the goal and timing of the simulation, including the individual reading phase and team meeting phase.

3b. Individual Reading Phase: Participants read through their individual role information sheet and complete the initial "Preference Form" (10-15 minutes).

3c. Team Meeting Phase: Participants meet with their functional team, discuss their location preferences, and complete another "Preference Form" (30 minutes).

3c. MTS Meeting Phase: Participants are informed that their preferences conflict with another team making the decision. They are asked to meet with this team, discuss their location preferences, and reach a collective decision. (40 minutes).

3d. Final Sign-Off: MTS members complete a final "Preference Form." All participants must "sign off" on this decision.

Appendix C: Towers Market Survey Items

Coordination

- It is/was important for functional team members to provide one another with task-related information without being asked.
- It is/was important for functional team members to monitor the progress of all members' performance.
- It is/was important for functional team members to adapt their behavior to the actions of other members.

Goal Interdependence

- If my functional team members attain(ed) their goals, it (would) facilitate(d) my goal attainment.
- Gains for my functional team members mean(t) gains for me.
- Success for my functional team members implies (implied) success for me.

Intra-Team Dynamics

- Functional team members will not collaborate with one another (reverse-coded)/There was little collaboration among functional team members (reverse coded).
- Functional team members will cooperate with one another/There was a high level of cooperation between functional team members.
- People will be/were willing to sacrifice their self-interest for the benefit of the functional team.

Core Self-Evaluation Scale

- I am confident I get the success I deserve in life.
- Sometimes I feel depressed (reverse coded).
- When I try, I generally succeed.
- Sometimes when I fail I feel worthless (reverse coded).
- I complete tasks successfully.
- Sometimes, I do not feel in control of my work (reverse coded).
- Overall, I am satisfied with myself.
- I am filled with doubts about my competence (reverse coded).
- I determine what will happen in my life.
- I do not feel in control of my professional success (reverse coded).
- I am capable of coping with most of my problems.
- There are times when things look pretty bleak and hopeless to me (reverse coded).

Leadership

- Who did you rely on for leadership (check all that apply)?

Appendix D: Project RED Tabletop Survey Items

Coordination

- It is/was important for functional teams to provide one another with task-related information without being asked.
- It is/was important for functional teams to monitor the progress of all teams' performance.
- It is/was important for functional teams to adapt their behavior to the actions of other teams.

Goal Interdependence

- If the Human Habitation team attains/attained their goals, it (would) facilitate(d) my goal attainment.
- If the Scientific Discovery team attains/attained their goals, it (would) facilitate(d) my goal attainment.

Intra-Team Dynamics

- Functional teams will/did not collaborate with one another (reverse-coded).
- Functional teams will/did cooperate with one another.
- Functional teams will not be/were not willing to sacrifice their self-interest for the benefit of the taskforce.

Leadership

- Who did you rely on for leadership (check all that apply)?

Appendix E: Project RED Tabletop Protocol (Original)

Step 1: Assign Trainees to Disciplinary Teams

Trainees are assigned to one of four disciplinary teams with unique skills & expertise, and if desired (based on training goals), one member of each team is assigned to a "boundary spanner" role.

Planetary Geology: Geologists with expertise in water yield possible at each location in the Agyre Quadrangle

Space Human Factors: Scientists with expertise in usability and accessibility factors that will affect the utility of the well to a future colony

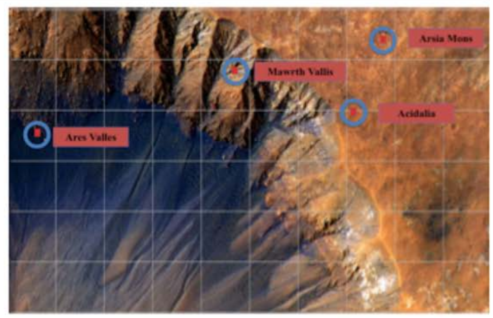
Extraterrestrial Engineering: Engineers with a proven track record for designing wells using innovative methods that maximize water yield

Space Robotics: Engineers with expertise in optimizing the use of robots & rovers in the construction of a well

Step 2: Prepare Trainees for Simulation

All trainees are told that the overarching goal of the simulation is to determine the location, well design, and robot utilization plan for a new water well on the surface of Mars that will maximize the utility of this well to a future human colony. There are four possible locations for the well. The MTS must decide one location.

In addition to these general instructions, the Project RED simulation provides additional instructions that are specific to each team. These instructions are designed to create the types of barriers to interteam collaboration that are commonly observed in many MTS settings (e.g., differences between teams with regard to norms, roles, goals, priorities, access to knowledge, and areas of expertise). These instructions will be modifiable so that the trainer will be able to highlight different lessons as needed.



Step 3: Complete the Project RED Tabletop Simulation


ATLAS
Project RED
Red planet Exploration & Development
Role: Drilling Specialist
Project RED Teams

3a. Introduction: Trainer provides a brief overview of Project RED to explain the goal of the simulation and the overall timing, including the individual reading phase, the team meeting phase, the MTS phase, and the final sign-off phase.

3b. Individual Reading Phase: Participants read through their individual Project RED Role Information Sheet, become familiar with calculation approaches, and complete initial "Preference Forms" (10-20 minutes).

3c. Team Meeting Phase: Participants meet with their disciplinary team (15 minutes). Teams separately discuss their location preferences and complete another "Preference Form" within their disciplinary teams (15 minutes).

3d. MTS Meeting Phase: Participants work together as a MTS to share location preferences and information regarding locations and reach a collective decision. If boundary-spanners were assigned in Step 1, these trainees are to interact with one another and with their respective teams during the MTS meeting phase.

3e. Final Sign-Off Phase: The MTS members complete a final "Preference Form." All participants must "sign off" on this decision.

3f. Post-Sign Off Survey: After the sign-off phase, participants complete evaluations of the MTS's performance and processes. Their responses, in addition to objective measures, can be compiled and used to debrief strengths and weaknesses of their approach to MTS work and provide guidance for future work involving multiple teams.

Appendix F: Interview Protocol for NASA Employees

1. Can you give a brief summary of what you do in your job? Please describe your current position, its roles and responsibilities, and how long you have held this position?
    a. How many missions have you in some way successfully contributed to?
    b. Have you ever been in space? In what mission type, for how long, and with how many people?
2. What is your unit's primary responsibility during space missions? What kinds of activities do the members of your unit do? Who do you consider part of your immediate work team? How often do the members of your unit interact with each other?
3. What are some of the ways that your team works together (e.g., shared files, meetings, emails, sharepoint)?
4. How do you and your team members make sure that your situation assessments are complete and accurate? Decisions cover all the critical circumstances? Plans cover all needed tasks and are properly coordinated? Is contingency planning adequate?
    a. A. Can you explain your coordination/integration processes?
    b. What does an off-nominal event look like?
5. What are some situations that require your group/unit to work closely with others who are outside your group/unit?
    a. How often do you feel you have to go outside your group?
    b. In what ways is it stressful and/or challenging to interact with individuals outside your immediate group/unit?
6. How often do members of the space crew need to work with members of the ground crew (hourly, daily, every few days, about once a week, about once a month)?
    a. What types of information/support is needed in these types of interactions?
    b. Are there any times the crew has information that the ground doesn't have?
    c. What does this look like for off-nominal events?
7. What do you see as the most critical team related issues/problems/gaps presented by long-duration space exploration?
    a. Off-nominal events in long-duration space exploration?
    b. Necessary skill sets?
    c. Other teamwork issues that are paramount in the long-duration space exploration context?
    d. Are there modifications that need to be made to training, particularly analog training, for long-duration space exploration to help with autonomy?

Appendix G: Interview Protocol for Astronauts on the International Space Station

1. Can you talk about just the nature of transitioning on the space station? What is it like and what are the consequences of rapid-fire transitions, getting behind the timeline, or the difference in the tasks you transition between?
2. To what extent do the challenges of task switching change over the course of the mission? You spent quite a lot of time there, so was there a learning curve?
3. Are there tasks more engaging than others? There may be some that require your full mental focus, some that garner greater interest, or maybe some of them are more physically demanding… Can you talk about how engagement with the different types of tasks affected how you were connected to them?
4. Do you have a specific example when you were really engaged in something, but then you switched and you were still thinking about what you were doing before?
    a. Did that distract or impair how well you did?
    b. On the flip side of that, did you ever find yourself looking forward, and that pulled your focus away from the task at hand?
5. What role did your emotions play? How did you feel maybe when you did something well? Any emotions of that excitement, enthusiasm, etc.?
6. What about negative emotions, did those play a role? Where maybe something didn't go well, or you were feeling frustrated or anxious?
7. What were your favorite or most rewarding tasks, and what were your least favorite tasks or ones you tried to avoid?
8. Could you identify one or two tasks you would consider to be the quintessential work task in each of these three categories: solo tasks, team tasks, and tasks with Mission Control?
9. Can you recall a specific incident where a transition that you were doing between tasks went smoothly? What would you say are some of the factors that contributed to that?
    a. Can you recall a task where the transition was so smooth? What factors made that transition difficult?
    b. How did interactions with others play out in the context of working together or helping someone? Can you give examples where there was a social catalyst for your transition to another task, be it helping someone on a solo task or a team task, like EVAs and spacewalks?
10. Is it more difficult to go from working more independently and then bringing Mission Control in, or to be working with Mission Control and then go back to doing things more independently?

Appendix H: Interview Protocol for SIRIUS Crew Members

1. When you think back over the mission, what would you say are some of the high and low points?
2. If you were to divide your mission into meaningful phases or chapters, what would those periods be?
3. Based on the experience you had in the analog, what factors do you think are the most critical to be considering to compose a crew for a long-duration space mission? Any qualities, traits, personal characteristics you thought were helpful?
4. What was the greatest strength of your crew and related to that, if there's one thing you could change to make this crew even better, what would that have been?
    a. When you think about what mission support needs to do, what did they do well and what could be done even better to support a crew?
    b. When you think about the teams that are designing the research, what are some recommendations you would make for behaviors that helped the crew in implementing the science, and things that could be done even better?
5. When we think about the different kinds of work you did, can you provide examples of tasks/activities that characterized tasks you did by yourself, with the crew, and ones that required you to work with mission control?
6. You did this mission with a very fixed schedule, so when you think about the transitions between those tasks, what made a transition easier or harder?
    a. When you think about creating the schedule, was there anything you preferred to happen earlier, or preferred to not happen later?
7. Are there any technologies that you wish that your crew had had access to that could have made your work easier?
8. What were some of your most and least favorite tasks/activities that you did as part of the mission?

Appendix I: Select Quotes of Challenges of Multiteam System Work

Structure	Timing	"*Sometimes there are other critical tasks that they just have to be done*, the other people got to step up or you just run long" (ISS crew member #2).	"*Low times would be, um… often times when, when people were stressed out* I guess when the schedule is packed with things or we had all sorts of blood draws to do, uh, followed by a lot of, uh, experiments that required a great deal of, um, set up and tear down…" (SIRIUS crew member #5).
	Engagement	"Puts a lot of demand on us to provide them with the experience—seeing [a] kid's game…involved in a funeral, talking to aunt/uncle. They continue to live and want to be a part of that…the more we can do that without diverting/splitting their attention is important…" (NASA employee #1).	"I think that's when mistakes happen—is you because you're not fully engaged, and you've been working from one thing, you move from one thing to the next to the next. It's hard to keep your head in one game after the other after the other" (ISS crew member #1).
	Myriad	"So [we] have some really smart people, but when you have so many issues that overwhelm[s] the crew" (NASA employee #4).	"So sometimes you'll end up where you have four or five controlling documents trying to direct your activities and to me that was just too much" (ISS crew member #1).
	Dynamic	"Other groups come to the forefront as issues develop: Issue-driven groups, dynamic…" (NASA employee #9).	"Um, the thing that was not so great, or not good was the disjointedness I guess, of the MCC of the medical, you know, the doctors and medical support and um, MCC in general" (SIRIUS crew member #3).
	Technical	"A year ago, there was a problem with a suit… training for an EVA, the helmet began filling up with water, [the astronaut] could have drowned! A fan pump separator was causing problems, had to replace it…" (NASA employee #4).	"*So it was the last segment of Mir… when [Progress] launched to Mir,* there was a fire onboard" (NASA employee #8).
	Performance	"Pressure to perform and be one of those 'steely-eyed' NASA flight directors like you've heard about since you were a kid… flight director is barking at you… pressure to look good and be good…" (NASA employee #3).	"*Because, when we have a volume of 80-plus experiments, I think it was almost like 90 experiments,* there is no way that we can, you know, do an outstanding job with all of them and keep everything in mind, and remember everything" (SIRIUS crew member #1).
Climate	Expectations	"Occasionally in some cases, a particular discipline would roll their eyes like, 'I thought they were supposed to be smart people?'" (NASA employee #4).	"And, uh, another interesting fact that you never knew exactly who would be listening, or who would be reviewing your messages, and in case of, for example, uh, video messaging, messages that were sent out, and who would be ultimately, uh, replying to those. Sometimes you did not know that" (SIRIUS crew member #6).
	Emotions	"*[Conference calls] are important, where we talk about personal issues…might be something going on in the family* or within the crew member and his/her perception within the wider group…" (NASA employee #1).	"It could. I mean, if you were having a bad day, I mean, it could make the whole day less enjoyable if something happened in the morning. That could make the whole day less enjoyable" (ISS crew member #1).
	Boundaries	"[Those on the] ISS find out that there are many cultures you have to deal with… pilots understand and gravitate to other pilots, scientists and researchers the same way… two geologists with common language and area, they are developing a subculture…" (NASA employee #9).	"And so from a, from a psychology perspective… you know, I'm thinking about a whole different set of priorities than those guys are thinking about. I'm in a whole different place mentally and, and looking at the mission and reflecting on what's going on and preparing mentally to come home. And those guys are full speed ahead" (ISS crew member #5).
	Perspectives	"Will always be a 'we vs. them'… because the ground people are not there, so they don't have a true understanding… 30 minutes to do this task with drawer and panel… may not have gotten the drawer open because of microgravity so couldn't even do the task because the ground doesn't understand what is happening in space flight…" (NASA employee #9).	"*The bad one is when it's a prototype, it's the first time, it hasn't been well hashed out, nobody's really thought about constraints, it feels like amateurism, the person on the radio doesn't really know the procedure better than you, you feel like people are wasting your time and what they ask of you is unreasonable, and* they just don't get it" (ISS crew member #4).
	Awareness	"But there are some sensational things they see that the ground control can't see, for example a fire situation or a depressurization situation. These are good examples of things the ground control team wouldn't know unless the space crew tells them… depressurization makes the space crews' ears pop, so they call down to mission control and tell them…" (NASA employee #3).	"*So the days the Russians go on duty, EVA where we performed a lot of tasks for them and, you know,* I don't think Houston had a really good sense for what my roles were during that day—it's a lot. Um, especially when it comes to dealing with fatigue and things like that…" (ISS crew member #2).
Integration	Coordination	"*[We] had a Progress vehicle ship hit the Mir a few years ago…* the crew may need to take over and lots of training comes into play… lots of integrated activities that cross across a lot of disciplines…" (NASA employee #6).	Speaking of acting as one team: "*And that's not something that we have here in SIRIUS.* We only spend about two months together…" (SIRIUS crew member #4).
	Priorities	"If the president wants to talk to the crew on a specific day, you won't have a choice, so you'll have to move stuff around with all these constraints like maintenance and number of payloads, battery, power, requirements… managing the activities across these constraints takes a lot of coordination across all these disciplines…" (NASA employee #6).	"*I'd say, uh, just maintain the discipline, collecting quality data and focusing on the bigger picture of* why you might be collecting that data" (SIRIUS crew member #5).
	Communication	"The flight director sending out the emails to this team, was using a distribution list he thought was correct, but after the activity where he was inviting people to the post-EVA celebration, he realized that the email list didn't get to the people he needed it to get to! [We] have had problems with communication in the past…" (NASA employee #2).	"*One thing they could improve on is, um, I suppose, um, maybe the, the quicker feedback. So a few instances they responded to our questions and concerns much later than, you know, we, we hoped or we wanted to, and it,* it wasn't even with some, uh, useful information" (SIRIUS crew member #1).
	Disconnect	"*It all comes down to the personalities involved… can look at different personalities but know how they work and okay,* but if interpreted incorrectly that sours the mission… there [are] multiple back-and-forth bad will with each other…" (NASA employee #7).	"Um…the downside, I mean it was so close. Um, there were some moments when there was, um, uh, misunderstanding although we speak the same language but when we say that we have, uh, issues with some, uh, experiments and, uh, I don't know why, but the answer came back totally not related" (SIRIUS crew member #2).
	Relationships	"*People are human and are subject to human idiosyncrasies…* [I have] been in charge of missions where there was significant disagreements…" (NASA employee #5).	"*[Crew member] does [an experiment] three times and then all of a sudden I do it the fourth time—that can actually lead to problems. That's actually kind of a biggie.* I'm glad this just came up because you know if [crew member's] done it three times, then he knows all the little 'isms' of that procedure, he's talked to the PD—either on a first-name basis, *you know they have the history to it…*" (ISS crew member #3).

Space Context	International	"Russian, U.S., and Japanese [members are] very different" (NASA employee #4).	"*...where you're talking to somebody* where English is their second language, *and maybe it's the only time they're running this experiment, or it's the first time they've touched the hardware… it's totally different*" (ISS crew member #3).
	Control	"So this I think this is one of the challenges of the space station is the level of control exerted by the ground" (ISS crew member #1).	"Um… but, you know, one of the things that we lack is a lot of dedicated training with each other" (ISS crew member #5).
	Training	"[The] problem with our training, *even now our training takes 18 months to train an astronaut… trains them how to operate the system safely, and to some level fix certain things for which there are predefined procedures… [to] train the crew for something more than that is hard to do…*" (NASA employee #2).	"Um… but, you know, one of the things that we lack is a lot of dedicated training with each other" (ISS crew member #5).
	Confined	"No matter how well you get along with people, but if you are closed up with them for a year, there will be problems…" (NASA employee #7).	"I don't know if you had a chance to see the facility but the crew quarters have extremely thin walls and you can hear what's happening in any one of our rooms, crystal clear (laughs), no matter how quiet people think they're being. Uh, and there were times when someone was watching, a, a funny show and they were laughing a lot, um, and it seemed like it was sort of loud I guess to others" (SIRIUS crew member #5).

Note. Non-italicized segments are examples of text coded for each category. Some selections include additional text for context, which has been italicized to denote that those pieces of text were coded as representing other challenges.

Appendix J: Select Quotes of Responses to Challenges of Multiteam System Work

Structure	Timing	"A lesson learned out of this is the requirement that there are no meetings between noon and 1:30-2pm, so people can actually eat…" (NASA employee #2).	"...I'd take the time. I'd finish my other tasks early so I could start at this one early" (ISS crew member #3).
	Engagement	"*The other aspect is that individuals need to be able to repair fences,* and that needs to be open and practiced" (NASA employee #1).	"...everybody is uh, pulling their weight, everybody is doing what they are supposed to be doing *and there is total you know harmony*" (SIRIUS crew member #4).
	Problem-solving	"*In a failure scenario, before they actually go in, they will need to talk to the ground…* carbon dioxide scrubber on station… had to replace… maintenance activity that failed…" (NASA employee #4).	"'Ground will work on it, they'll figure it out, will come back with something else'" (ISS crew member #5).
Climate	Awareness	"I certainly enjoyed the success, but they're usually pretty short-lived because then you were on to something else that was compl- as equally complicated and important to someone. Everything's important to someone up there because everyone they've got their vested interests in their piece of the pie so…" (ISS crew member #1).	"So just, you know, being aware of each other's, uh, ups and downs. That's very important too. I've noticed that as well" (SIRIUS crew member #1).
	Emotions	"Overcome emotional obstacles and be nimble enough to make it work… and not get personal… going to have to be that way… almost turning off emotions" (NASA employee #7).	"*Allow the crew members- to give them… you know "here's a list of what you have to choose today; you just figure it out." That is the most efficient way,* the most pleasant way; it's the most rewarding way" (ISS crew member #4).
	Expertise	"*Their job is to act as liaisons in each control center,* given their knowledge of their respective systems, *to help prevent miscommunication…*" (NASA employee #6).	"So I think from on the science side, it's better to have one person you know with that perspective. So for instance, you know you think about Dave Scott and the moon rock that he found; if a different person was doing that- was looking at these rocks every single day that may not have stuck out, but for him he noticed that every single day they all looked like this, and all of a sudden it looked like that. And so I think from a science side, it's better to keep one person on an experiment" (ISS crew member #3).
Communication	Communication	"For any given day, there are 5-10 flight notes *that I have to concur on…*" (NASA employee #3).	"...now you got to make a call *down to the Ground, you know*" (ISS crew member #2).
	Coordination	"*During the mission, psychologist/ psychiatrist assigned to each person [and] talk to the crew member every other week... how sleeping/interacting with ground team and with each other on the station, any issues with family* they can take care of, what other things they could help with, like sports information… works with family to put together crew care packages on commercial vehicles…" (NASA employee #9).	"*So some mission control is actively there, like* when we're doing rodent dissection, *we're wearing our headsets, and we're just we're not reading a procedure, we're following orders,* or when you're doing a spacewalk, same thing. So sometimes it's more obvious, but the… you never do anything completely out of your own- on your own, at the very least, you're reading a procedure written by mission control" (ISS crew member #4).
	Cooperation	"Work as a team and work with the larger team… knowing that that team …. close-by on the ground can help…" (NASA employee #7).	"Now occasionally there'll be a task where it's like an audit of something and the ground says "hey, we're going to take this off your schedule, we'll push that to tomorrow, we'll get a schedule later; don't worry about it" (ISS crew member #2).
	Expectations set	"*So, they knew if they were having a bad day* and they would say, 'Look, guys, I'm grumpy today, I apologize, I'm just grumpy,'" (ISS crew member #2).	"So, being proactive about what might they ask *and how can we provide those answers quickly and efficiently* when they- if and when they do ask" (SIRIUS crew member #5).
	Collective perspective	"It was actually when I saw that I was working with him, I was like, 'Oh this is going to be easy because he and I can read each other's minds at this'" (ISS crew member #3).	"Sometimes it took them several times, you know, three or four drafts, basically re-reading and reviewing their own, uh, radio grams, and changing them, and making sure they're basically putting them in the shoes of the MCC to kind of test for understanding on the other side, to make sure that, you know, they answer it adequately" (SIRIUS crew member #6).
	Relationship building	"You need to develop a social relationship with these people so that once you are remote you will be able to manage your relationships with them… develop a reservoir of social interactions with these folks so that you can draw on them when you are distant" (NASA employee #1).	"It's going to sound weird, but most of our instructors in Houston we ended up going and having a drink with after work, *or we end up having sidebar conversations with because we see the same people over and over again*" (ISS crew member #4).
	Boundary spanning	"[That's where] the CAPCOM can be very helpful to the flight crew and ground crew… and this is what the crew is thinking… can be the liaison between the crew and the ground *to keep everyone in sync.*" (NASA employee #8).	"[The crew member is] saying that there were two people who were important to the success of the MCC and support, one on the Russian side and one on the U.S. side and uh, one guy who is basically the project uh, physician. He is a medical monitor, and he was in charge of uh, all of the doctors and assistants uh, who were on duty here at the MCC. So that person and uh, myself on the-on the U.S. side" (SIRIUS crew member #3).
	Goal management	"...the best way to handle this is for mission control to do a better job explaining to crews what the priorities *and constraints and let them take a more active role in accomplishing the priorities given constraints*" (NASA employee #3).	"Then I would just call the ground and say, 'Hey, it doesn't look like, you know- we need some help with the timeline because I have my exercise coming up, and I don't want to be late for it, so tell me what your priority is, and see if we can find some time for the activities that are not going to fit in'" (ISS crew member #1).
	Parsimony	"If talking timeline and how to fit, might drill down number of folks to the meeting because [we] don't necessarily need the extra folks…" (NASA employee #5).	"So the easier instructions, the simplest forms, uh, of explanation are the best" (SIRIUS crew member #1).

Space Context	Independence	"Allow the crew members- to give them… you know, 'Here's a list of what you have to choose today; you just figure it out'" (ISS crew member #4).	"...and uh, where we, uh, sat and doing them, we, um, adapted the schedule for, as we understood, would be more useful, more uh, convenient, and, uh, uh, it'll all be more logical. So, uh, some of the experiments, they were taking less time, or, or the opposite and there's been, yeah, adjusting this by ourselves" (SIRIUS crew member #2).
	Training	"Training for these scenarios is to be aware of these issues and communicate them as soon as possible" (NASA employee #3).	"Need to train *the whole crew together and need to make sure you make time for that to happen… cross-cultural training and crew and understanding that cross culture…*" (NASA employee #9).
Non-leadership behaviors	Leadership	"Leader needs to know when not to be a leader and when to turn over to a technical expert… leadership/ followership… when to fade back and when to step up even if not the assigned leader…" (NASA employee #1).	"Our, um, the head of, yeah, the [PI] of medical, um, the medical support, he was, uh, very good. *He was caring a lot and, um, you could communicate with him, uh, anytime and, uh, he would give you great advice*" (SIRIUS crew member #2).
	Performance	"All work together to develop a flight ops plan to develop the best margins to make timeline as resilient to failures… so can respond to off-nominal situations to get everything done…" (NASA employee #5).	"And that is what makes the difference a lot of times with crew efficiency, with how much a crew can get done… you know, with a lot of things. And it ties in the tasks, tremendously" (ISS crew member #2).
	Expectations met	"*I mean eventually you get experienced enough* that you know, 'Oh, I know what happens when this happens…'" (ISS crew member #4).	"The main two things are um, experience, and I'll elaborate, and uh, we're talking about uh, space flight experience here. Experience being, you know, a real, uh, you know, uh, space flight, I guess" (SIRIUS crew member #3).

Note. Non-italicized segments are examples of text coded for each category. Some selections include additional text for context, which has been italicized to denote that those pieces of text were coded as representing other responses.