Virtual Team Communication and Team Outcomes

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ABSTRACT

Virtual Team Communication and Team Outcomes

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Abstract. Virtual team communication is a critical antecedent of virtual team outcomes, such as team trust, satisfaction, and performance. However, communicating through virtual tools can be difficult. Many studies have shown that the relationship between virtual team communication and team outcomes is complicated and not well understood. The purpose of this thesis is therefore to answer the question: how can virtual teams communicate effectively to achieve positive team outcomes? My thesis consists of two studies to answer this question. In study 1, I reviewed and synthesized 103 peer-reviewed empirical articles about virtual team communication and its outcomes to delineate this important relationship and suggest promising directions for future research. Results indicate that different dimensions of team communication impact various virtual team outcomes differently. Nonetheless, this study identified that virtual team communication affects virtual team outcomes mainly through two theoretical mechanisms - relational and informational - and that two main contextual variables - communication tool and team development stage - moderate these relationships. In study 2, I explored the relationship between specific communication content and team performance in virtual teams, especially in the context of the COVID-19 pandemic. The results of study 2 demonstrate that four types of team communication content (i.e., problem-focused, positive procedural, action-oriented, and social-emotional communication) can help virtual teams perform well and even adapt to disruption caused by the COVID-19 pandemic. Together, these papers provide a comprehensive

review and testable framework to help us better understand the effects of virtual team communication on virtual team performance, including important qualifiers of this relationship that are critical for effective team communication in virtual teams today.

Keywords: Virtual team communication, Team outcomes, Team personality composition

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CONTRIBUTION OF AUTHORS

I am the sole author of this thesis. My use of “we” in this thesis is trying to communicate with readers and make the thesis more readable.

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Study 2 Virtual Team Communication Content, Team Performance, and the Effect of the COVID-19 Pandemic

General Introduction

Virtual teams are work teams in which team members are geographically dispersed, have limited face-to-face communication, and achieve common goals through the use of telecommunication and information technologies (Dulebohn & Hoch, 2017). Virtual teams have several advantages over traditional, face-to-face teams. First, virtual teams can enlarge an organization's collective pool of knowledge (Gibson & Gibbs, 2006). Virtual communication tools enable organizations to access relevant expertise from geographically dispersed team members with diverse perspectives. As a result, organizations can benefit from more diverse talent and increased innovation through virtual team structures (Davidekova & Hvorecky, 2017; Dennis, Minas, & Williams, 2019). Second, virtual teams can operate 24/7 with limited interruptions, given that virtual team members are likely to be working in teams that span across time zones (Dulebohn & Hoch, 2017; Lilian, 2014). Third, virtual teams can reduce costs related to real estate, travel, relocation, office expenditures, and operating expenses (Dulebohn & Hoch, 2017). Fourth, virtual teams can facilitate team functioning as their communication processes are often automatically documented. For instance, email communication in virtual teams can easily be stored and revisited when misunderstandings or conflicts occur (Krumm, Kanthak, Hartmann, & Hertel, 2016). Also, communication records capture the knowledge assets such as business processes, human memory, culture, and history in an integrated platform (Hackbarth & Grover, 1999). Thus, these records help team members understand other members with different functional backgrounds (Levin & Cross, 2004), consequently facilitating team functioning. Finally, virtual working affords teams a higher level of flexibility in their work, schedule, time, and locations (Fan, Chen, Wang, & Chen, 2014; Lilian, 2014; Ruiller, Van Der Heijden, Chedotel, & Dumas, 2019). Team members can reconcile their work and family life by working

from home or on vacation (Rafnsdóttir & Stefánsson, 2014), and as such, organizations have less employee absenteeism and fewer workplace accidents while enjoining higher productivity and retaining valuable employees.

In light of these many advantages, organizations' use of virtual teams has grown exponentially over the past ten years (Culturewizard, 2020). More and more employees accomplish their work virtually. A 2016 survey showed that 85% of employees in the US had worked in a virtual team, while almost 20% of employees spent over half of the day interacting within virtual teams (RW3 Virtual Teams Survey, 2016). A survey in 2019 found that 50% of US workers held a job that part of it could be done remotely, and approximately 40% of them worked remotely sometimes (GlobalWorkforceAnalytics.com, 2019). Above and beyond these trends, the recent COVID-19 pandemic has dramatically changed organizations and teamwork even further since it has forced millions of people worldwide to work remotely. According to Gallup, 62% of US workers said they were working from home during the pandemic (Brenan, 2020). At the beginning of 2020, only 3.4 % of US workers worked remotely part-time (Feitosa & Salas, 2020). A survey in May 2020 found that 89% of workers worldwide said virtual teamwork is critical to their productivity (Culturewizard, 2020).

What will happen after COVID-19? According to Gallup, three in five (59%) of US workers who have been doing their jobs from home during the pandemic would prefer to continue to work remotely as much as possible once public health restrictions are lifted (Brenan, 2020). Another survey found that 43% of US full-time workers would like to work remotely more often after COVID-19 because of less commuting time, more flexibility, and productivity gains (GetAbstract, 2020). According to responses of over 2,300 remote workers around the world, 97.6% of them said they would like to work remotely occasionally for the rest of their

careers (Buffer & AngelList, 2021). Gartner's CFO survey revealed that 74% of companies expect some of their employees to continue working remotely after the pandemic ends (Gartner, 2020). These data indicate that the pandemic's remote working experience has made many employees and organizations more accepting of remote working and motivated them to reconstruct future work creatively. Therefore, given the organizations' urgent needs for dispersed talents, product innovation, the support of advanced e-collaboration technologies, and positive virtual working experiences during the COVID-19 pandemic, the growth of virtual teams is very likely to continue such that most teams will be to some extent virtual in the future.

This increased reliance on virtual teams in organizations suggests we need to better understand how to facilitate teamwork in a virtual context. Virtual team members, like members of other types of teams, share common purposes and interdependencies. In order to perform well and complete team tasks, they must communicate effectively with each other (i.e., team communication is defined as a team process through which two or more team members exchange information (Adams, 2007)). This is because team communication not only exchanges needed information among team members but also facilitates many key team processes, such as coordinating actions, making decisions, and solving team problems (Kozlowski & Ilgen, 2006; Salas, Sims, & Shawn Burke, 2005). However, communicating through virtual tools can be challenging. Compared to face-to-face communication, many verbal (e.g., words), nonverbal (e.g., facial expressions), and paraverbal cues (e.g., tone of speech) that convey meanings could be lost in virtual communication, especially when using text or audio tools, such as emails or phone calls (Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002). Besides these difficulties, time zone differences among virtual team members and the use of asynchronous virtual tools (e.g., email) may delay team communication and make it challenging to coordinate team

members' schedules (Kurtzberg, 2014; Segalla & Open, 2010). As a result, virtual teams often take a longer time to complete tasks (e.g., Cappel & Windsor, 2000; Graetz, Boyle, Kimble, Thompson, & Garloch, 1998). Therefore, "just bringing people with the required knowledge and skills together virtually provides no guarantee that they will be able to work effectively and innovate across contexts" (Cramton, 2001, p. 452). Difficulties of virtual communication could mitigate or even supersede the advantages of virtual teams, and yet it is an area of research that has largely produced inconsistent results to date (e.g., Marlow et al., 2017). Thus, it is essential to better understand how virtual teams, in the face of these difficulties, can communicate effectively to achieve positive team outcomes**.**

Thesis Research Overview

In light of organizations' increased reliance on virtual teams and these teams' unique communication challenges described above, this thesis aims to answer the question: *how can virtual teams communicate effectively to achieve positive team outcomes?* My program of research consists of two studies to answer this question and to more fully assess the relationship between team communication and team outcomes in virtual teams. In the first study, I systematically reviewed and integrated 103 peer-reviewed empirical articles about virtual team communication and its outcomes. The results delineate which aspects of communication are most relevant to virtual team outcomes, connect different aspects of communication and show how they interact to impact team outcomes, as well as suggest promising directions for future research. This review also offers an integrated framework that provides further theoretical coherence and justification for the study of virtual team communication moving forward.

In the second study, I explored further the impact of communication content on virtual team performance because the effect of team communication content, in particular, is considered

critical and yet remains under-investigated (Marlow et al., 2017). Specifically, in this study, I empirically tested the relationship between four types of communication contents and virtual team performance in 99 virtual teams during a six-month period (January to June 2020). I also explored how the Covid-19 pandemic influenced the "virtual team communication and performance" relationship. The results of this study help to enrich our knowledge about the effects of team communication content on virtual team performance. This study also reveals how virtual teams dealt with external environmental challenges due to the pandemic by engaging in different communication behaviors, which extends the literature on virtual working during times of disruption in general and during the Pandemic in particular.

Overall, this research offers more nuanced insights into virtual team communication and its performance implications in today's organizations. Before presenting these two studies, I first provide a brief overview of the key constructs in my research program.

General Literature Review

Virtual Teams

Virtual teams are composed of members who are geographically dispersed, have limited face-to-face communication, work on interdependent tasks, and achieve common goals through technology-mediated communication (Dulebohn & Hoch, 2017). Because co-located team members tend to also communicate through virtual tools, a virtual team's central distinguishing factor is its team members' geographic dispersion (Foster, Abbey, Callow, Zu, & Wilbon, 2015). While early researchers classified teams as either virtual or face-to-face, recent researchers view geographic dispersion in virtual teams as a continuous variable (e.g., Bell & Kozlowski, 2002;

Eisenberg, Post, & DiTomaso, 2019) with multiple dimensions, such as spatial (i.e., geographic) and temporal (time difference) distance (O'Leary & Cummings, 2007).

Another defining feature of virtual teams is that team members communicate through virtual communication tools (Gibson & Cohen, 2003). Teams that use virtual tools with low informational value and synchronicity (e.g., email) are considered high virtuality teams. In contrast, teams that use virtual tools with high informational value and synchronicity (e.g., video conferencing) are considered low virtuality teams because they are more similar to face-to-face teams (and thus less "virtual") (Mesmer-Magnus, DeChurch, Jimenez-Rodriguez, Wildman, & Shuffler, 2011; Schaubroeck & Yu, 2017). It is important to point out that while video-mediated communication (e.g., Zoom, Skype, Google Meet) is more similar to face-to-face communication than other virtual communication, it still differs from such in-person communication due to reasons outlined below (e.g., information about team members' body movements and postures are easily lost in video-mediated communication). Accordingly, the majority of studies to date regard video-mediated communication as virtual communication (e.g., Anderson, McEwan, Bal, & Carletta, 2007; Baker, 2018; Darics, 2010), and thus, in this thesis research, teams communicating through video conferencing tools are considered virtual teams and not face-to-face teams. Finally, following previous virtual team studies (e.g., Baker, 2018; Espinosa, Nan, & Carmel, 2015; Karayaz, 2006), in this thesis research, dyadic teams are also regarded as teams.

Virtual Team Communication

Virtual team communication is a team process through which two or more team members exchange information using virtual tools, such as email, phone, and video (Marlow, Lacerenza, & Salas, 2017; Adams, 2007). Virtual team communication can be difficult for team members for several reasons. First, communicating precisely in virtual teams is challenging due to the lack

of meaningful cues (e.g., nonverbal cues such as facial expressions and paraverbal cues such as tone of speech) present in virtual communication tools (Baltes et al., 2002). Even though video-mediated communication can convey richer cues (e.g., Zoom, Skype, Google Meet), cameras usually only focus on team members' heads instead of their body movements or postures, leading to fewer cues than in-person communication. For the same reason, team members have to engage in excessive amounts of close-up eye contact with others, which is unnatural and stressful (Bailenson, 2021). Video-mediated communication also requires more effort. While complex nonverbal and paraverbal cues can be exchanged naturally and effortlessly in face-to-face communication, in video-mediated communication, people have to exert more effort to send and receive these cues, such as looking directly into the camera (instead of to the faces on the screen) to make direct eye contact, exaggerating head movement (e.g., nodding) to signal attitudes, and speculating the meaning of a quick, sidelong glance of others (Bailenson, 2021). In addition, in video-mediated communication, team members often view themselves, which can shift their focus from their team tasks to self-presentation and impression management, resulting in reduced individual satisfaction and team performance (Hassell & Cotton, 2017).

Second, virtual communication can be superficial and take a longer time. Since virtual team members are often in different time zones, their working hours have a small overlap. They have fewer opportunities to communicate synchronously through synchronous tools (e.g., video conferencing tools) than team members in the same time zone (Kozlowski & Bell, 2012). When communicating asynchronously, team members seem less inclined to engage in deep discussions to resolve ambiguity (Kurtzberg, 2014). Even if they were motivated to have an in-depth discussion, it could take a long time because of the asynchronous nature of the communication. This explains the consistent finding that virtual teams take a longer time to accomplish tasks than

face-to-face teams (e.g., Cappel & Windsor, 2000; Graetz, Boyle, Kimble, Thompson, & Garloch, 1998). The delays in communication may lead to untimely decision-making and hinder virtual teams' planning and coordination processes (Kayworth & Leidner, 2000). Third, virtual communication can easily lead to distractions. The proliferation of computers and hand-held devices has made it easier and more tempting for individuals to handle multiple tasks simultaneously (Kurtzberg, 2014). Team members are likely to work on other tasks while participating in teamwork, divide attention between activities, and therefore not fully invest in any tasks or cooperate with their teammates. These behaviors are detrimental to their task performance, which in turn can hamper the effectiveness of virtual teams. Fourth, according to Allen's law of propinquity (Krackhardt, 2003), team members may be less likely to have positive feelings towards physically far away teammates. Since positive feelings are a component of team cohesion (Castaño, Watts, & Tekleab, 2013), virtuality may hurt cohesion and the way in which team members communicate. Similarly, according to construal-level theory of psychological distance, a high level of time or spatial distance could lead to stereotypes and bias (McCrea, Wieber, & Myers, 2012; Trope & Liberman, 2010). Bias and negative stereotypes toward others could hinder trust formation (McKnight, Cummings, & Chervany, 1998), further harming their communication efforts.

To sum up, the above literature suggests that virtual communication can hurt team processes and outcomes. However, meta-analyses have produced inconsistent results. Marlow, Lacerenza, Paoletti, Burke, and Salas's (2017) meta-analysis found that team virtuality moderated the relationships between communication and team performance, including creative performance (e.g., the novelty of product produced), decision-making performance (e.g., the accuracy of the decision of team as compared to expert solution), and generic task performance

(e.g., score on simulation), such that these relationships were less positive in virtual teams than in face-to-face teams. In contrast, another meta-analysis demonstrated that virtual communication improves the sharing of unique information but hinders information-sharing openness (Mesmer-Magnus et al., 2011).

These empirical studies suggest that we cannot draw a generalizable conclusion about the relationship between virtual team communication and team outcomes. The following two reasons could explain these inconsistent findings. First, virtual team communication may interact with other variables to impact team processes and outcomes together because the context of the research matters for its results (Johns, 2006). For instance, Purvanova (2014) found that the setting of studies (laboratory vs. field) moderates the effects of virtuality on team outcomes because typical virtual teams in laboratory settings differ from typical teams in organizational settings in terms of team size, composition, and task complexity. However, these critical moderating, contextual variables are often not assessed, such as the type of information shared (Mesmer-Magnus & Dechurch, 2012), task characteristics, and team context (e.g., legal environment; Dulebohn & Hoch, 2017). Schaubroeck and Yu (2017) argued that three core team attributes in particular (i.e., skill differentiation, temporal stability, and authority differentiation) might moderate team virtuality's impact on team outcomes and thus deserve further attention.

Second, the inconsistent conceptualization of key variables related to virtual team communication and virtual team outcomes may lead to inconsistent results. Communication is a broad concept and can be conceptualized in various ways (e.g., quality versus frequency as described in greater detail in Study 1), and as such, different aspects of team communication may impact team outcomes differently (Stout, Cannon-Bowers, & Salas, 1996). Besides, many distinct team outcomes exist (e.g., performance versus satisfaction), where particular aspects of

team communication might be beneficial or detrimental to specific types of team outcomes. Therefore, it is critical to address how and why virtual team communication impacts virtual team outcomes in more nuanced ways, including investigations into *what aspects of communication are most relevant to which virtual team outcomes, how they interactively impact certain virtual team outcomes, and how contextual variables moderate the effects of virtual team communication on team outcomes.* I will try to answer these questions in my thesis research, starting with a systematic review of the virtual team communication literature in Study 1, followed by an investigation into the ways in which specific types of team communication affect different types of team performance in virtual teams in Study 2.

Study 1. Virtual Team Communication and Team Outcomes: A Systematic Literature Review and Integration

Virtual teams (i.e., teams of geographically dispersed members collaborating using technology) are growing in prevalence because of organizations' urgent need for talent and as a result of challenges from the external environment today (e.g., COVID-19 Pandemic, financial constraints) (Morrison-Smith & Ruiz, 2020). Virtual teams, like non-virtual teams, need team communication to manage expectations, complete tasks, and make plans for future work and changing circumstances (Schaubroeck & Yu, 2017). However, communicating in virtual teams can be challenging due to the limited informational cues available in virtual tools (e.g., email), as well as time differences and a lack of team cohesion among geographically distributed virtual team members (Baltes et al., 2002; Kurtzberg, 2014). Inefficient or inappropriate virtual communication could mitigate or even supersede the advantages of virtual teams and lead to negative team outcomes. Therefore, it is important to better understand virtual team communication for team effectiveness today.

Although team communication has been consistently identified as a critical antecedent of virtual team outcomes, previous studies have yielded inconsistent results (Marlow, Lacerenza, & Salas, 2017). The inconsistent conceptualization of key variables in this research may have caused these inconsistent results. First, Stout, Cannon-Bowers, and Salas (1996) argued that team communication is a broad concept, and it has accordingly been conceptualized differently in different studies, such as communication frequency and quality. These various aspects of team communication may impact team outcomes differently (Marks et al., 2000). Second, Marlow, Lacerenza, Paoletti, et al. (2017) argued that different communication aspects may interact to predict team outcomes. For instance, different combinations of frequency level and quality level

(e.g., high quality + low frequency or high frequency + low quality) may lead to different team performance levels. Third, team communication may have different effects on different team outcomes. Many distinct team outcomes exist, such as team performance, efficiency, learning, and adaptation. Teams can succeed in terms of certain types of outcomes, but not necessarily all of them. Efficient teams may only meet the minimum requirements of tasks, while teams pursuing high product quality may need a longer time to complete tasks. Schaubroeck and Yu (2017) relatedly argued that particular configurations of team attributes might be beneficial or detrimental to specific types of team outcomes. These inconsistent findings lead to further questions, such as *what aspects of communication are most relevant to what virtual team outcomes, and how do they interact (e.g., communication frequency and quality) in their impact on virtual team outcomes?* Previous research has not investigated these questions.

Therefore, to address the research gaps discussed above, the purpose of this paper is to answer the overarching question: *how can virtual teams communicate effectively to achieve positive team outcomes*? Specifically, it aims to delineate which aspects of communication are most relevant to virtual team outcomes, connect different aspects of communication to show how they interact to influence team outcomes, explore the role of moderating variables, and suggest promising directions for future research. To meet these goals, I conducted a systematic literature review of 103 empirical articles related to "virtual team communication and team outcomes" relationships to summarize their findings. I also integrated theories used in these studies to identify the main mechanisms through which virtual team communication affects virtual team outcomes and the main contextual variables that moderate the relationships. Thus, according to Paré, Trudel, Jaana, and Kitsiou (2015), this review has the characteristics of both a systematic literature review and a theoretical review.

This paper contributes to the literature in three ways. First, I summarize and synthesize the currently mixed findings of the relationships between virtual team communication and team outcomes by conceptualizing team communication as a profile multidimensional construct (Keyton, 1999; Law, Wong, & Mobley, 1998; Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017; Norton, 1983) that is composed of five dimensions: communication frequency, quality, content, style, and structure. These dimensions of team communication are interrelated but conceptually different. They can be fully combined to form many different profiles of team communication (i.e., high/medium/low frequency + high/low quality + task/relational content + certain type of communication style + certain communication structure). Based on this conceptualization, I examine the impact of each dimension of team communication on various virtual team outcomes. I also connect these dimensions to show how they interact to influence different team outcomes. This conceptualization allows for a more clear and precise examination of the relationship between virtual team communication and team performance. Thus, the results of this review enrich the knowledge of the current state of "virtual team communication-team outcomes" research, including the effects of different virtual team communication aspects on various virtual team outcomes and the main moderating factors that change these effects.

Second, building on these results, I develop a theoretical framework that identifies the primary theoretical mechanisms through which virtual team communication affects virtual team outcomes and describes the contextual variables that moderate these relationships. This framework offers a comprehensive view of the "virtual team communication - team outcomes" relationships, which can guide scholars to examine the effects of different aspects of virtual team communication, and enable practitioners to manage or participate in virtual teams in a more

efficient way. Finally, based on this extensive review using a profile multidimensional construct conceptualization of team communication, and the proposed integrative framework, this paper identifies research gaps and proposes promising avenues for future research that will promote further progress in this area.

Literature Review

Team Communication Conceptualizations

Team communication is a broad concept that can be conceptualized in a variety of ways. For example, literature reviews about virtual team communication classify team communication into three categories: communication frequency, quality, and content (Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017). *Communication frequency* refers to communication volume over any communication medium (Marks et al., 2000). *Communication quality* refers to the clarity, effectiveness, accuracy, and completeness of communication (González-Romá & Hernández, 2014). *Communication content* within teams is either task-oriented or relational-oriented (Keyton, 1997). For instance, task-oriented communication could be "we should do … first," and relational-oriented communication could be "You have not said anything to that yet, Thomas. Why don't you say something?"

Many other studies also measure team communication as communication styles and structures. *Communication style* refers to "the way individuals verbally or paraverbally interact to signal how literal meaning should be taken, interpreted, filtered, or understood" (Norton, 1978, p. 99). It differs from communication content since the communication style could be shortly defined as "the way content is communicated" (Norton, 1983, p. 12). C*ommunication*

structure refers to a network in which particular members communicate with certain other members through specific routes when group members interact (Keyton, 1999).

These five aspects of team communication (i.e., communication frequency, quality, content, style, and structure) are interrelated, but different conceptually and functionally. For instance, frequent communication could include too much irrelevant information (e.g., gossip) and be low in communication quality (DeSanctis & Monge, 2006). While there is not a single theoretical overall construct that can summarize and represent all these five dimensions, we can specify various levels of these five dimensions. Thus, according to Law, Wong, and Mobley (1998), team communication can be conceptualized as a profile multidimensional construct.

In order to answer the overarching research question of this paper (i.e., how can virtual teams communicate effectively to achieve positive team outcomes?), we need to examine the impact of each of these dimensions of team communication on various virtual team outcomes. Based on the characteristics of a profile multidimensional construct, we also need to connect these dimensions and show how they interact to impact team outcomes. Specifically, these five dimensions of team communication can form many different profiles of team communication (i.e., high/medium/low frequency + high/low quality + task/relational content + certain type of communication style + certain communication structure), which may impact team outcomes differently.

Team Outcome Conceptualizations

It is critical to recognize that particular aspects of team communication may only impact specific team outcomes in virtual teams. Hertel, Geister, and Konradt (2005) stated that team satisfaction may increase when team members share more non-task-related information with

other team members. However, this communication may not contribute to team performance. Therefore, following previous team outcome criteria (Marlow, Lacerenza, & Salas, 2017; Roberson & Colquitt, 2005; Schaubroeck & Yu, 2017), I categorized team outcomes into the following categories: (a) team attitudes, (b) team behavioural processes, (c) emergent states, (d) performance, and (e) team evolution. Team attitudes include satisfaction with team, commitment, attachment, and cohesion. Team behavioural processes include cooperation and help, conflict management, and task strategies. Team emergent states are dynamic team properties that are a function of team context, inputs, processes, and outcomes (Marks, Mathieu, & Zaccaro, 2001). These states include team trust, transactive memory systems (TMS), and shared mental models (SMM). Team performance definitions vary depending on the type of team and the nature of the task it performs. It could be decision-making performance, task performance, task speed, or team efficiency. The last category - team evolution – includes team learning outcomes, adaptation to the environment, team viability, team creativity and innovation. Based on these categorizations, we can more clearly delineate the relationship between virtual team communication and several team outcomes. Therefore, I address how virtual team communication impacts virtual team outcomes by systematically reviewing the literature on virtual team communication and team outcomes in line with the above reviewed conceptualizations of both communication and its outcomes.

Research Design and Methodology

The objective of this review was to answer the question: how does virtual team communication impact virtual team outcomes? To do so, I conducted a systematic literature review on research focused on virtual team communication and its impacts on virtual team outcomes to 1) delineate which aspects of communication are most relevant to virtual team

outcomes, 2) connect different aspects of communication and show how they interactively impact team outcomes, 3) explore the effects of moderating variables, and 4) suggest promising directions for future research.

Literature Search

Studies were collected through a computerized search of the following *databases*: PsychInfo, ProQuest, ABI/Inform, Web of Science, Business Source Premier. The literature search started from the available start date to the end of 2020 utilizing combinations of the following keywords: ① "virtual team," "virtuality," "computer-mediated group" ② "team communication," "communication frequency," "communication quality," "communication content," "communication style," "communication structure" ③ "team satisfaction," "commitment," "attachment," "cohesion"; ④ "cooperation," "conflict management," "task strategies"; ⑤ "trust," "transactive memory systems," and "shared mental models"; ⑥ "task product quality," "task completion speed," "task performance," "team performance"; ⑦ "team learning," "team adaptation," "team innovation," and "team creativity."

Criteria for Inclusion

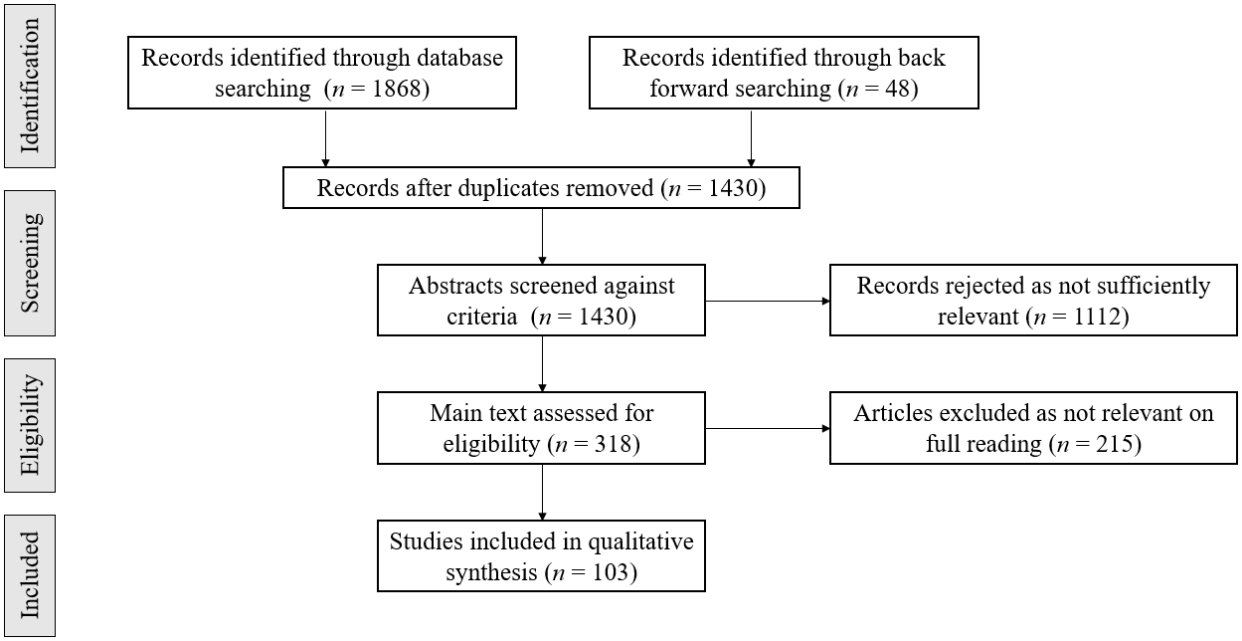
Studies were included if they met the following criteria: were in English, were empirical, examined the relationship between virtual team communication and virtual team outcomes, were at the team level of analysis, and included an adult sample (i.e., all participants were over the age of 18). I excluded conceptual papers, working papers, magazine articles, opinion articles, or empirical studies that did not include virtual team data.

Process of Selection

To identify and select the relevant studies for this research, I conducted the search in four steps (see Figure 1)**. Step 1**, I searched in the databases with multiple search strings that combined the terms related to virtuality (e.g., computer-mediated, virtual), terms related to team outcomes (e.g., team performance), and terms related to virtual team communication (e.g., communication frequency). I extracted all the articles whose abstracts or titles contained combinations of the keywords. This primary search produced more than 1,868 articles. **Step 2**, among these 1,868 articles, following Siddaway, Wood, and Hedges' (2019) suggestion, I also searched through references of literature reviews and meta-analyses about virtual team communication to locate all potentially relevant empirical works. This backward search produced 48 additional articles. **Step 3**, after removing duplicates, I was left with 1,430 articles. I read all those articles' titles and abstracts and excluded studies that did not meet the inclusion criteria, or that did not focus on the impacts of virtual team communication on virtual team performance (e.g., articles on virtual simulation training, virtual communication tools selection, or human work with virtual intelligent agents). This review considered only empirical studies that collected and analyzed primary data, so literature reviews, meta-analyses, and theoretical articles were excluded. This step led to the removal of a further 1,112 articles, which left 318 articles. **Step 4**, for the 318 papers that still appeared relevant, the main text was then read and checked in detail against the inclusion criteria, leading to a further 215 articles being rejected. Among the rejected articles, studies about virtual team leaders' communication strategies or virtual leaderships were excluded because this literature review focuses on how virtual team members' communication impacts team outcomes, but not the impacts of virtual leaders. This final filter left 103 articles that fully met the inclusion criteria.

Figure 1

Literature Search Process



Summary of Data

I summarized each paper along several dimensions: the communication-related constructs, research questions, theories used, hypotheses, research methods (study settings, data sources, measurements, analyses), results, and limitations. I then analyzed the relationships between virtual team communication and team outcomes using the proposed five communication categories (i.e., communication frequency, quality, content, style, and structure) and five team outcomes categories (i.e., team attitudes, team behavioural processes, emergent states, performance, and team evolution). More specifically, I analyzed the relationships of different "team communication - virtual team outcomes" pairs (e.g., communication frequency and team trust), delineated which aspects of communication are most relevant to virtual team outcomes, connected different aspects of communication, showed how they interactively impact team

outcomes, showed the effects of moderating, contextual variables, as well as suggested promising directions for future research.

Results of Literature Review

Most of the included studies took a quantitative approach (n = 79, 77%), while others took a qualitative approach (n = 24, 23%). Among the quantitative studies, most of the studies adopted a cross-sectional approach (n = 49), while others used longitudinal analyses (n = 28). Most of these studies' data were collected through surveys (n = 59) of virtual team members or leaders, and the sample sizes varied from thirty to thousands. Among the qualitative studies, data were collected through interviews (n = 20), archival datasets (n = 6), and researchers' observations (n = 6). The majority of studies examined teams with at least three members; only four studies included dyadic teams (Baker, 2018; Espinosa et al., 2015; Karayaz, 2006; Li, Rau, Li, & Maedche, 2017). Most of the studies examined the impacts of communication frequency (n = 42) and quality (n = 39), while others examined the impacts of communication content (n = 21), style (n = 10), and structure (n = 4).

My review of these studies is organized into five sections. In each section, I summarize how each of the proposed five dimensions of team communication has been studied in relation to the identified five virtual team outcome categories, including a review of the relevant theories used as well as their empirical results of these studies.

Communication Frequency and Team Outcomes

Studies measure communication frequency in mainly three ways. First, team members report the number of communication with other members through certain communication tools or the amount of communication that their teams had conducted over certain communication

tools during a specific period of time. The team members' average responses reflect the teams' communication frequency over a particular medium in a certain period (e.g., He, Butler, & King, 2007; Patrashkova-Volzdoska, McComb, Green, & Compton, 2003). Second, objective communication records, such as the number of messages sent in team communication, reflect team communication frequency (e.g., Jarvenpaa, Shaw, & Staples, 2004; Karayaz, 2006). Third, researchers observe team communication frequency (e.g., Chamakiotis, Boukis, Panteli, & Papadopoulos, 2020).

According to my analysis of the included studies, virtual communication frequency has three kinds of relationships with virtual team outcomes: positive, negative, and inverted U-shaped (see table 1). In the following part, I describe these results, including a review of the theories adopted by these three groups of studies in depicting the "communication frequency - team outcomes" relationships, as well as a discussion of their main empirical findings and the contingency factors that affect these relationships.

Table 1

Relationship Between Virtual Communication Frequency and Team Outcomes.

Relationship	Outcome	Theory	Moderator
+	cohesion, social attraction, coordination, task conflict [a], trust, TMS, performance [b], learning, adaptation, creativity	social information processing theory, social cognition theory	early trust level, peer feedback, communication tool, time, project complexity, team size, team lifespan
-	task, relational, and process conflict		
	satisfaction, performance [b]	cognitive load theory	
inverted u-shaped	cohesion, performance [b], creativity		

Note: [a] positive relationship between communication frequency and team task conflict is explained by cognitive load theory. [b] five qualitative and seven quantitative studies showed

positive relationships between communication frequency and virtual team performance; six quantitative studies demonstrated negative or curvilinear relationships.

Theories Depicting the Relationships Between Communication Frequency and Virtual Team Outcomes

The positive effects of communication frequency on virtual team outcomes are most commonly explained by social information processing theory and the shared cognition perspective. In comparison, the negative or inverted U-shaped relationships between virtual team communication frequency and team outcomes are mainly explained by the cognitive load theory (Sweller, van Merriënboer, & Paas, 1998).

Social Information Processing Theory. Social information processing theory posits that individuals require more time to develop interpersonal impressions and relations in virtual interactions than in face-to-face interactions because virtual communication has a limited carrying capacity and takes longer time to exchange information (Walther, 1992). When given enough time, virtual teams can achieve the same level of liking, trust, and sociable states as face-to-face teams (Walther & Burgoon, 1992). Thus, virtual teams need more frequent interactions and more time for communicators to reach the relationship development level that face-to-face partners accomplish in a shorter time. According to this theory, virtual teams that communicate more frequently are more likely to have better team outcomes.

Shared Cognition Perspective. Team cognition refers to information shared by all team members relating to team and task, such as task demands, team goals, team members' knowledge, skills, experience, roles, and responsibilities (Cannon-Bowers, Salas, & Converse, 1993). The shared cognition perspective posits that the development of team cognition will lead

to effective team processes and better team outcomes (Cannon-Bowers et al., 1993; Marlow, Lacerenza, & Salas, 2017). This is because sharing team- and task-related information among all team members can ensure that team members' knowledge, skills, and experience are brought to bear on team tasks (Gajendran, 2009). It also can develop and reinforce shared beliefs and understandings regarding team roles and responsibilities (Kanawattanachai & Yoo, 2007; Macmillan, Entin, & Serfaty, 2004). Based on the shared cognition perspective, frequent team communication could help virtual team members share information, understand each other and the organizational context (Levin & Cross, 2004), thus foster team trust (Becerra-Fernandez & Sabherwal, 2001), establish mutual knowledge, build and maintain a shared mental model of the situation, solve coordination difficulties, and prevent team conflicts. In contrast, a low level of communication frequency between individuals could result in insufficient knowledge of others and underpin coordination difficulties, leading to more conflict episodes (Wall & Callister, 1995).

Cognitive Load Theory. This theory argues that individuals have a limited working memory capacity; when the capacity is exceeded, individuals' learning and processing abilities are impaired (Sweller et al., 1998). Virtual team members with different knowledge and social-culture backgrounds need frequent communication to develop a shared understanding and relations. However, too frequent information sharing and processing in team communication can overwhelm team members, leading them to perform poorly. Indeed, Armon (2013) argued that too much virtual communication might be annoying and stressful for team members, especially when communication mainly contains team conflicts or basic communication, such as check-ins. Thus, this theory predicts that communication frequency can also be negatively related to virtual team outcomes.

Empirical Findings

Team Attitudes. The findings from research on the relationship between communication frequency and team attitudes are inconsistent. Some studies found that frequent virtual communication can build and maintain team cohesion (Scholz, 2003), as well as increase social attraction (Walther & Bunz, 2005). However, one study found that frequent communication was negatively related to virtual team satisfaction (Armon, 2013). Another study found that team communication frequency had a curvilinear relationship with team cohesion: both low and high communication frequencies were associated with lower levels of team cohesion, while a moderate frequency was associated with higher team cohesion (Patrashkova-Volzdoska et al., 2003).

Why do the relationships between communication frequency and virtual team attitudes vary across studies? Virtual teams' early trust level can explain these inconsistent relationships. Jarvenpaa et al. (2004) found that virtual teams' early trust level moderated the impact of communication frequency on team satisfaction and cohesiveness. When the teams' early trust level was low, communication frequency was positively associated with team satisfaction and cohesiveness; by contrast, when the trust level was high, the relationships were non-significant (Jarvenpaa et al., 2004). Jarvenpaa et al. (2004) explained that, in the high-early-trust condition, team members are likely to devote more effort to tasks, regardless of the level of others' communication, because teams' early trust level influences members' expectations about other members' behaviours. When team members trust each other, unexpected behaviours will be attributed to situational factors (Jones & Nisbett, 1972). For example, delays in communication will be attributed to technical issues. Thus, the level of communication may have less influence on a team member's team attitudes. By contrast, unexpected behaviours in the low-early-trust

condition will be attributed to others' internal factors (Jones & Nisbett, 1972), such as low commitment to the team. Thus, a low-early-trust member is more concerned about others' commitment and will appraise the team's commitment based on others' communication level. More communication may thus lead to more positive attitudes when early trust is low.

Team Behavioral Processes: Team Coordination. Several studies have found positive effects of communication frequency on team coordination in virtual teams. Frequent communication can provide virtual teams with more opportunities to share information about the work process and cultures (Hinds & Mortensen, 2005), have helpful discussions, solve problems (Wang, Liu, Wang, Zhang, & Fan, 2015), and foster team synergy (Mattison, 2013). However, McLarnon et al. (2019) found that the positive relationship between communication frequency and process coordination existed only when virtual teams' peer feedback (about team members' engagement, effort, intellectual contribution, and collegiality) was collected and shared within teams weekly. These authors explained that peer feedback could help a team focus on issues hindering coordination, thus enabling them to coordinate more effectively (McLarnon et al., 2019).

Team Behavioral Processes: Team Conflict. The evidence on the effect of communication frequency on team conflict is mixed. Some studies indicate that frequent virtual communication relates to less task, relational, and process conflict (Hinds & Mortensen, 2005; Sarbaugh-Thompson & Feldman, 1998; Wakefield, Leidner, & Garrison, 2008). In particular, frequent spontaneous communication can mitigate the impact of the team's geographic distribution on team conflict (Hinds & Mortensen, 2005) by identifying team conflicts early and preventing conflicts from escalating (Hinds & Bailey, 2003). However, another study reported that frequent communication is positively related to team task conflicts (Kankanhalli, Tan, &

Kwok-Kee, 2006). This positive relationship can be explained using the cognitive load theory, in which a large amount of communication results in information overload among team members. In such cases, some team members' contributions are overlooked, which causes team conflicts.

Team Emergent States: Trust. Many studies have found that communication frequency is positively related to virtual team trust (Alsharo, Gregg, & Ramirez, 2017; Jarvenpaa et al., 2004; Mattison, 2013; Meixner, 2018; Park & Lee, 2014). However, the type of communication tool can moderate this relationship. A study found that the frequency of certain communication tool usage was positively related to team trust (i.e., email, phone, phone conference, video conference); while asynchronous, threaded tool usages did not have significant relationships with team trust (i.e., wiki/Web-based thread) (Thomas, 2010). One possible reason is that asynchronous/threaded discussion carries less information than other communication tools (Newberry, 2001), and thus, according to the social information processing theory, virtual team members may need more threaded discussion to develop team trust.

Team Emergent States: TMS. TMS refers to a team's meta-knowledge about each team member's different expertise domains (Wegner, 1987). Studies have indicated that frequent communication can facilitate TMS development (He et al., 2007; Oguntebi, 2010; Shi & Weber, 2018). However, the type of communication tools and time moderate this relationship. One study found that phone call frequency among virtual team members was positively related to TMS, but email use frequency had no effect (He et al., 2007). Another study found that the relationship between virtual communication and TMS emergence significantly improved over time (Oguntebi, 2010).

Team Performance. The evidence for the impact of virtual team communication frequency on team performance is both mixed and context-dependent. While one group of

studies reported a positive impact of frequent team communication on virtual team performance, supporting the shared cognition perspective and the social information processing theory, the second group of studies supports the cognitive load theory by finding negative or curvilinear relationships between communication frequency and virtual team performance. Besides, other studies found several contextual variables that moderate the effects of communication frequency on virtual team performance. I elaborate on these results below.

The first group of studies has found that communication frequency has a positive effect on virtual team performance. A number of interview studies have revealed that virtual team leaders and members tend to believe that frequent communication contributes to better team performance (Agbi, 2018; Ekpo, 2015; Gaines, 2018; Jordan & Adams, 2016; Morgan, Paucar-Caceres, & Wright, 2014). In support of this belief, several quantitative studies found that communication frequency was positively related to team decision-making performance (Ceschi, Dorofeeva, & Sartori, 2014), general performance indicated by team project scores, instructors' rating, self-rating (Gajendran, 2009), course project grades (Hardin, 2005), product and process performance (Oguntebi, 2010), groups' work quality (Espinosa et al., 2015; Walther & Bunz, 2005), and team production speed (Espinosa et al., 2015). Further, a study found that frequent team communication enhanced virtual team performance even when team members use various communication technology types (i.e., email, phone, video conference, intra/extranet) (Thomas, 2010).

However, the second group of studies has reported negative (Armon, 2013), non-significant (McLarnon et al., 2019; Montoya, Massey, & Lockwood, 2011), or curvilinear relationships between communication frequency and virtual team performance (Handke, Schulte, Schneider, & Kauffeld, 2018; Patrashkova-Volzdoska et al., 2003). In studies that report

curvilinear relationships, both low- and high-communication frequency are associated with lower team performance levels. In comparison, moderate frequency is associated with higher levels of team performance. Lippert and Dulewicz (2018) found that high-performing global virtual teams were more likely to refrain from talking too much at any one time than low-performing teams. Similarly, Ruiller et al. (2019) found that experienced virtual team members were less likely to submit requests or initiate contacts with others because they feared being intrusive to the remote teammates when they were busy with their tasks.

As alluded to above, the impact of virtual team communication frequency on team performance is context-dependent. Several contextual variables have been shown to moderate the effects of communication frequency on virtual team performance, including project complexity, time, communication tools, team size, feedback, and early trust.

Project Complexity. Kennedy et al. (2011) found that when project complexity increased, virtual teams must communicate more frequently to achieve their optimal performance. In this experimental study, the result indicated that communication frequency and team performance have an inverted U-shaped relationship depending on project complexity. When the team projects' complexity is low, the communication frequency level at which teams maximize their performance is low; When the team projects' complexity increases, the maximal point of communication frequency also increases.

Time. Handke et al. (2018) found that the positive relationship between communication frequency and virtual team performance became stronger over time. According to compensatory adaption theory (CAT), virtual team members do not passively accept the obstacles posed by unnatural communication tools (Hantula, Kock, D'Arcy, & DeRosa, 2011). Instead, they will (voluntarily and involuntarily) compensate for these obstacles by altering their communication

behaviours. Since they, therefore, tend to become more skillful in their virtual communication, the relationship between communication frequency and performance becomes stronger over time. However, Yoo and Kanawattanachai (2001) found that the positive influence of communication volume on team performance instead decreased over time. They explained that as a virtual team develops its TMS through repeated interaction over time, the direct influence of communication frequency on the team performance would decrease.

Communication Tool. Kennedy, McComb, and Vozdolska (2011) found an inverted U-shaped relationship between communication frequency and virtual team performance such that the communication frequency at which teams maximized their performance depended on the communication tools' cue-carrying capacity. Communication tools have different cue-carrying capacities (Daft & Lengel, 1986; Newberry, 2001), and as the communication tools' cue-carrying capacity increases, the relative communication frequency level associated with optimal performance increases. Since emails' cue-carrying capacity is lower than for phones, Kennedy et al. (2011) found that for teams communicating through emails, their communication frequency level that optimizes their performance was lower than teams communicating through phones. Kennedy et al. (2011) explained that too much email communication might be more difficult to process than the same amount of phone communication. Thus, email communication optimizes team performance at lower frequency levels than phone communication.

In addition, communication tools seem to moderate the moderating effect of time on the "communication frequency - team performance" relationship. As mentioned above, the positive relationships between communication frequency and virtual team performance become stronger over time in Handke et al. (2018) but become weaker in Yoo and Kanawattanachai (2001). Why? A possible explanation is that their virtual teams' communication tools differ. Virtual teams in

Yoo and Kanawattanachai's (2001) study communicated only through one simple tool, the web-based discussion message. Over time, they developed TMS, and the direct influence of communication frequency on team performance decreased. In contrast, teams in the study by Handke et al. (2018) communicated through multiple communication tools: video, message chat, telephone, and email. In the beginning, team members may not be familiar with all the tools and not know how to communicate efficiently by using these tools in combination. Nevertheless, the compensatory adaption theory (CAT) argues that people will gradually overcome the obstacles posed by virtual communication tools and become more skillful at communicating through these tools in combination. As a result, the impact of frequent communication on team performance increased over time. However, since these two studies have not examined the moderating effect of communication tools directly, future research is needed to examine how communication tools and time interactively impact the "communication frequency - team performance" relationship.

Team Size. The communication frequency and team performance relationship is also moderated by team size. Karayaz (2006) found that dyadic teams performed as well as teams with three or four members, even though dyadic teams communicate less frequently than other teams. In other words, smaller teams need less communication to perform well. This may suggest that dyadic communication can focus more on task-related issues, while large groups may have too many different perspectives to reach a common view.

Feedback. McLarnon et al. (2019) found a stronger effect between communication frequency and virtual team performance when virtual team members also gave and received weekly feedback. This effect was trivial when the feedback was given and received only at project completion or given weekly but not distributed until project completion.

Early Trust. Similar to the moderating effect of trust when it comes to the impact of communication frequency on team satisfaction and cohesion, Jarvenpaa et al. (2004) also found that team members' early trust in the team moderated the relationship between team communication frequency and the perceived quality of the team's outcome. Under the lower-early-trust condition, more frequent communication was associated with higher quality. Under the high-early-trust condition, a higher level of communication was not associated with better outcomes.

Team Evolution. Stull (2008) found that frequent team communication can facilitate team learning in small virtual teams. One explanation is that team learning requires new knowledge, routines, or behaviours to be shared among team members (Kozlowski & Blawath, 2012; Wilson, Goodman, & Cronin, 2007), and frequent communication can facilitate this information-sharing process. Another study found that frequent team communication can also help virtual teams smoothly adapt to organizational challenges (Qureshi, Liu, & Vogel, 2006).

Regarding the communication frequency and team innovation relationship, the evidence is mixed. Some studies found that frequent communication could contribute to team creativity (Han, Chae, Macko, Park, & Beyerlein, 2017) and to team innovation as both a process (e.g., new services, methods, or procedures) and an outcome (e.g., technical innovation, novelty, or creativity of team solutions) (Gajendran & Joshi, 2012). However, others have reported nonsignificant (Ocker, 2005) and inverted-U-shaped relationships, such that virtual team creativity requires a moderate frequency of communication (Leenders, Van Engelen, & Kratzer, 2003). However, team lifespan can moderate this relationship. Chamakiotis et al. (2020) found that for virtual teams with a short lifespan (i.e., 24 hours), frequent communication can reduce the uncertainty characterizing the early stages of innovation. While for virtual teams with a

longer lifespan (i.e., five months), less frequent communication allows dispersed members to work simultaneously on different, complementary aspects of the innovation task at hand.

Summary of Results for Communication Frequency

This section included a review of studies linking virtual team communication frequency and virtual team outcomes, indicating this relationship is complicated. On the one hand, frequent virtual team communication positively affects team attraction, coordination, trust, TMS development, learning, and adaptation. These results support the shared cognition perspective and the social information processing theory. On the other hand, the relationships between communication frequency and team cohesion, conflicts, performance, and innovation have been shown to be positive, negative, or inversely related. These results suggest that the effects of communication frequency on virtual team outcomes depend on the level of communication frequency. According to the shared cognition perspective and social information processing theory, frequent team communication can lead to better team outcomes by sharing social and task information among team members. However, as the cognitive load theory argues, too frequent communication can impair team members' ability to work with teammates; thus, a medium level of communication frequency is optimal such that virtual teams will have fewer team conflicts, better team cohesion, performance, and creativity. Lastly, the effects of communication frequency on virtual team outcomes also depend on contextual variables, including team early trust level, peer feedback, communication tool, time, project complexity, team size, and team lifespan.

Communication Quality and Team Outcomes

Studies tend to operationalize communication quality in two ways. First, team members' averaged responses on communication quality scales are used to measure team communication quality (Flanagin, Sun Park, & Seibold, 2004; Pitts, Wright, & Harkabus, 2012). Second, team communication quality can also be assessed by researchers directly (e.g., Colquitt, Hollenbeck, Ilgen, Lepine, & Sheppard, 2002; Zaugg & Davies, 2013). While some studies assess overall team communication quality (e.g., Chang, Hung, & Hsieh, 2014), others focus on specific aspects of communication quality (e.g., communication efficiency, Baker, 2018; or communication precision, Watanuki & De Oliveira Moraes, 2016).

According to my analysis, virtual team communication quality is generally found to affect virtual team outcomes positively (see table 2). I review these results below by first addressing their theoretical foundations, then discussing the main empirical findings, and the contingency factors that affect the relationships between "communication quality - virtual team outcomes."

Table 2

Relationship Between Virtual Communication Quality and Team Outcomes.

Relationship	Outcome	Theory	Moderator
+	satisfaction, task attraction, social attraction, identification, cohesiveness, trust, TMS, performance [a], creativity, learning, adaptation	social cognition perspective, attribution theory	task interdependence, team development stage, virtuality
-	performance [a]		
not significant	performance [a]		

Note: [a] most studies showed positive relationships between communication quality and virtual team performance; only one demonstrated negative, and two found not significant relationships.

Theories Depicting the Relationships Between Communication Quality and Virtual Team Outcomes

Shared Cognition Perspective. Virtual team members often have different sociocultural backgrounds and diverse expertise. The shared cognition perspective (Cannon-Bowers et al., 1993; Marlow, Lacerenza, & Salas, 2017) predicts that high-quality communication among team members can ensure that these members' knowledge, skills, and experience are brought to bear on the team task (Gajendran, 2009). In addition, the shared cognition perspective also argues that sharing information among team members can help them understand each other, their organizational context, and share beliefs regarding their team roles and responsibilities (Kanawattanachai & Yoo, 2007; Levin & Cross, 2004; Macmillan et al., 2004). Thus, high-quality communication lets virtual team members know how to contribute to interdependent team tasks, coordinate smoothly with their teammates, and perform well (Marlow, Lacerenza, & Salas, 2017). Such shared understanding enables team members to work interdependently with little communication, thus conserving team members' cognitive resources and contributing to better team effectiveness (Macmillan et al., 2004).

Attribution Theory. The attribution theory argues that actors tend to attribute their actions to situational requirements, whereas observers tend to attribute the same actions to the actors' stable characteristics (Jones & Nisbett, 1972). In a virtual context, individuals lack cues about each other; they accordingly build stereotypical impressions of others based on limited information, such as others' communication patterns (Lea & Spears, 1992). High-quality team communication that is timely, open, consistent, clear, and complete will help team members form dedicated, motivated, or committed perceptions about each other; thus, virtual teams with high communication quality will have more positive team attitudes.

Empirical Findings

Virtual Team Attitudes. Many empirical studies have indicated the positive influence of communication quality on virtual team satisfaction (Egan et al., 2009; Heuser, 2010; Piccoli, Powell, & Ives, 2004), task attraction, social attraction (Walther & Bunz, 2005), satisfaction, identification (Timmerman & Scott, 2006), and team cohesiveness (Knoll, 2001). According to attribution theory, high-quality team communication will be attributed to team members' high level of dedication, motivation, or commitment to the team. Therefore, virtual team members will have positive attitudes toward the team when they engage in high-quality communication.

Team Emergent States: Trust. Research has shown that virtual team managers and members think that virtual team trust could be developed via high-quality virtual communication that (a) repeats essential information back to information givers to show understanding, (b) explains phrases to prevent misunderstanding, (c) limits the use of vernacular phrases (Zaugg & Davies, 2013), and (d) is regular, open, and honest (Henttonen & Blomqvist, 2005; Meixner, 2018). Similarly, many other studies have found that communication quality positively relates to trust (Baker, 2018; Chang et al., 2014; Egan et al., 2009; Jarvenpaa & Leidner, 1999; Timmerman & Scott, 2006; Walther & Bunz, 2005).

Specific aspects of communication quality have also been found to be positively related to virtual team trust, including explicit, regular, and efficient communication. Explicit virtual communication was positively related to virtual team trust (Jarvenpaa & Leidner, 1999; Walther & Bunz, 2005). Since dispersed teams do not stand on common ground (Cramton, 2001), being explicit allows them to cohere on decisions and action plans more effectively than when suggestions go unconfirmed or unchallenged. Regular communication, which means communication with certain patterns (e.g., weekly meetings), was positively related to trust-

building and maintenance (Henttonen & Blomqvist, 2005; Jarvenpaa & Leidner, 1999). Regular communication is predictable, and according to attribution theory (Jones & Nisbett, 1972), it can help team members appropriately attribute others' intentions, thus prevent trust decline at the end of team projects. Efficient communication was positively related to virtual team cognitive trust (Baker, 2018) such that a team of highly efficient communicators (i.e., members who convey the same amount of information in less time and using fewer words) consider each other to be more competent and reliable, leading to higher cognitive trust.

In terms of contextual effects, Rico et al. (2009) found that the relationship between communication quality (i.e., complete communication) and trust was stronger when task interdependence was higher and when team members had worked together for longer (i.e., at the later team development stage), indicating the importance of teams having sufficient interactions for communication quality to have this positive effect.

Team Emergent States: TMS. Research indicates that high-quality communication helps virtual team members know each other well and understand each other's expertise, thereby facilitating TMS development (Kanawattanachai & Yoo, 2007; Zhang, Chen, de Pablos, Lytras, & Sun, 2016).

Team Performance. A large body of research has demonstrated that a higher level of communication quality relates to better virtual team performance. Several qualitative studies of virtual team leaders and members suggested that high communication quality can maintain virtual team function and enhance team performance (Agbi, 2018; Chang, Chuang, & Chao, 2011; Ekpo, 2015; Gaines, 2018; Jordan & Adams, 2016; Morgan et al., 2014; Qureshi et al., 2006), while low communication quality was the main obstacle to working in virtual teams (Horwitz, Bravington, & Silvis, 2006). Similarly, Cramton's (2001) case analysis study found

that low communication quality (e.g., failing to communicate contextual information, unevenly distributing information, and differences in speed of access to information) caused mutual knowledge problems, deficient decision-making quality, and poor performance in virtual teams.

Quantitative studies have also found positive relationships between communication quality and virtual team performance, including global team performance (Eisenberg et al., 2019; González-Romá & Hernández, 2014; Gorman & Cooke, 2011), task completion (Stewart & Gosain, 2006), team's technical achievement (Chen, Li, Clark, & Dietrich, 2013), project success (Magby, 2017), teamwork quality (Walther & Bunz, 2005), decision-making performance (Colquitt et al., 2002), and team viability, which refers to the degree to which the team is likely to continue to function together as a team in the future (Pitts et al., 2012).

Certain specific aspects of communication quality have also been shown to positively influence virtual team performance, including turn-taking, language and communication competency, fluency, and communication efficiency. Turn-taking, which refers to the extent to which members take turns when communicating, positively affected information convergence that can improve product quality (i.e., accuracy) (Espinosa et al., 2015). Language and communication competency can contribute to the effectiveness of cross-culture virtual teams (Liu, 2006). Being fluent in a common language and technical vocabulary related to projects was essential for virtual design teams' success (Jordan & Adams, 2016). Communication efficiency, which refers to the extent to which a team can convey the same amount of information in less time and using fewer words, was positively related to the number of completed modules (Baker, 2018). According to interviews with virtual team leaders, regular communication, such as weekly meetings, was good for virtual team performance (Agbi, 2018; Ekpo, 2015; Gaines, 2018). Regular virtual meetings also increased teams' interaction frequency,

provided team members with rapid feedbacks, and helped teams find answers and solutions to difficulties encountered rapidly (Fernandez & Jawadi, 2015).

In contrast to the above findings, one study found that communication quality was instead negatively related to team performance (Chang et al., 2014). One possible explanation for the negative relationship here is that most virtual team members of this field study had more than one year of virtual team experience. These team members might have been working with their teammates for a while such that they had developed TMS; in teams with high TMS, performance is less dependent on team communication (Macmillan et al., 2004; Yoo & Kanawattanachai, 2001).

Other studies did not find significant relationships between communication quality and virtual team performance (Piccoli et al., 2004; Watanuki & De Oliveira Moraes, 2016). In a study by Piccoli et al. (2004), the non-significant result may be because the team communication quality was measured at the end of a five-week project. As discussed above, communication quality at the end stage of a team may not relate to virtual team performance since the team may have already developed TMS, in which case virtual teams can perform well regardless of their communication quality. Watanuki and De Oliveira Moraes (2016) explained that their non-significant result might be because the communication quality was not measured by the most appropriate scale. In their study, communication quality was measured in terms of communication precision, which refers to the degree to which information is properly communicated and comprehended within the team (Watanuki & De Oliveira Moraes, 2016). However, communicating precisely in virtual teams cannot guarantee team members develop a shared understanding because the shared understanding is facilitated by transmitting information with rich details, such as different experiences, knowledge, or perceptions (Martins, Gilson, &

Maynard, 2004). Thus, if the communication quality was measured as the richness of details in the communication process instead, they expected to find a significant relationship between communication and team performance (Watanuki & De Oliveira Moraes, 2016).

It is also important to point out that virtuality, as a contextual variable, moderates the effect of communication quality on virtual team performance. A team's virtuality refers to the degree to which the team's members are geographically dispersed, communicate mainly through electronic communication tools, and are from different cultures (Dulebohn & Hoch, 2017; Hoch & Kozlowski, 2014). Hoch and Kozlowski (2014) found that virtual teams' communication quality was positively related to team performance at high but not low virtuality. They argued that high communication quality in highly virtual teams may mitigate the difficulty of virtual team coordination by facilitating connectivity, removing perceptions of distance, and facilitating the organization and accessibility of information, thus contributing to team performance. In comparison, members of less virtual teams may be geographically closer, have more opportunities for face-to-face interactions, and be from similar cultures. They are more connected and have more access to organizational information; thus, teams with low virtuality can coordinate and perform well even when teams' virtual communication quality is not that high.

Team Evolution. While the research in this domain is scarce, an interview study found that virtual team members thought that low-quality communication inhibited virtual team learning (Stull, 2008). This is because team learning requires team members to share new knowledge, routines, or behaviours (Kozlowski & Blawath, 2012; Wilson et al., 2007). High-quality team communication can facilitate this information-sharing process; thus, it is positively related to virtual team learning.

Summary of Results for Communication Quality

This section reviewed studies linking virtual team communication quality and virtual team outcomes. These relationships are mainly explained by the shared cognition perspective and attribution theory. My analysis demonstrates that communication quality generally positively affects virtual team outcomes, such as team satisfaction and learning. However, a few studies found negative or non-significant relationships between communication quality and virtual team performance, indicating that this relationship depends on contextual variables, including task interdependence, team development stage, and virtuality.

Communication Content and Team Outcomes

Virtual teams' communication content can relate to task completion or relationship building within team (Keyton, 1997; Marlow, Lacerenza, & Salas, 2017). Researchers code these types of communication content into several categories according to published coding schemes (e.g., Bartelt & Dennis, 2014; Li et al., 2017), or self-developed coding schemes (e.g., Cheng, 2008; Hsu & Chou, 2009; Kahai, Huang, & Jestice, 2012). Recently, researchers have begun to use a machine learning approach to classify virtual communication content (Tonidandel, King, & Cortina, 2018).

In the following part, I first discuss theories adopted by these studies in depicting the "communication content - team outcomes" relationships. Then, I review the empirical studies about the effects of relational- and task-oriented communication on virtual team outcomes, respectively. The contingency factors that affect these relationships will also be discussed. See the summary of results in this section in Tables 3 and 4.

Theories Depicting the Relationships Between Virtual Communication Content and Virtual Team Outcomes

Time, Interaction, And Performance (TIP) Theory. The TIP theory argues that teams often strive to address three interdependent functions simultaneously and continuously: (1) production (i.e., problem-solving and task performance), (2) group well-being (i.e., development and maintenance of good social relationships among team members), and (3) member-support (inclusion of team members; and team member's participation, loyalty, commitment) (McGrath, 1991). Teams can engage in two types of team activities to achieve these functions: task-related activity and non-task social-relationship activity (McGrath, 1991). According to TIP theory, task- and relational-oriented communications represent these activities that can help virtual teams perform, build good social relationships among team members, and trigger positive team attitudes. TIP theory also argues that a team needs to engage in different activities to achieve the three functions depending on its context (McGrath, 1991). For example, at the early development stage of teams, team members may have to get familiar with each other, make plans and solve technical issues, whereas, at the later stages, team members have to coordinate, complete tasks, and evaluate performance. Thus, different activities are needed at different team development stages for teams to achieve their functions. We could expect that task- and relational-oriented communication may play different roles at different team development stages based on this idea.

Shared Cognition Perspective. As discussed above, the shared cognition perspective (Cannon-Bowers et al., 1993; Marlow, Lacerenza, & Salas, 2017) predicts that team- and task-related information sharing among team members helps teams make the most of their diverse knowledge, skills, and experience (Gajendran, 2009) and help team members develop shared beliefs and understandings regarding team roles and responsibilities (Kanawattanachai & Yoo,

2007; Macmillan et al., 2004). This perspective has mainly been used to explain the effect of task-oriented communication on team outcomes in virtual teams. Based on the shared cognition perspective, virtual teams that engage in task-oriented communication content can fully share information, make the most of team members' expertise, develop a shared mental model of the team tasks, coordinate smoothly, and perform well.

Table 3

Relational-Oriented Communication and Virtual Team Outcomes

Relational-oriented communication	+/-	Outcome	Theory	Moderator
general relational communication	+	satisfaction, task attraction, cohesion	TIP theory	emotion incongruence
		trust		team development stage
disclosure	not sig			
inflammatory	-			
general relational communication	+	performance		
disclosure	not sig			

Empirical Findings

Relational-Oriented Communication and Virtual Team Outcomes.

Team Attitudes. Studies found that relational-oriented communication was positively associated with group satisfaction (Li et al., 2017) and task attraction (Walther & Bunz, 2005), which means team members think it is easy and worthwhile to work with each other (McCroskey & McCain, 1974). An interview study also revealed that virtual team members thought that frequent communication that paid attention to more than just the team's tasks was the best practice for building and maintaining team cohesion (Scholz, 2003).

The effects of relational-oriented communication content on team attitudes may depend on the speakers' behaviours. Virtual team members' behaviours are perceived as emotionally charged: resolute behaviour is perceived as a display of anger and flexible behaviours as a display of happiness; similarly, communication content could also express happiness or anger (Cheshin, Rafaeli, & Bos, 2011). Cheshin, Rafaeli, and Bos's (2011) experiment indicated that incongruence between a team member's behaviour and text-based communication content led to other team members' negative team affect; congruence, in contrast, led to positive team affect.

Team Emergent States: Trust. Walther and Bunz (2005) found that relational-oriented communication was positively related to trust in virtual student teams. Similarly, interviews with virtual team members showed that side conversations about topics not related to tasks helped these team members form stronger initial trust (Zaugg & Davies, 2013); caring talk, personal conversation, storytelling, and humour were also sources of trust (Henttonen & Blomqvist, 2005).

However, not all types of relational-oriented communication content have the same effects on virtual team trust. Wilson, Straus, and McEvily (2006) developed finer-grained coding categories for relational-oriented communication, including disclosure and inflammatory comments. The disclosure category includes self-disclosure (e.g., "Sorry, don't ask me I'm not creative like that.") and personal questions (e.g., "Anyone here a Monty Python fan?"). The inflammatory category includes teasing (e.g., "300 bucks [reference to team incentive] will buy a lot of women"), antagonistic comments (e.g., "cut the music, have you made up your mind yet so we could move along here?"), and use of offensive words (e.g., "OK, the feminist in me might have to come out and kick your ass right now."). Based on these categories, studies did not find significant relationships between disclosure and team trust (Altschuller & Benbunan-Fich, 2010;

Wilson et al., 2006). However, Wilson et al. (2006) found that inflammatory comments were negatively correlated with team trust. Moreover, when excluding inflammatory content from the relational-oriented communication, the remaining relational communication content was not significantly related to team trust. These results suggest that inflammatory remarks in particular impede the development of trust in teams.

Team development stage could moderate the impact of relational-oriented communication on virtual team trust. Jarvenpaa and Leidner (1999) found that social communication (e.g., discussed hobbies, weekend activities, and families at length) can facilitate trust early in a group's life, but not later in the group's life; team members must make a successful transition from a social to a procedural to a task-oriented communication. However, another study did not find a significant relationship between relational-oriented communication and team trust at any period (Rico et al., 2009).

Performance. Research has revealed how relational-oriented communication in general is positively associated with both subjective and objective performance (Walther & Bunz, 2005). However, in one study, self-disclosure of relational-oriented communication did not significantly affect virtual team performance (Altschuller & Benbunan-Fich, 2010).

Task-Oriented Communication and Virtual Team Outcomes.

Team Attitudes. One study found that task-oriented communication was positively associated with teams' task attraction and social attraction (Walther & Bunz, 2005). Another study found that frequent task-oriented communication was also related to higher group satisfaction in global virtual collaborations (Li et al., 2017).

Table 4

Task-Oriented Communication and Virtual Team Outcomes

Task-oriented communication	+/-	Outcome	Theory	Moderator
general task-oriented communication	+	task and social attraction, satisfaction	TIP theory, shared cognition perspective	
		trust, TMS, performance		development stage
	Not sig	performance		
solicitation	+	process conflict		
criticism		task conflict, process conflict, relationship conflict, team performance		
delegation		task conflict, process conflict, relationship conflict, task completion		
convergence	+	decision quality, product quality		
conveyance		production speed		

Team Behavioral Processes: Team Conflict. One empirical study has found that task-oriented communication relates to virtual team conflicts (Hsu & Chou, 2009). Hsu and Chou (2009) identified three task-oriented communication genres related to virtual team conflict: solicitation, criticism, and delegation. Solicitation, which refers to statements that inquire how others' subtasks are going or ask for renewing the subtask deadline when the subtasks could not be finished on time, was positively associated with process conflict. Criticism, which refers to statements that blame team members for being late, was positively associated with task conflict, process conflict, and relationship conflict. And delegation, which refers to statements that coordinate teamwork and command team members, was also positively associated with task conflict, process conflict, and relationship conflict. Although delegation helps the team complete

tasks, it increases the possibilities of team conflicts. This may be because team members have to "sacrifice" their ideas to conform to the "group decision" about subtasks allocation when they are unsure about others' thinking in virtual teams, as a consequence, leads to team conflicts (Hsu & Chou, 2009).

Team Emergent States: Trust. Walther and Bunz (2005) found that task-oriented communication was positively associated with team trust. Importantly, studies have provided some evidence regarding a moderating effect of team development stage on the "task-oriented communication - team trust" relationship. Jarvenpaa and Leidner (1999) found that task-oriented communication can facilitate trust early in a group's life. Kanawattanachai and Yoo (2007) also found that the frequency of task-oriented communication among team members was positively related to cognitive-based trust in the early, but not the middle, or the final team development stages. However, Rico et al. (2009) showed that task-oriented communication positively impacted virtual team trust at both the middle and end of the team project. Different samples (i.e., student teams, Jarvenpaa & Leidner, 1999, Kanawattanachai & Yoo, 2007; employee teams, Rico et al., 2009) may cause the difference in results among these studies. It seems that task-oriented communication plays a more critical role in fostering trust in employee teams than student teams at the later team development stages.

Team Emergent States: TMS. Expertise location, an aspect of TMS, refers to team members' meta-knowledge of each other's expertise areas (Faraj & Sproull, 2000). Kanawattanachai and Yoo (2007) found that the frequency of task-oriented communication was positively related to expertise location in the early, but not the middle, or the final team development stages.

Team Performance. Empirical research has illustrated the positive effects of task-oriented communication on virtual team performance (Bradley, Baur, Banford, & Postlethwaite, 2013; Curtis, Dennis, & McNamara, 2017; Walther & Bunz, 2005). For example, Fjermestad and Ocker's (2007) interview study revealed that high-performing teams discussed more design alternatives; they also spent considerably more effort summarizing their work than low-performing teams. Similarly, Bartelt and Dennis (2014) found that when task-focused discussion decreased, team decision quality also decreased.

Specific types of task-oriented communication are also related to virtual team performance. Massey, Montoya-Weiss, and Hung (2003) coded task-oriented communication as either conveyance or convergence statements. Conveyance statements are communication content that shares information, perspectives, and opinions; convergence statements are communication content that involves criticisms, disagreements, and qualifications of members' ideas and positions. Through cluster analysis, they found that high-performing (i.e., high decision quality) virtual teams spent a significantly greater proportion of time on convergence-oriented communication and the least amount of time on conveyance communication than teams that perform less well (Massey et al., 2003). Similarly, Espinosa et al.'s (2015) study of dyadic virtual teams found that convergence communication was positively associated with higher product quality (i.e., accuracy), but also that conveyance communication was positively associated with production speed.

Some types of task-oriented communication seem to be double-sided swords. Hsu and Chou (2009) found that, although criticism and delegation led to team conflict, delegation also helped the team complete tasks because delegation can coordinate teamwork. Similarly, Yilmaz's (2016) experiment revealed that having a team member who often criticizes other

group members' views was positively related to team performance compared with having a team member who often acts agreeably. Yilmaz (2016) explained that criticizing members trigger a critical communication norm; thus, all team members are more likely to evaluate their decisions' validity according to the task requirements. In contrast, without such a dissenting member, team members tend to decide without critically analyzing their choices' pros and cons.

In contrast to the above, one study found a non-significant relationship between task-oriented communication and team performance (Li et al., 2017). One possible explanation is that this study's virtual teams were composed of members with different cultural backgrounds (China and Germany); thus, the effect of task-oriented communication may differ for diverse versus homogenous teams.

Several longitudinal studies demonstrate that team development stages can moderate the effects of task-oriented communication content on virtual team outcomes. Task-oriented communication content seems to play a more critical role at the early stages of virtual teams. Kanawattanachai and Yoo (2007) found that the frequency of task-oriented communication was positively related to team performance in the early and middle, but not the final team development stages because TMS was established in the late stages, such that task-oriented communication became less important. Bianchi, Knopper, Eris, Badke-Schaub, and Roussos (2015) also found that successful design teams had more task-oriented communication in the early phase but less in the late phase than unsuccessful teams. In comparison, unsuccessful teams attempted to "catch up" in the later phases but fell short.

However, Chiocchio's (2007) time-series analysis found that, compared to low-performing teams, high-performing teams engaged in more task-oriented communication when it was the due date to submit a part of a team project (i.e., a milestone). High-performing teams

also started task-oriented communication about team coordination after the first milestone and maintained higher levels of this communication afterward. In contrast, low-performing teams engaged in task-oriented communication about coordination only before the first milestone; then, they did not discuss team coordination much later (Chiocchio, 2007). These results suggest that task-oriented communication could be critical for team performance at all team development stages if these teams' performance is assessed in each stage.

Summary of Results for Communication Content

This section reviewed studies linking virtual team communication content and virtual team outcomes. These relationships are mainly explained by two theories: time, interaction, and performance (TIP) theory, as well as the shared cognition perspective. My analysis demonstrates that relational- and task-oriented communication contents are positively related to virtual team satisfaction, attraction, coordination, trust, and performance. Relational-oriented communication is also positively related to virtual team cohesion. Although some forms of task-oriented communication, such as delegation and criticism, can cause more team conflicts, they also improve team performance. Finally, team development stages can moderate the impacts of both relational- and task-oriented communication contents on virtual team outcomes, such that they tend to play more critical roles in the early team development stages.

Communication Style and Virtual Team Outcomes

Virtual team communication styles are typically assessed using different communication style scales (e.g., Kahai et al., 2012, positive style; Lippert & Dulewicz, 2018, high- or low-context style). However, it can also be assessed by people unrelated to the teams, who evaluate the virtual team communication style after reading the virtual teams' communication records

(Burke & Kraut, 2008). Besides, researchers can use a machine learning approach to measure virtual team communication styles (Ortu et al., 2015, polite communication style; Tonidandel, King, & Cortina, 2018).

Studies have examined the effects of several types of team communication styles on virtual team outcomes, including the polite, high and low context, positive, constructive, aggressive, passive, and deceptive communication styles. In the following part, I review each of these communication styles' theories and empirical findings (see the summary in table 5).

Theories Depicting the Relationships Between Virtual Communication Style and Virtual Team Outcomes

Politeness Theory. Politeness refers to communication that considers others' feelings, such as complimenting, expressing understanding, agreement, or appreciation, using hesitation in disagreement, and apologizing (Brown & Levinson, 1987). Politeness theory (Brown & Levinson, 1987) argues that when a speaker communicates politely, a recipient likely infers that this speaker has positive intentions. This perception can foster positive reactions. In contrast, when a speaker communicates impolitely, the recipient may think the speaker has hostile intentions and intends to harm (Brown & Levinson, 1987). Thus, polite communication is likely to trigger positive interaction among team members, bringing about other positive team outcomes.

Table 5

Communication Styles and Virtual Team Outcomes

Communication Style	+ /-	Outcome	Theory	Moderator
politeness	+	team attractiveness, task speed	politeness theory	type of team
high- and low-context communication	+	performance	cross-cultural communication	
positive communication	+	discussion satisfaction, social presence, cohesion, efficacy, decision quality	broaden-and-build theory of positive emotions	
	+	trust		task interdependence, team development stage
	-	task time		
constructive communication	+	trust	team interaction style	communication tools, task complexity
	-	relationship conflict		
	+	performance		
passive communication	-			
aggressive communication	-			
deception	-	trust, mutuality, performance	interpersonal deception theory	

A Model of Cross-Cultural Communication Style. Hall (1976) developed a model of cross-cultural communication style that differentiates between high-context communication and low-context communication. High-context communication means that team members use indirect language, non-confrontational, or vague language to avoid confrontations. Others have to "read between the lines" to fully understand a message and imply a message without uttering it. In contrast, teams that engage in low-context communication will communicate directly and

precisely, talk based on true intentions, clarify ambiguous information, and use fact-oriented rational arguments to convince others.

Cross-cultural communication style is vital for global teams. Team members with different nationalities or relational status may have different expectations about appropriate communication behaviours; thus, the point is for team members to be sensitive to team members' cultural background or status, and use language appropriate to their relational status and cultural backgrounds (Abu Bakar & McCann, 2015). Then, virtual team communication can facilitate team functions without someone being offended unknowingly (Lippert & Dulewicz, 2018).

Broaden-And-Build Theory of Positive Emotions. The broaden-and-build theory of positive emotions (Fredrickson, 1998, 2004) argues that positive emotions, including joy, interest, contentment, and love, broaden people's scopes of attention and cognition (i.e., their thoughts become more flexible and open), which in turn facilitates more novel and creative actions. Positive team communication styles could trigger team members' positive emotions, which according to broaden-and-build theory of positive emotions (Fredrickson, 1998, 2004), will make the team members are more likely to trust their teams and ultimately perform better. In addition, by triggering positive emotions, positive communication styles also prompt people to sit back, savor the current circumstances, and appreciate others' contributions (Fredrickson, 1998). Thus, team members are more likely to be more satisfied with their teams.

Team Interaction Style Framework. Cooke and Szumal (1994) proposed that three separate yet interrelated group interaction styles exist, including constructive, aggressive, and passive. According to the team interaction style literature (Cooke & Szumal, 1994; Potter & Balthazard, 2002), this framework can capture the dimensions of team communicative behaviours and predict their impacts on team outcome. Specifically, the constructive

communicative style consists of free exchanging of information, offering cooperative, integrative, and mutual support among group members. Thus, it enables teams to achieve high-quality performance and maintain good team relationships. The passive communicative style emphasizes team harmony and refers to a conformist and dependent style. It limits information sharing, questioning, and impartial analysis, producing lower-quality solutions than those produced by constructive teams. In comparison, the aggressive style emphasizes personal achievements more than group outcomes. It refers to a competitive, imperative, persuasive, and directive mode between group members, consequently producing solutions with inconsistent quality and are less likely to by accepted by team members .

Interpersonal Deception Theory. Deception refers to "a message knowingly transmitted by a sender to foster a false belief or conclusion by the receiver" (Buller & Burgoon, 1996, p. 381). According to interpersonal deception theory, deception can dampen team trust and performance since deceptive communication shares false information within teams (Burgoon, Stoner, Bonito, & Dunbar, 2003).

Empirical Findings

Polite Communication Style. Polite communication is often seen in virtual teams (e.g., Burke & Kraut, 2008; Ortu et al., 2015; Wei, Crowston, Eseryel, & Heckman, 2017). Ortu et al. (2015) found that the level of politeness in the communication among software developers did affect the time required to fix issues and team attractiveness. Their study indicated that the more polite developers were, the less time they took to fix an issue, the more the developers wanted to be part of the project, and the more they were willing to continue working on the project over time. However, the overuse of polite language in communication might be perceived as insecure or powerless, hindering virtual team outcomes.

The effects of polite communication on virtual team outcomes have also shown to be dependent on the types of virtual teams. Burke and Kraut (2008) found that polite communication tripled reply counts in technical groups, while rudeness was more effective in eliciting replies in political groups. This is because rude messages often stimulate repliers to argue with others with different points of view in political groups, whereas in technical groups, communication attempts to seek assistance for technical problems rather than incite arguments (Burke & Kraut, 2008). Thus, polite language, such as saying thanks in advance, could attract more replies from other members in technical groups but not in political groups.

High- And Low-Context Communication Styles. Lippert and Dulewicz (2018) found that both high- and low-context communications are beneficial to global virtual team performance. High-performing cross-cultural teams engaged more in both low- and high-context communication; in contrast, low-performing teams rarely engaged in these cultural communication styles. This result suggests that global virtual team members should be sensitive to each other's cultural background or status and communicate with appropriate styles.

Positive Communication Styles. Positive communication styles can trigger team members' positive emotions, though they have been named and operationalized differently in different studies. For example, in Kahai, Huang, and Jestice (2012), the positive communication style was named as positive feedback, and was operationalized as team communication with many supportive remarks (e.g., "I agree," "good idea,") and few critical remarks (e.g., "I do not like that," "That is not a good idea"). In contrast, Rico et al. (2009) named the positive communication style as communication enthusiasm, which refers to a team communication style that expresses optimism and transmits positive tones about teamwork.

Supporting the broaden-and-build theory of positive emotions (Fredrickson, 1998, 2004), Kahai et al. (2012) found that positive feedback related to discussion satisfaction, social presence, group cohesion, group efficacy, decision quality, and negatively related to task time. However, contextual variables, such as task interdependence and team development stage, moderate the effects of positive communication styles on virtual team trust. Rico et al. (2009) found that before the project mid-point, the effect of communication enthusiasm on trust depended on task interdependence: the effect of communication enthusiasm was positive when teams perform at low levels of task interdependence and negative when teams perform at high levels of task interdependence. They also found that the communication enthusiasm before the project mid-point was negatively related to team trust at the project end (Rico et al., 2009). Rico et al. (2009) explained that communication enthusiasm is negatively related to team trust when the task is interdependent or when it occurs at the project end because positivity in team communications under these contexts might be perceived as distracting, inappropriate, or even suspicious.

Constructive, Aggressive, and Passive Communication Styles. Supporting Cooke and Szumal's (1994) framework of group interaction styles, research shows different effects of constructive, aggressive, and passive communication styles on virtual team performance. Moreover, their effects also depend on the teams' communication tools and task complexity. González-Navarro, Orengo, Zornoza, Ripoll, and Peiró (2010) found that in a videoconference condition, constructive communication style positively related to team performance, while passive style negatively related to performance. In contrast, in a computer-mediated communication condition, constructive communication style negatively related to team performance, while passive style positively related to performance. In both conditions, the

relationships between aggressive communication style and team performance were not significant.

However, this finding is contrary to Potter and Balthazard's (2002) results. They found that computer-mediated communication teams' constructive interaction positively related to subjective team performance, whereas aggressive and passive interaction styles negatively related to team performance (Potter & Balthazard, 2002). The different results of the two studies may be due to different task complexity levels. Team tasks of González-Navarro et al. (2010) were complex: team members had to create a human resources company in one month. At the end of the month, constructive communication may bring new ideas that are hard to be merged into plans that have been formed or may even mess up the formed plans. Whereas passive interactions may indicate that team members have achieved agreement on the plans, thus is positively related to team performance. In comparison, the virtual team tasks of Potter and Balthazard (2002) were to rank the importance of items in a desert survival simulation in seven consecutive days. It is easy to revise the ranking after constructive communication. Thus, constructive communication can improve team performance by helping teams find a more reasonable ranking.

In addition to having performance effects, one type of constructive communication, taking initiative (i.e., proactive information-sharing, personalized communication, openness, and the willingness to learn), was positively related to trust-building at the orientation stage of virtual teams (Henttonen & Blomqvist, 2005). In addition, constructive communication style also related to fewer team relationship conflicts (Cheng, 2008).

Deceptive Communication. Fuller, Marett, and Twitchell (2012) found that the perception of deceptive communication was negatively associated with team trust and feelings of mutuality among virtual team members; Deception also hurt virtual teams' task performance.

Summary of Results for Communication Style

This section reviewed studies linking virtual team communication styles and virtual team outcomes. The impacts of these communication styles were explained by different theories, including the politeness theory, cross-cultural communication theory, broaden-and-build theory of positive emotions, the team interaction style framework, and interpersonal deception theory. The analysis of empirical results demonstrates that high context, low context, and positive communication styles are related to better team outcomes. In contrast, the deceptive communication style hurts the team's trust and performance. Lastly, some communication styles are context specific such that the polite communication style impacts team performance positively in technical discussion groups but negatively in political groups, and the effects of constructive, aggressive, and passive interaction styles on virtual team performance depend on communication tools and task complexity.

Communication Structure and Team Outcomes

When group members interact with each other, they may create a structure in which particular members communicate with certain other members through specific routes (Keyton, 1999). Hsu and Chou (2009) argued that these communication structures influence individuals' feelings, thoughts, and behaviours as well as their teams' outcomes. Drawing on social network analysis (SNA), several studies have examined how virtual teams' communication structure impact virtual team outcomes. These studies capture communication structure in virtual teams

using one of the following five communication structure indices: communication density, group centralization, nodes, cliques participation index (CPI), and standard deviation of structural holes (SH_SD).

First, communication density describes the overall level of team interaction. It is measured by the ratio of the number of communication lines (i.e., connection between communicators) present and the number of maximum lines possible. It is analogous to the mean number of ties per team member. The value of communication density varies between 0 (no communication in the team) and 100% (everyone communicates with everyone, at least once in a period) (Wasserman & Faust, 1994). The higher the density, the more communication occurs within the team. According to the definition and measurement, communication density is similar to communication frequency. However, it also considers a single communicator's communication activities within a team, not just the whole team's communication. Second, group centralization reflects the extent to which interactions are concentrated in one or a small number of team members rather than distributed equally among all members (Mazzoni & Gaffuri, 2009). Third, a node represents a discussion participant in a tree graph, a network type that captures the post-reply relationships in a discussion; in a tree graph, nodes (i.e., participants) are connected by edges, representing relationships between two participants (Wang et al., 2015). If a discussion has more nodes, it will have more diverse participants and be more likely to have diverse knowledge sources (Wang et al., 2015). Fourth, the CPI measures group members' mean involvement within their cliques (Choi & Lee, 2016). Within a communication network, such as a virtual team, an individual may interact with some individuals more than others. If team members participate in more discussion cliques, they are more likely to access different opinions. The higher the CPI value, the more opportunities members have to participate in different group

discussions (Gaggioli, Riva, Milani, & Mazzoni, 2013; Mazzoni, 2014). Finally, a structural hole is an empty space between nonadjacent individuals in a network (Burt, 1992). In structural holes, novel information that differs from that shared in network closure (i.e., cluster of strongly interconnected individuals) is shared (Burt, 2017). The SH_SD means heterogeneity of structural hole of individuals in the team; the higher the SH_SD value, the more non-redundant and diverse knowledge and information teams can have (Choi & Lee, 2016).

My analysis shows that most studies about communication structure are data-driven or "atheoretical," as the relationships between communication structures and virtual team outcomes are not sustained by theory. Authors generally referred to findings of previous empirical studies to support their research hypotheses or questions. Thus, I mainly focus on empirical findings of the communication structures' impacts on virtual team outcomes in the following part.

Empirical Findings

Team Behavioral Processes: Team Coordination. Gaggioli, Mazzoni, Milani, and Riva (2015) found that communication decentralization and density positively related to a group flow experience, which refers to a collective experience of team members having global positive affect, high concentration and involvement, feeling of control, clear goals, and intrinsic motivation. According to Armstrong (2008), decentralization ensures the actions of a group and the decisions that it takes are shared and distributed rather than managed by a single member; high communication density reflects that team members have sufficient interactions to participate and exchange ideas fully. Thus, decentralization and density foster greater participation and allow the group to exploit its internal diversity fully.

Team Behavioral Processes: Team Conflict. Hsu and Chou (2009) found that communication density negatively related to relationship conflict. This result is consistent with communication frequency studies that indicate that frequent team communication can lead to fewer team conflicts by identifying team conflicts early and preventing conflicts from escalating (Hinds & Mortensen, 2005).

Team Performance. Wang et al. (2015) found that networks of threaded discussions with at least four nodes (i.e., discussion participants) were more likely to have helpful discussions and solve problems. This result suggests that having diverse participants in team discussion can contribute to team performance (Wang et al., 2015).

Team Innovation, Learning, And Adaptation. Research demonstrates that communication density, centralization, CPI, and structural holes are related to virtual team innovation.

Density. Choi and Lee (2016) found that the greater the network density, the greater the teams' innovative performance. However, Leenders et al. (2003) found that team creativity requires a moderate density of communication. This is consistent with the findings of the relationship between communication frequency and team creativity. Although frequent communication can enable team idea sharing, too much information sharing and processing within a team can overload members' processing capability, thus harming their creativity.

Centralization. Leenders et al. (2003) found that a low level of communication centralization can contribute to team creativity. They argued that a high level of communication centralization may reduce the autonomy, motivation, and commitment of non-central members;

thus, a low centralized communication structure is more likely to induce team innovation (Leenders et al., 2003).

CPI and SH_SD. In an experimental study, Choi and Lee (2016) found that CPI increased over time and influenced innovation performance positively. They also found that SH_SD increased over time and was positively related to team innovation performance (Choi & Lee, 2016). They explained that the higher the CPI value, the more opportunities members have to participate in different team discussions and share their ideas, thus facilitating team creativity; likewise, the higher the SH_SD value, the more novel information and knowledge teams can apply to achieve innovation performance (Choi & Lee, 2016).

Summary of Results for Communication Structure

This section reviewed studies linking virtual team communication structures and virtual team outcomes. Most studies in this domain are data-driven and not sustained by theory. My analysis of these investigations shows that a high level of communication density relates to fewer relationship conflicts and more group flow experience, while communication centralization is negatively related to a group flow experience. Team diversity (measured by nodes) improves the likelihood of having helpful discussions. Decentralized team communication, with a moderate density level, high CPI, and high SH_SD, can foster virtual team innovation.

Discussion

The goal of this systematic literature review was to answer the question: *how can virtual teams communicate effectively to achieve positive team outcomes?* To answer this question, I defined team communication as a profile multidimensional construct (Keyton, 1999; Law et al., 1998; Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017; Norton,

1983), and based on the characteristics of a profile multidimensional construct, I delineated the impacts of each dimension of team communication on various virtual team outcomes. I also connected different dimensions of communication to show how they interact in their impact on various team outcomes, and I explored the role of moderating variables. According to my analysis of the reviewed literature, the profiles of virtual team communication that bring about positive virtual team outcomes have the following characteristics: 1) communication frequency is not too high or too low, 2) communication quality is high, 3) communication includes both relational- and task-oriented contents, 4) the choice of communication styles considers teams' tasks, cultures, status, and communication tools, and 5) communication structure is low-centralized such that all team members fully participate in team communication. Further, two theoretical mechanisms - relational and informational - and two main contingency factors – communication tool and team development stage – help to explain this "virtual communication and team performance" relationship. An illustrative summary of these results is provided in Figure 2. In the following section, I summarize and elaborate on the results, discuss the theoretical bases for the "virtual team communication - team outcomes" relationship, and explain the moderators' role in this relationship. Then, practical implications, limitations, and future research directions are discussed in the end.

Summary of Results

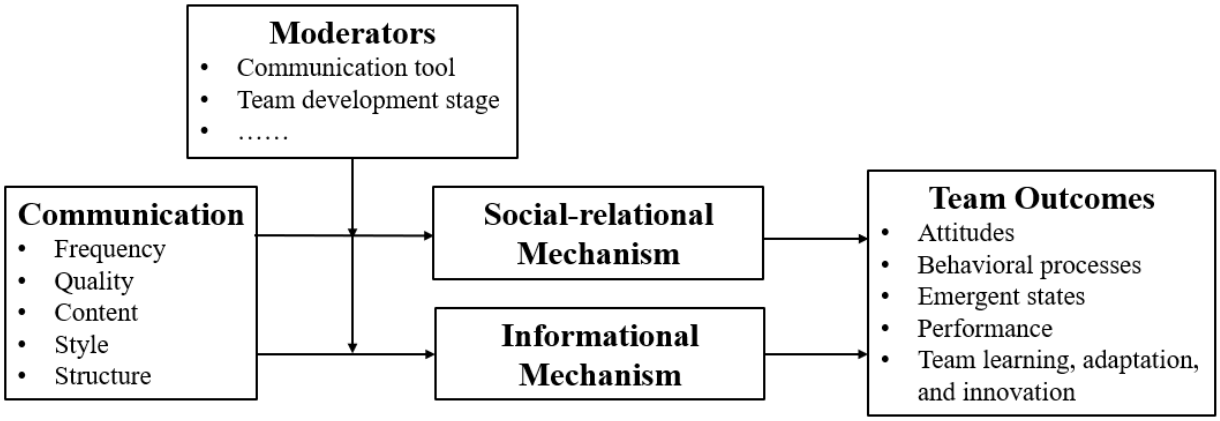
Communication Frequency

My analysis shows that communication frequency has different effects on different virtual team outcomes. Although frequent team communication positively impacts some team outcomes (i.e., attraction, coordination, trust, TMS development, learning, and adaptation), the relationship between communication frequency and other outcomes (i.e., cohesion, conflicts,

performance, and innovation) can be positive, negative, or inversely related. While frequent communication facilitates teams' social and task information sharing, too much information is hard to process, thus impairing team members' ability to work with each other. Therefore, a medium level of communication frequency is optimal, such that virtual teams will have fewer team conflicts, better team cohesion, performance, and innovation. These findings are consistent with previous literature reviews about virtual team communication (Gilson, Maynard, Jones Young, Vartiainen, & Hakonen, 2015; Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017; Powell, Piccoli, & Ives, 2004).

Figure 2

"Virtual Team Communication - Team Outcomes" Framework.



Communication Quality

My analysis demonstrates that communication quality is generally found to have positive effects on team outcomes. This finding is consistent with prior arguments and meta-analytical results by Marlow, Lacerenza, and Salas (2017) and Marlow, Lacerenza, Paoletti, et al. (2017), indicating that team communication quality has a stronger positive relationship with team performance than communication frequency in virtual teams. However, the present review found

some exceptions, such that certain aspects of communication quality (i.e., communication precision) may not relate to virtual team performance. In addition, my review further indicates that virtual team communication quality impacts not only team performance but also other virtual team outcomes, such as team satisfaction, trust, and innovation, which suggests the critical role of communication quality on virtual teams' overall function.

Relational- And Task-Oriented Communication Content

Based on my review, it is clear that both relational- and task-oriented communication contents positively relate to virtual team performance. This result is consistent with Marlow, Lacerenza, Paoletti, et al.'s (2017) meta-analysis. My analysis further shows that relational- and task-oriented communication contents also relate to virtual team satisfaction, attraction, coordination, and trust. Besides, relational-oriented communication is positively related to virtual team cohesion. Although two types of task-oriented communication, delegation and criticism, can cause more team conflicts, they improve team performance.

Communication Style

My analysis shows that communication styles such as high context, low context, and positive communication styles are related to better team outcomes. In contrast, deceptive communication hurts the team's trust and performance. Importantly, the effect of certain communication styles (i.e., politeness, constructive, aggressive, and passive interaction styles) on team performance depends on team tasks and communication tools.

Communication Structure

My analysis demonstrates that communication structures such as communication decentralization, diversity, CPI, and SH_SD are related to better virtual team outcomes. In contrast, communication density has different effects on different virtual team outcomes. Although high communication density can lead to group flow experience and fewer relationship conflicts, team creativity may require a moderate density of communication.

Different Aspects of Communication Interactively Impact Team Outcomes

As discussed above, team communication is a profile multidimensional construct. Five dimensions of team communication can be fully crossed to form many different profiles of team communication, which may impact team outcomes differently. My analysis shows that communication frequency and other aspects of team communication can interact to impact virtual team outcomes. Highly frequent communication that only includes distracting and irrelevant information will hinder team processes and be detrimental to team performance. In contrast, frequent communication containing relational- and task-related contents lets team members share more information, solve conflicts (Hinds & Mortensen, 2005), increase team production speed, and improve product quality (i.e., accuracy; Espinosa et al., 2015). As another example, frequent communication that clarifies information related to the task, and develops shared understandings regarding team members' roles and responsibilities, enables team members to cooperate smoothly (Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017).

Communication frequency also interacts with communication quality such that frequent high-quality team communication makes the virtual teams' adaptation process smooth (Qureshi

et al., 2006) and contributes to better team results (Tong, Yang, & Teo, 2013), while frequent low-quality communication does not. Frequent routines with high-quality, consistent communication reconfirm the team's objectives, especially when they are not performing against the target developed overall effectiveness (Morgan et al., 2014).

Theoretical Implications

To clarify the "virtual team communication - team outcomes" relationship and the role of moderators in this relationship, I identified two main theoretical mechanisms – relational and informational – that help to explain how and why virtual communication affects virtual team outcomes.

Relational Mechanism

Virtual team communication can impact virtual team outcomes by developing social relationships necessary for team coordination and trust-building. Based on my analysis of the current research, two main theories: social information processing theory and attribution theory – underpin this mechanism.

Social information processing theory posits that virtual teams require more time to develop interpersonal impressions and relations than face-to-face teams because virtual communication has a limited social-information carrying capacity and takes longer time to exchange information (Walther, 1992). Thus, virtual teams that communicate more frequently are more likely to exchange social information for relationships to develop fully. They can then achieve the same level of liking, trust, and sociable states as face-to-face teams (Walther & Burgoon, 1992), which are critical for their performance and other team outcomes.

According to attribution theory, virtual team members lack cues about others; they tend to build stereotypical impressions of others based on limited information, such as others' communication patterns (Lea & Spears, 1992). High-quality team communication that is timely, open, consistent, clear, and complete will therefore help team members form more positive perceptions about each other, which can foster team trust, liking, satisfaction, and other positive team outcomes.

Informational Mechanism

Virtual team communication can also impact virtual team outcomes by sharing information about tasks, contexts, and team members, thus fostering shared mental models and TMS. My analysis reveals two theoretical perspectives that underpin this informational mechanism: the shared cognition perspective and cognitive load theory.

Based on the shared cognition perspective (Cannon-Bowers et al., 1993; Marlow, Lacerenza, & Salas, 2017), team communication can help virtual team members establish mutual knowledge, build and maintain a shared mental model of the situation, solve coordination difficulties, prevent team conflicts, and develop team trust (Becerra-Fernandez & Sabherwal, 2001). However, many studies found negative or curvilinear relationships between virtual communication and team outcomes. In trying to explain these relationships, authors mainly draw on insights from the cognitive load theory (Sweller et al., 1998), which argues that individuals have a limited working memory capacity. When this is exceeded, team members' learning and processing abilities are impaired. Virtual team members need communication to develop a shared understanding. However, too much information sharing and processing within a team can overwhelm members' processing capability, leading to poor team performance.

Relational and Informational Mechanisms

Several other theories incorporate both the relational and the informational mechanisms in explaining the impact of virtual team communication, recognizing the importance of both for positive team outcomes. The time, interaction, and performance (TIP) theory argues that teams engage in two types of team activities, the task- and the social activities, to solve problems, complete tasks, develop and maintain good relationships among team members (McGrath, 1991). According to TIP theory, task- and relational-oriented communications can collectively trigger positive team attitudes, help virtual teams perform well, and build good team relationships.

Similarly, previous literature on group interaction styles argues that problem-solving team members face both informational and relational pressures (Cooke & Szumal, 1994; Maier, 1967; Potter & Balthazard, 2002). On the one hand, they must share unique and possibly controversial information to maximize the team's resources; thus, teams can achieve high-quality solutions. On the other hand, they have to maintain good relationships to make sure all team members accept solutions and solve problems. According to Cooke and Szumal (1994), constructive communication style can bring about positive team outcomes by activating both the informational and relational mechanisms; passive style contributes to positive team outcomes mainly through activating the relational mechanism; conversely, an aggressive style is most likely to facilitate information sharing but also harm team relationships.

Although my analysis shows that most studies about communication structure are data-driven or "atheoretical," the relationships between communication structures and virtual team outcomes can also be explained by these two mechanisms, such as the effects of communication density on virtual team outcomes. Empirical studies found that communication density was negatively related to team conflicts (Hsu & Chou, 2009), positively related to group flow

experience (Gaggioli et al., 2015), and team innovation performance (Choi & Lee, 2016). One explanation is that high communication density reflects that team members have sufficient interactions to participate and exchange ideas fully; it also reflects that team members have built rich social relationships within their teams. Therefore, according to the informational and relational mechanisms, high density will lead to positive virtual team outcomes. As another example, Choi and Lee (2016) found that CPI was positively related to virtual team innovation performance. This may be because high CPI reflects team members' participation in more discussion cliques such that they are more likely to access different information and develop social relationships with different team members. According to the informational and relational mechanisms, they will therefore perform well.

Different Communication Profiles' Impact on Team Outcomes via Relational and Informational Mechanisms

As discussed above, team communication is a profile multidimensional construct consisting of five dimensions that can be combined into different profiles of team communication. Since my framework shows that virtual team communication influences virtual team outcomes by activating relational or informational mechanisms, I expect that different profiles of virtual team communication may trigger different team interactions and influence virtual teams' relationship development and information sharing differently. For instance, certain profiles (e.g., medium frequency + high quality + task-related content + constructive style + low centralized structure) may more strongly activate the information mechanism to contribute to team performance and innovation than other profiles (e.g., high frequency + low quality + task-related content + aggressive style + centralized structure). Furthermore, and as per the results of this review, I expect that certain team communication profiles (e.g., medium frequency + high

quality + task-related content + polite style + low centralized structure) are most likely to bring about optimal virtual team outcomes as the features of these different team communication dimensions can complement each other, thus it is likely that they are activating both the relational and informational mechanisms. However, as I elaborate upon below, future research needs to examine the potential of these different profiles for team effectiveness as empirical investigations are currently lacking.

Contingency Factors That Affect the "Virtual Team Communication - Team Outcomes" Relationship

My analysis suggests there are several moderators that influence the "virtual team communication - team outcome" relationship: the most common being communication tools and team development stages.

Communication Tools. The effect of communication tools can be explained by various theories: social presence theory (Short, Williams, & Christie, 1976), media richness theory (Daft & Lengel, 1986), and compensatory adaption theory (CAT; Hantula et al., 2011). The social presence refers to the degree to which a medium permits communicators to experience others as being psychologically present or the degree to which a medium is perceived to convey the communicating participants' actual presence (Short et al., 1976). Communication tools that can convey nonverbal, social context, and feedback cues, are high in social presence, while tools such as email or phone call are low in social presence. According to social presence theory, different tasks require communication with different social presence levels (Short et al., 1976). Tasks that require interpersonal interactions (e.g., resolving disagreement) demand high social presence, while tasks that involve exchanging routine information demand low social presence (King & Xia, 1997). Thus, video conferences may be appropriate for tasks that require

interpersonal interactions, while email is appropriate for tasks that involve exchanging routine information.

The media richness theory similarly argues that communication tools (e.g., phone calls, video conferencing, and emails) have different richness levels (Daft & Lengel, 1986). While rich media carries the most information, lean media carries the least information (Newberry, 2001). For example, a phone call cannot transmit virtual cues such as gestures and facial expressions, making it a less rich communication medium than video conferencing. The media richness theory argues that leaner media, such as email and documents, are more appropriate for tasks that require objective and well-understood procedures. In contrast, rich media, such as video conferences, are more appropriate for tasks that involve processing equivocal information or dealing with uncertain situations (Dennis & Valacich, 1999). For example, frequent phone calls help virtual teams form team TMS, while frequent e-mail use has no effect (He et al., 2007).

Supporting these two theories, Mattison (2013) found that virtual team members thought that effective virtual communication depended on proper tool selection to enable information sharing, enhancing responsiveness, and increasing the willingness to communicate. Whether the characteristics of the available communication technologies are appropriate for the tasks can enable or constrain effective team communication and virtual team functioning (Cramton, 2001). When team members use verbal communication for tasks that are best suited to verbal communication and use email for tasks best suited to text communication, they are more likely to perform well (Colquitt et al., 2002).

The above two theories stress that communication tools' features can moderate the "virtual team communication - team outcomes" relationship, as I have illustrated in this review. However, the moderating effect of communication tools may lose its impact over time because

virtual team members can adapt to the features of different communication tools and become more skilled at virtual communication over time (Carlson & Zmud, 1999; Hantula et al., 2011). Supporting this, DeLuca, Gasson, and Kock (2006) found that virtual team members can adapt their communication behaviors to overcome the obstacles caused by low media richness and achieve team success.

Team Development Stage. My review also shows that virtual team communication impacts team outcomes differently at different team development stages. The team development stage's effect could be explained by time, interaction, and performance theory (TIP), which argues that a team needs to engage in different activities to function well in different contexts (McGrath, 1991). At the early development stage of teams, team members have to get familiar with each other, make plans, solve technical issues, whereas, at the later stages, team members have to complete tasks and evaluate performance. Thus, different activities are needed at different team development stages. Based on this idea, virtual team communication may play different roles at different virtual team development stages.

For instance, at early stages, relational-oriented communication can facilitate trust, while task-oriented communication can facilitate team TMS formation. However, to maintain trust at later stages, teams must transfer from relational to task-communication (Jarvenpaa & Leidner, 1999). Further, task-oriented communication plays a vital role in the early team development stages, facilitating trust development. Once virtual teams' TMSs were established, they do not need as much task communication to develop trust or maintain team function (Kanawattanachai & Yoo, 2007).

To sum up, my systematic review identified two mechanisms – relational and informational – through which virtual team communication helps virtual teams develop the

necessary social relationships and share relevant task information that lead to positive team outcomes. In addition, contingency factors, such as communication tools and the development stage, affect the "virtual team communication - team outcomes" relationship. Future scholars could use this framework (figure 2) to guide their research for further insights into the effects of virtual team communication on virtual team outcomes. I elaborate on this below.

Suggestions for Future Research

The empirical papers in this review focus mostly on the effects of virtual team communication quality and frequency. However, as I have highlighted above, other dimensions of team communication can also influence various virtual team outcomes through informational or relational mechanisms. For example, communication content that encourages all team members to participate in team communication can let more new ideas be shared within teams, thus increasing teams' innovation performance. Besides, given that the constructive communication style consists of offering cooperative, integrative, and mutual support among the group members, it may facilitate relationship development and information sharing, increase team satisfaction, and motivate team members to engage in creative works. Therefore, I suggest that future studies examine the effects of other aspects of team communication on virtual team outcomes.

As discussed above, team communication is a profile multidimensional construct made up of five dimensions that in combination form different profiles of team communication (i.e., high/medium/low frequency + high/low quality + task/relational content + certain type of communication style + certain communication structure). However, most empirical papers only tested the effects of one aspect of virtual team communication. Few studies have examined how different profiles of team communication may impact virtual team outcomes. Given that those

different aspects of communication impact team outcomes simultaneously in real settings, I suggest future research examine how different profiles of virtual team communication influence virtual team outcomes.

Although my analysis demonstrates that communication quality generally has positive effects on virtual team outcomes, a few studies found negative or non-significant relationships between communication quality and virtual team performance. Some possible explanations are 1) certain aspects of communication quality (i.e., communication precision) may not relate to virtual team performance; 2) virtual teams that have developed TMS can perform well regardless of their communication quality; or 3) teams' virtuality level is low. Thus, it will be desirable to examine these potential explanations in future research.

Purvanova (2014) found that the setting of studies (laboratory vs. field) moderates the effects of virtuality on team outcomes because typical teams in laboratory settings differ from typical teams in organization settings. In a simulated environment, researchers arbitrarily assign roles to participating students. Most studies also assume that individuals would participate in only one team at a time. Moreover, these virtual teams in lab studies exist for a short time. In contrast, in real work settings, team members are more likely to be assigned to a role based on their expertise and knowledge. Individuals are often members of multiple teams with different roles, expectations, and temporal rhythms. Virtual teams in real settings also last longer. Since these contextual variables can impact the effects of virtual team communication together in real work settings, I suggest that researchers examine virtual teams in field settings. Field studies that explore the impacts of various contextual variables could let researchers and practitioners have a more precise understanding of how virtual team communication influences team outcomes in different environments. Promising moderators include the type of information shared (Mesmer-

Magnus & Dechurch, 2012), task characteristics, team context (e.g., legal environment; Dulebohn & Hoch, 2017), skill differentiation, temporal stability, and authority differentiation (Schaubroeck & Yu, 2017).

The development of communication tools may change the impact of virtual team communication on team outcomes. Most previous studies assume that individuals have access to a limited set of traditional communication tools, such as email messages. However, as technology has advanced, virtual communication tools with advanced features have become available to teams. An example is that virtual team members can meet in avatar-based, 3-dimensional virtual environments, in which each team member controls an avatar's movement by carrying movement tracking devices. This virtual communication has several advanced features. First, when communicating in this 3D virtual world, team members can exchange nonverbal information, such as gestures and body movements. Presenting movements by avatars could make virtual communication more natural (Marks, Windsor, & Wünsche, 2011). Second, team members can communicate through text and voice, allowing virtual team members to have side conversations with some team members through text chat without interrupting the whole team's video conference. Third, the avatar-based, 3-dimensional virtual tool can show team members' positions in a virtual space, signaling team members' communication intention. Anderson et al. (2017) described a case where one team member wanted to lead his first team meeting. He positioned his avatar at the "head" of the table and gave directions to the other team. Because of these useful features, the avatar-based, 3-dimensional virtual tool is used in virtual design teams, medical training teams, and study teams (e.g., Anderson et al., 2017; Dalgarno, Gregory, Carlson, Lee, & Tynan, 2013; Marks et al., 2011; Quade, 2015).

Another example could be that, after the COVID-19 pandemic, virtual team members now use a much broader set of advanced communication tools, such as project management apps, and video conferences. Although some studies argue that video conferencing (e.g., through Zoom, Skype, Google Meet) is still unnatural, cannot transmit all information in communication (Bailenson, 2021), or hurt team performance and individual satisfaction (Hassell & Cotton, 2017), we can expect that, with the development of communication technology, the differences between virtual communication and face-to-face communication will become smaller. Many technology companies are trying to use 3D holographic technology to make virtual communication more authentic and closer to face-to-face communication (Ha, 2022). Will virtual team communication through these technologies be as natural as face-to-face communication? Will it still hurt virtual team outcomes? What benefits or challenges would it bring to virtual teams? One study showed how virtual teams using chat plus the online whiteboard had increased collective mindfulness, which led to improved decision quality (Curtis et al., 2017). However, not all teams are using the whiteboard effectively, which suggests that is not the whiteboard that changes team outcomes but how teams use it. Thus, how can virtual team members use these advanced communication tools effectively? How can virtual team communication be effective when using a group of communication tools simultaneously? Few studies have investigated the impacts of these types of newly developed virtual tools on the relationship between virtual team communication and team outcomes. Thus, I encourage future research to examine the impacts of these promising communication tools to provide more insight into how to communicate effectively in future virtual teams. Finally, I analyzed qualitative and quantitative virtual team studies in this systematic literature review to delineate the relationship between team communication and team outcomes in virtual teams. However, future researchers

should also conduct meta-analyses of only quantitative studies, which may offer different types of insights about the relationship between team communication and team outcomes in virtual teams.

Practical Implications

The results of this systematic review and the development of the above framework offer practical implications for companies and individuals. For example, it is important to be aware that frequent virtual communication does not guarantee a high level of team performance. Virtual team functions need frequent high-quality communication to develop social relationships among team members and facilitate task coordination. Thus, organizations can improve virtual team performance by providing virtual communication training or managing virtual team communication to facilitate not just the frequency but the quality of such communication.

Many studies have demonstrated that communication training can facilitate virtual team processes and outcomes. Virtual teams with appropriate training exhibited improved perceptions of the interaction process over time, specifically regarding trust, commitment, and the frank expression between members (Warkentin & Beranek, 1999). Virtual teams receiving communication training also showed more cohesiveness, better perceptions of group processes (e.g., member participation, equality in participation, trust, and openness), and higher satisfaction (Beranek & Martz, 2005). Huang, Wei, Bostrom, Lim, and Watson (1998) proposed that a dialogue technique that facilitates effective communication can help team members build shared mental models. Using this technique, teams will communicate about each other's past experiences and expectations for effective communication. In the end, shared mental models of effective communication would be built and used to guide their later team interaction. Research found that virtual teams using this dialogue technique are more likely to be satisfied with team

communication, have stronger team cohesion, better team collaboration, perceived decision quality, and decision satisfaction than virtual teams that did not (Guo, D'Ambra, Turner, & Zhang, 2009; Tan, Wei, Huang, & Ng, 2000), emphasizing the importance of organizations providing this type of training to virtual teams.

Lastly, virtual team managers and leaders should facilitate transparent, clear, and adequate information sharing among team members (Hoch & Kozlowski, 2014). One possible way is to implement a temporal coordination structure in virtual teams. The temporal coordination structures can direct the pattern, timing, and content of interactions in a team (Marks, Mathieu, & Zaccaro, 2001; McGrath, 1991; Ocker, Hiltz, Turoff, & Fjermestad, 1996). Thus, it can influence team coordination and consequently influence virtual team performance and virtual team learning (Stull, 2008).

Conclusion

The inconsistent conceptualization of virtual team communication and team outcomes have contributed to the mixed findings regarding their relationships in previous literature. To address this deficiency, this paper defined team communication as a profile multidimensional construct. It summarized and synthesized findings of related literature by examining each dimension's effects on five categories of team outcomes. Results indicate that the impacts of different dimensions of team communication on various virtual team outcomes are different. Nonetheless, this paper identified that virtual team communication affects virtual team outcomes mainly through two theoretical mechanisms - relational and informational, and two main contextual variables moderate these relationships - communication tool and team development stage. These findings have theoretical and practical implications. Future scholars should use the proposed multidimensional conceptualization of team communication, and the framework

identified, to guide their research for further insights into the effects of virtual team communication on virtual team outcomes. Moreover, organizational training or regulations that facilitate all five dimensions of virtual team communication may contribute to positive virtual team outcomes.

Study 2 Virtual Team Communication Content, Team Performance, and the Effect of the COVID-19 Pandemic

Virtual teams are work teams in which geographically distributed team members accomplish organizational tasks via telecommunication technologies (Dulebohn & Hoch, 2017; Powell et al., 2004). Since virtual teams can use geographically dispersed talent, operate 24/7, reduce travel costs, and overcome external environment challenges, such as the COVID-19 pandemic (Dulebohn & Hoch, 2017; Feitosa & Salas, 2020), they are increasingly used in today's organizations. Besides, effective teamwork can help organizations increase profitability (Harter & Mann, 2017; Oteshova, Niyazbayeva, Prodanova, Sabirova, & Zayed, 2021), and as such, there is great interest in helping virtual teams become more effective today (Schaubroeck & Yu, 2017). Thus, many studies have investigated antecedents of virtual team performance and found significant relationships between team communication and virtual team performance in particular (Marlow, Lacerenza, Paoletti, et al., 2017). However, these relationships have been shown to be inconsistent because prior studies have conceptualized team communication differently, such as looking at the role of team communication frequency versus quality (Marlow, Lacerenza, & Salas, 2017). As a result, we lack a more nuanced understanding of the relationships between team communication and team performance, which hinders organizations from supporting their virtual teams to best perform.

The impacts of particular aspects of team communication on virtual team performance appear to be especially under-investigated. Most studies have measured team communication as communication quality or frequency. They have consistently shown that communication quality positively affects virtual team performance (e.g., Eisenberg, Post, & DiTomaso, 2019; González-Romá & Hernández, 2014; Gorman & Cooke, 2011; Stewart & Gosain, 2006). Regarding

communication frequency, moderate frequency is associated with higher levels of team performance, whereas both too low- and too high-communication frequency are associated with lower virtual team performance levels (Handke et al., 2018; Patrashkova-Volzdoska et al., 2003). However, another aspect of team communication, communication content, can also influence team performance by determining what information is shared within these teams. According to the shared cognition perspective, information sharing within teams ensures that team members' knowledge, skills, and experience are brought to bear on the team tasks (Gajendran, 2009). It also develops and reinforces team members' shared beliefs and understandings regarding team roles and responsibilities (Kanawattanachai & Yoo, 2007; Macmillan et al., 2004). As a result, information sharing facilitates team coordination and contributes to team performance, and yet we have limited insights about the role of different communication content being shared in virtual teams.

This omission is concerning as team communication content is especially relevant for virtual teams in which information sharing is challenging. In particular, information shared in face-to-face teams is rich and complete because team members' paraverbal (e.g., tone of speech), non-verbal (e.g., facial expressions), and contextual (e.g., office environment) cues can be transmitted timely, whereas, in virtual teams that mainly communicate through text messages, these paraverbal, non-verbal, and contextual cues are lost. Even though many virtual teams communicate through video chat tools that can convey richer cues (e.g., Zoom, Skype, Google Meet), virtual team members still receive fewer cues than in face-to-face communication. Thus, communication content largely determines what information is shared within a virtual team, influencing team performance.

Investigating the effects of team communication content on virtual team performance is accordingly essential as it can provide a more comprehensive and nuanced understanding of the relationships between team communication and performance in virtual teams. The knowledge of communication content can guide virtual teams to use their limited communication opportunities, share integral information within teams, and avoid distracting and irrelevant communication content that may hinder virtual team processes and be detrimental to team performance. However, as alluded to above, the effect of team communication content on virtual teams is relatively under-investigated (Marlow, Lacerenza, & Salas, 2017). Therefore, to address this research gap, the purpose of this research was to investigate the impact of four different types of team communication content (problem-focused, procedural, action-oriented, and social-emotional statements (Kauffeld, 2006; Kauffeld & Lehmann-Willenbrock, 2012; Kauffeld, Lehmann-Willenbrock, & Meinecke, 2018) on virtual team performance.

More specifically, I utilized the Time, Interaction, and Performance (TIP) theory (McGrath, 1991) to develop hypotheses regarding the relationships between these four types of virtual team communication content and virtual team performance. TIP theory describes effective teams as being engaged in both task-oriented and social-emotional activities related to three team functions: production/performance, group well-being, and member support (McGrath, 1991). For virtual teams to effectively perform, they accordingly need to communicate in ways that address these different activities. Based on this theory, I argue how and why, in virtual teams, task-oriented communication content (i.e., problem-focused, positive/negative procedural, and positive/negative action-oriented communication) influences team performance. In addition, according to TIP theory (McGrath, 1991), positive social-emotional communication can facilitate, and negative social-emotional communication can hinder a team's well-being and

member support functions. Thus, I argue that by facilitating (hindering) the implementation of well-being and member support functions, positive (negative) social-emotional communication content may also facilitate (hinder) team performance. I tested these hypotheses using a sample of 99 virtual teams that develop open-source software (OSS) during the first six months of 2020.

Moreover, as I was in the process of my data collection to investigate the relationship between virtual team communication content and performance, a worldwide pandemic happened. Given that the COVID-19 pandemic represents a major disruptive event that may have greatly influenced virtual teams, I took this opportunity to also investigate how virtual teams' communication content, performance, and their relationship changed from before to during the pandemic. Doing so helps shed light on virtual teams' communication patterns and performance during times of disruption.

Finally, issues in measuring communication content reduce our confidence in previous findings. Specifically, prior research has mainly measured virtual team communication content by asking team members to assess their team communication experiences on scales after completing team tasks (e.g., Altschuller & Benbunan-Fich, 2010; Walther & Bunz, 2005). Team members' subjective assessment of team communication may not reveal the actual virtual team communication. In contrast, analyzing actual team communication content can reveal how language use and naturally occurring interactions within virtual teams affect various team outcomes. Given that many virtual teams keep their communication records (e.g., chat transcripts), researchers have suggested that future research examine the impact of actual communication content on team outcomes (Darics, 2010; Gilson et al., 2015; Marlow, Lacerenza, & Salas, 2017). Following these calls, I measured virtual team communication content via textual analyses of actual communication records. In order to code these

communication records more efficiently, the coding work was done by both human coders and supervised machine learning algorithms.

Overall, this research furthers our knowledge about the effects of different team communication contents on virtual team performance – especially during times of disruption – which is increasingly important for organizations to understand and to utilize today. By measuring virtual team communication content according to actual team communication records – using both human coders and a supervised machine learning algorithm – these findings can be used to corroborate previous work that has mostly relied on self-reported, subjective assessments, and provide a promising direction and guidance for team communication content research moving forward.

Theory and Hypotheses

Time, Interaction, and Performance (TIP) Theory

McGrath's (1991) TIP theory includes a group of propositions about the nature of teams, illustrating how teams are complex, time-based, multifunctional social systems. Many virtual team communication studies have used TIP theory as their theoretical framework (e.g., Bartelt & Dennis, 2014; Daim et al., 2012; DeLuca & Valacich, 2006; Massey et al., 2003; Warkentin, Sayeed, & Hightower, 1997) because it allows for a rich understanding of various team processes and outcomes. More specifically, TIP sheds light on three different types of team functions and how they are influenced by multiple types of team activities over time. Thus, it allows researchers to examine the impacts of different aspects of communication on many team outcomes (e.g., team performance, trust, satisfaction) in depth. Besides, TIP theory proposes that teams have to carry out certain activities to implement team functions when they face new tasks,

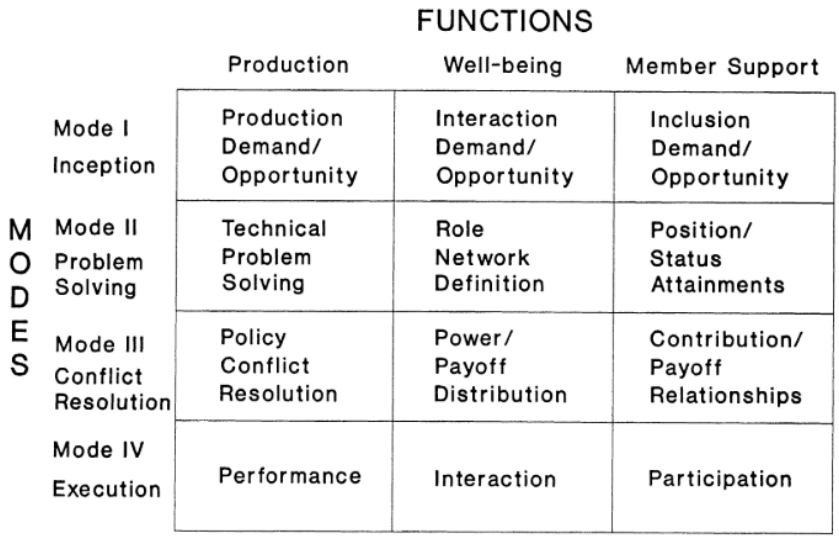
have new members, or encounter changing environments, which are common for virtual teams. As a result, TIP theory also helps researchers investigate team activities that facilitate virtual team learning, development, and adaptations over time.

Team Functions and Activity Modes

TIP theory proposes that teams usually engage in three interdependent functions: production, group well-being, and member support (see figure 1; McGrath, 1991). The production function refers to the completion of tasks assigned to teams (i.e., team performance). The group well-being function refers to developing and maintaining good social relationships among team members. The member support function refers to the inclusion of team members, team member participation, loyalty, and commitment. Teams implement these three functions by carrying out four modes, or types of activities: inception (Mode I), problem solving (Mode II), conflict resolution (Mode III), and execution (Mode IV). For example, teams implement the production function, i.e., successfully complete tasks assigned to teams, by carrying out four modes of activities (see figure 1): identifying goals and selecting initial performance strategies (Mode I); determining the most appropriate means (techniques, procedures, or algorithms) to achieve the team's goal (Mode II); resolving conflicting preferences, values, or interests within the team (Mode III); and carrying out behaviors necessary for attaining the team's goals or completing team tasks (Mode IV).

Figure 1

Team Functions and Activity Modes



Note. This figure is adapted from McGrath (1991; p. 154).

Activity Paths to Implement Team Functions

According to the TIP theory (McGrath, 1991), the modes of activities taken by each team to implement its functions are not fixed, but rather are dependent on the characteristics of the team, tasks, technology, time, and other environmental contingencies (McGrath & Hollingshead, 1994). Specifically, teams take one of the four activity paths, from Modes I to Mode IV, to implement production, well-being, or support functions. First, they can use the simplest path (i.e., engaging in both Modes I and IV activities) if their purpose, resources, and circumstances allow them to use it. Under this situation, Modes I and IV activities are sufficient for teams to implement team functions satisfactorily.

However, when teams' projects involve new tasks, teams have new members, or conditions of these teams change substantially, Modes II and III activities are necessary for

teams to adapt to the new environments and implement team functions (McGrath, 1991). In other words, they have to use one of the three paths to implement team functions: a three-mode path (i.e., engaging in Modes I, II, and IV activities), a different three-mode path (i.e., engaging in Modes I, III, and IV activities), or an even more complex path (i.e., engaging in Modes I, II, III, and IV activities). For example, when a team receives novel tasks, team members cannot perform well by merely choosing team goals and carrying out the same behaviors as before to complete tasks (i.e., Modes I and IV). Instead, they have to also determine the most appropriate means to solve new technical issues in these tasks (Mode II) or make new policies to resolve conflicting preferences among team members due to the new tasks (Mode III). After that, they will be able to complete new tasks.

To sum up, TIP theory suggests that teams carry out four modes of activities to implement team functions. The modes of activities necessary to implement these functions depend on the characteristics of the team, tasks, technology, time, and other environmental contingencies (McGrath, 1991).

Virtual Team Communication Content and Team Performance

This study examines the impacts of team communication content on virtual team performance. According to TIP theory (McGrath, 1991), team communications are team activities that can help implement team functions. Specifically, I argue that task-oriented communication content (i.e., problem-focused, positive/negative procedural, and positive/negative action-oriented statements; see table 1; Kauffeld, 2006; Kauffeld & Lehmann-Willenbrock, 2012; Kauffeld et al., 2018) can influence the team production function, i.e., team performance. In comparison, I argue that social-emotional-oriented communication content indirectly influences the production function by facilitating (or hindering) team well-being and

member support functions. And then, teams with a good production function will successfully complete assigned tasks and perform well. I explain how these different types of communication content affect team performance via these functions in greater detail below.

Table 1

Team communication content

Problem-focused statements	Procedural statements	Socio-emotional statements	Action-oriented statements
Problem	**Positive**:	**Positive**:	**Positive, proactive**:
Describing a problem	Goal orientation	Encouraging	Expressing positivity
Connections	Clarifying	participation	Taking responsibility
with problems	Procedural suggestion	Providing support	Action planning
Defining the objective	Procedural question	Active listening	**Negative,**
Solution	Prioritizing	Reasoned	**counterproductive**:
Describing a solution	Time management	disagreement	No interest in change
Problem with a	Task distribution	Giving feedback	Complaining
solution	Visualization	Humor	Seeking someone to blame
Arguing for a solution	Summarizing	Separating opinions	Denying responsibility
Organizational	**Negative**:	from facts	Empty talk
knowledge	Losing the train of	Expressing feelings	Ending the discussion early
Knowing who	thought	Offering praise	
Question	(running off	**Negative**:	
	topic)	Criticizing/backbiting	
		Interrupting	
		Side conversations	
		Self-promotion	

Note. This table is adapted from Kauffeld and Lehmann-Willenbrock (2012; p. 134-135)

Problem-focused Statements

Problem-focused statements refer to communication content that aims at understanding and analyzing the problem at hand, asking and sharing information, finding and developing ideas and solutions, and evaluating those solutions (e.g., “the problem is …”, “the cooperation in this group is bad,” “In the future, we have to…”) (Kauffeld & Lehmann-Willenbrock, 2012).

Problem-focused communication that identifies problems, defines objectives, or proposes solutions, can be regarded as Mode I activities since they help teams choose goals and consequent initial performance strategies. Communication that compares different solutions and shares organizational knowledge related to tasks, can be regarded as Modes II activities of the production function. This communication content can help determine the most appropriate means (techniques, procedures, or algorithms) to carry out the project. Communication that proposes or describes solutions to resolve the conflict of political issues, such as proposing a new policy that attempts to resolve potential conflicts, can be regarded as Mode III activities. In short, problem-focused communication can be regarded as Mode I, II, or III activities. According to TIP theory (McGrath, 1991), these activities help teams perform, i.e., achieve the production function.

Moreover, problem-focused communication that defines and analyzes task-related problems helps teams understand the problems correctly (Kauffeld & Lehmann-Willenbrock, 2012). A correct understanding of the task-related problems is necessary for successful team decision-making and problem solving (Wittenbaum et al., 2004). Problem-focused communication that describes and evaluates solutions helps teams find better solutions (Yilmaz, 2016). Finally, problem-focused communication that shares knowledge helps team members consider more options and learn from others' knowledge and experiences (Lee, Gillespie, Mann, & Wearing, 2010). All of these problem-focused communications are related to positive team outcomes.

Supporting the literature above, Kauffeld and Lehmann-Willenbrock (2012) found that, in face-to-face teams, the percentage of problem-focused communication in team discussions was positively related to these teams' productivity and organizational success. Other studies also demonstrate that problem-focused statements that aim at solving teams' task-related problems

can significantly impact virtual team performance (Bradley et al., 2013; Curtis et al., 2017; Espinosa et al., 2015; Hsu & Chou, 2009; Massey et al., 2003). Therefore, I expect that an increase in the use of problem-focused statements will improve virtual team performance. I posit:

> *Hypothesis 1: Problem-focused statements are positively related to virtual team performance.*

Procedural Statements

Procedural statements refer to communication content that aims at structuring and organizing team discussions (e.g., "our topic today is …", "we should discuss that later") and can be positive or negative (Kauffeld & Lehmann-Willenbrock, 2012). Positive procedural statements, such as suggesting further courses of action, questioning teams about the further course of action, judging what is more important, and weighing the costs and benefits of solutions, can be regarded as Mode II activities. They help teams determine the most appropriate means (techniques, procedures, or algorithms) to carry out the project. Other positive procedural statements represent Mode IV activities of the production function: communication that highlights team goals, manages time, distributes tasks, and summarizes what has been reached. These communicative activities encourage behaviors necessary and sufficient to attain teams' goals. According to TIP theory (McGrath, 1991), these Mode II and IV activities can help teams achieve the production function, meaning they positively influence team performance.

Research on face-to-face teams suggests that structured team discussions can enhance team performance by making team members more focused on team information sharing (Mesmer-Magnus & Dechurch, 2012). Positive procedural statements are particularly critical for virtual teams because their team members often work on other tasks while participating in virtual

teamwork; consequently, they divide their attention among activities without fully engaging in the present team communication (Dulebohn & Hoch, 2017; Malhotra, Majchrzak, Carman, & Lott, 2001). Procedural statements structure and organize team discussions, thus can draw their attention back to and engage in team task-related communication, then help virtual teams complete tasks. In addition, Kauffeld and Meyers (2009) found that positive procedural statements can promote more functional discussion processes by inhibiting dysfunctional behaviors such as complaining.

In contrast, negative procedural statements, such as lengthy monologues and redundant explanations, can be distracting and time-consuming, leading to an unstructured discussion process (Kauffeld & Lehmann-Willenbrock, 2012; Kauffeld, Lehmann-Willenbrock, & Meinecke, 2018; Kauffeld & Meyers, 2009). In other words, speakers only talk about examples or information irrelevant to teams' goals (e.g., "she said…and then I said…and then Mark said…"), which harms team performance. Therefore, I posit:

> *Hypothesis 2: Positive (negative) procedural statements are positively (negatively) related to virtual team performance.*

Action-oriented Statements

Action-oriented statements refer to communication content expressing a team's willingness to take action to improve their work (Kauffeld & Lehmann-Willenbrock, 2012). Action-oriented statements can also be positive or negative. Positive action-oriented statements include communication content that expresses interest in change or action, takes responsibility for changes ahead, or plans concrete actions, such as "I will do that." In line with TIP theory

(McGrath, 1991), these positive action-oriented statements can be regarded as Mode IV activities that enable teams to execute the necessary and sufficient behaviors to attain their goals.

Specifically, I expect positive action-oriented statements to improve virtual team performance for the following reasons. First, positive action-oriented statements are particularly crucial for virtual teams' task completion. In face-to-face teams, teams' task-completing actions can be triggered by action-oriented communication or ambient stimuli within groups, such as other members' tones, levels of arousal, or emotional expressions (Hackman, 1992). In comparison, the ambient stimuli are lost in virtual communication (Martins et al., 2004). Positive action-oriented communication statements can ensure that ideas and solutions developed in teams will be carried out (Kauffeld & Lehmann-Willenbrock, 2012), such that they may represent the main factor that impacts task-completing actions. Second, positive action-oriented statements may motivate team members to take action to improve their work (Lindsley, Brass, & Thomas, 1995). Research found that face-to-face teams composed of members who always facilitate planning or foster team development were more likely to perform well in terms of technical or service quality (Chiu, Owens, & Tesluk, 2016).

In contrast, negative action-oriented communication includes negative statements about change, complaining, seeking others to blame, or denying responsibility, such as "we will never be able to accomplish that." I expect these negative action-oriented statements to negatively affect virtual team performance because they tend to lead to further negative action statements in team communication (Kauffeld & Meyers, 2009; Klonek, Quera, Burba, & Kauffeld, 2016)，which could be demotivating (Marks et al., 2001). Furthermore, Cooke and Szumal (1994) found that face-to-face teams who lacked participation or interest developed poor solutions. As a result,

they can lead teams into a vicious cycle in which both team confidence and performance are continuously decreasing (Lindsley et al., 1995). Thus, I posit:

> *Hypothesis 3: Positive (negative) action-oriented statements are positively (negatively) related to virtual team performance.*

Social-emotional Statements

Virtual teams can also communicate positive and negative social-emotional content (Adler, 1995; Chidambaram, 1996; Walther, 1995). Positive social-emotional statements include communication content that encourages participation, provides support, gives feedback, shows humor, expresses feelings, and offers praise. In comparison, negative social-emotional statements include interrupting, teasing, antagonistic comments, offensive words, and self-promotion (Kauffeld & Lehmann-Willenbrock, 2012). According to TIP theory (McGrath, 1991), positive social-emotional communication can facilitate, and negative social-emotional communication can hinder teams' well-being and member support functions. For example, research has found that positive social-emotional communication content can foster virtual team trust (Gupta & Govindarajan, 2000; Henttonen & Blomqvist, 2005; Jarvenpaa & Leidner, 1999; Walther & Bunz, 2005), whereas negative social-emotional communication is negatively related to virtual team trust (Wilson et al., 2006).

Given that teams' production, member support, and well-being function are interdependent, McGrath's (1991) TIP theory suggests that teams with good member support and well-being functions are more likely to perform well. For example, a high degree of trust fostered by positive social-emotional communications can reduce concerns among virtual team members about whether others will complete their responsibilities; this trust, in turn, enables

team members to depend on each other to reach the team's collective goal (Greenberg, Greenberg, & Antonucci, 2007). Moreover, the broaden-and-build theory of positive emotions (Fredrickson, 1998, 2004) argues that positive emotions can broaden people's scopes of attention and make them think flexibly, creatively, openly, and efficiently, which in turn enables them to create, explore, and take in new information. Therefore, since positive social-emotional communication is likely to trigger positive team emotions, these teams are more likely to perform well. Therefore, I posit:

> *Hypothesis 4: Positive (negative) social-emotional communications are positively (negatively) related to virtual team performance.*

The COVID-19 Pandemic

To build on the hypotheses above, I next turn to the question of how virtual communication can be influenced by disruptive events such as the COVID-19 pandemic. The WHO declared the COVID-19 outbreak a pandemic on March 11, 2020 (World Health Organization, 2020). Madhav et al. (2017) define pandemics as "large-scale outbreaks of infectious disease over a wide geographic area that can greatly increase morbidity and mortality and cause significant economic, social, and political disruption" (p. 35). Many countries implemented lockdowns to control the spread of the virus. By April 2020, more than 3.9 billion people in more than 90 countries or territories were under lockdown (Sandford, 2020). Due to the lockdown, many people worked virtually from home.

Virtual working during the COVID-19 pandemic has created many new problems for teams. At the beginning of the COVID-19 pandemic, team members had to adapt to the virtual-team mode quickly. The sudden reconstruction of working modes could be challenging when

team members did not have adequate virtual team experience, sufficient technical support, or appropriate remote working devices. In addition, many organizations lack appropriate policies, resources, or management practices to support team production in a virtual environment. While team members hoped organizations could provide them with curated guidance to enable them to work efficiently with others (Ford et al., 2022), most companies supported their teams merely by organizing regular virtual team meetings, which was not perceived as helpful by team members (Ralph et al., 2020).

Although virtual working is not new for some industries, such as the software development industry, virtual working during the COVID-19 pandemic nonetheless posed challenges. First, during the pandemic, these virtual team members worried about their organizations shutting down, being laid off, childcare, the health situation of their families, friends, and themselves. Second, their mental health worsened during the COVID-19 lockdown. Nearly 30% to 50% of software developers had sleep disorders and higher stress levels during the pandemic (da Mota Silveira Neto et al., 2020). Due to the pandemic, developers also had lower emotional well-being while working from home (Ralph et al., 2020). Third, virtual team members who were quarantined at home during the pandemic were more likely to be distracted by their partners, children, siblings, parents, roommates, and pets (Ralph et al., 2020).

The disturbing, stressful, and distracting situation of COVID-19 also influenced the way in which virtual teams worked and performed. According to the working memory literature, worries due to a stressful environment compete for working memory available for team tasks (Miyake & Shah, 1999). Working memory is a cognitive system with limited capacity; it is used to control, regulate, and maintain information immediately relevant to the task at hand (Miyake & Shah, 1999). Worries and execution of team tasks vie for the limited working memory

capacity that, in a less stressful situation, could all be devoted to team activities (Beilock, 2008). Thus, during the pandemic, virtual team members would only have limited working memory to process tasks, which may lead to worse team performance. In Ford et al.'s (2020) longitudinal study, some software developers reported that they were less productive when working virtually than working in the office; but the percentage of developers reporting to be less productive consistently dropped from March 2020 to May 2020. However, it is unclear whether virtual team performance changed in a similar pattern. Furthermore, we know little about whether and how virtual communication content changed during the pandemic so far due to its recent emergence.

In addition, the relationship between virtual team communication content and performance was also likely to change before, during, and after the pandemic (see figure 2). According to TIP theory, teams usually implement their production function by engaging in Modes I and IV activities (i.e., the simplest path), such as team communication that helps them choose task goals, propose performance strategies, and complete tasks (McGrath, 1991). However, when teams' external environment changes substantially, technical problems and conflicting interests will likely arise, forcing them to engage in additional Modes II or III activities to implement production function (McGrath, 1991). Specifically, teams will use the second path – a three-mode path (i.e., engaging in Modes I, II, and IV activities) – when they need to identify an appropriate means to solve technical problems. Alternatively, they will use the third path – a different three-mode path (i.e., engaging in Modes I, III, and IV activities) – to resolve conflicting interests or values related to team performance. Sometimes teams will use the fourth path – an even more complex path (i.e., engaging in Modes I, II, III, and IV activities) – if they have to solve both technical problems and resolve conflicting interests.

Therefore, according to TIP theory (McGrath, 1991), when the COVID-19 pandemic began, teams' external environment changed substantially. In order to implement production function, teams must engage in extra communication activities (i.e., Modes II or III) to solve new-arising problems or resolve conflicting preferences, values, or interests. Given that these extra communications are meant to solve the new-arising issues, but do not directly perform team tasks immediately, it is possible that the relationship between team communication and performance would become weaker at the beginning of the COVID-19 pandemic (i.e., March 2020; WHO, 2020). However, these virtual teams will likely adapt to this stressful situation over time. According to TIP theory (McGrath, 1991), although these extra communicative activities may not facilitate task completion instantly and even damage short-term performance slightly, they help teams gradually adapt to the new working mode, overcome difficulties in the pandemic, and contribute to long-run team performance (McGrath, 1991). Thus, after having overcome the initial shock of the disruption from COVID-19, teams may be more likely to perform tasks well by engaging in the default simplest communication again (i.e., mode I and IV of choosing task goals, proposing performance strategies, and completing tasks accordingly). Since there is limited empirical and theoretical foundation for the disruptive impact of the pandemic here, I refrain from developing hypotheses and rather pose the following research questions:

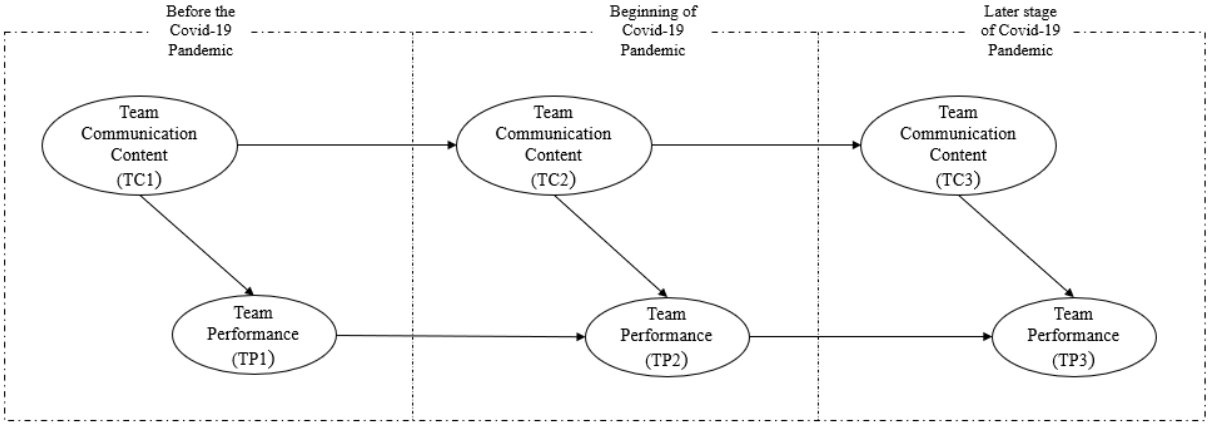
Research question 1: How did virtual team communication content change before, during, and after the pandemic?

Research question 2: How did virtual team performance change before, during, and after the pandemic?

Research question 3: How did the relationship between communication content and virtual team performance change before, during, and after the COVID-19 pandemic?

Figure 2

Temporal Model of This Study



Methodology

Setting

The virtual teams of the present study were teams that develop open-source software (OSS). OSS refers to "software released under a license that permits the inspection, use, modification, and redistribution of the software's source code" (Crowston, Wei, Howison, & Wiggins, 2012, p.1). OSS teams have the characteristics of virtual teams. Its members are geographically dispersed and coordinate through telecommunication technologies to achieve common goals (e.g., developing open-source software), mainly through emails, messages, or discussion fora (Crowston et al., 2012; Nagle, 2018; Wei et al., 2017).

As an example of virtual teams, the OSS team has attracted much attention from researchers in the fields of management, information system, and computer science who hope to develop theories of virtual team management (Howison & Crowston, 2014; Stewart & Gosain, 2006). OSS teams also attract lots of developers and organizations to participate. For example, GitHub, one of the OSS development platforms, has more than 19 million users and 52 million repositories (i.e., projects; Coelho & Valente, 2017). Many companies worldwide use, sponsor, and contribute to open-source projects, such as Facebook, Google, and Huawei (Shahi, 2020). Moreover, a lot of successful OSS projects span a wide range of applications, including the Linux operating system, the ApacheWeb Server, and projects on internet infrastructure (e.g., Sendmail, bind), user applications (e.g., Mozilla Firefox), programming language (e.g., Perl, PHP), programming environments (e.g., Eclipse), and enterprise systems (e.g., eGroupware, openCRX) (Crowston et al., 2012; Harvey, 2016; Opensource Year Book, 2017).

Characteristics of OSS Teams

An open-source project is started when individual developers or organizations need to develop a project in public[1]. Two types of OSS teams exist: autonomous and firm-sponsored OSS teams (see Appendix 1; Ritvo, Hessekiel, & Bavitz, 2017; West & O'mahony, 2008). The autonomous OSS teams are presently independent of any firm and are community-managed. Developers voluntarily participate in these teams mainly because of their intrinsic or extrinsic motivations, such as altruism, kinship, fun, earning reputations among OSS communities, and learning techniques (von Krogh, Haefliger, Spaeth, & Wallin, 2012). For these projects, attracting and keeping voluntary developers is vital for project success (Crowston et al., 2012).

[1] https://opensource.guide/starting-a-project/#:~:text=Open%20source%20is%20powerful%20because,computing%2C%20relative%20to%20closed%20source.

Many factors influence OSS project teams' attractiveness and retention, such as politeness of team communication, the popularity of the project (in terms of stars), project age, programming languages, and license restrictiveness (Destefanis et al., 2016; Fronchetti, Wiese, Pinto, & Steinmacher, 2019; Santos, Kuk, Kon, & Pearson, 2013).

In contrast, firm-sponsored OSS teams are where one (or more) corporate entities control the community's short- or long-term activities. These corporate entities could be organizations[2] that benefit from the developed software or OSS foundations[3] (Eckert, 2018). A greater part of the developers of these firm-sponsored OSS teams is paid to contribute to these project teams. According to Berdou (2006), these paid OSS developers receive instructions from employers with different levels of restrictiveness. While many paid developers have a clear mandate from their employers about what they should do, some of these developers receive no clear instructions from employers about what to work on. They used to be voluntary developers, and now, they are just expected to do the same work they did when they were volunteers and not hired. Nonetheless, firm-sponsored OSS teams also attract voluntary developers to work on their projects, especially famous ones. Given that firm-sponsored OSS teams can attract and hire developers, it is not surprising that firm-sponsored OSS teams are larger than autonomous OSS teams, i.e., nineteen vs. five developers (Bonaccorsi, Lorenzi, Merito, & Rossi, 2011).

Pull-Based Software Development

The development of OSSs often requires the OSS project teams to coordinate members responsible for different tasks and work at different places. The technology that makes this happen is the git. Git is a version control system that tracks file changes, and coordinates work

[2] A list of companies that sponsor open-source software: https://github.com/ossfriendly/open-source-supporters
[3] A list of OSS foundations: https://opensource.com/resources/organizations

on those files among multiple people. It supports distributed and non-linear workflows and enables pull-based software development.

The pull-based development means that any team members or potential members of a software project can propose code changes by working locally on a local clone (i.e., a branch) of the central repository (i.e., the original code or the main branch) (Gousios, Pinzger, & Deursen, 2014). These proposed code changes are called pull requests, which are then reviewed and evaluated by project owners or core developers. If the pull requests are qualified, they will be merged into the main branch. Members could also just detect and report issues in the source codes without providing a pull request to fix them. These issues could be fixed in the future by other members. Both proposing pull requests and reporting issues contribute to the development of the OSS.

Role of Communication for OSS Teams' Performance

Many researchers have investigated how to improve the performance of OSS project teams. One relevant factor is team communication within OSS project teams. While communication in OSS teams can be challenging (Poba-Nzaou & Uwizeyemungu, 2019), research suggests that OSS teams that communicate effectively are more likely to perform well. For example, Stewart and Gosain (2006) found that OSS teams' communication quality positively affected teams' task completion speed. Méndez-Durón and García (2009) found that knowledge sharing among OSS team members improved project success (i.e., number of downloads per month). Similarly, the frequency of communication was positively related to the defect-fixing effectiveness of OSS project teams (Ghapanchi, Wohlin, & Aurum, 2014). As discussed above, communication content is particularly relevant for the performance of virtual

teams that communicate mainly through text messages. Thus, I expect that the OSS teams' communication content will also influence their team performance as per my hypotheses.

Sample

Many OSS development platforms provide numerous communication records of OSS teams, allowing us to test the hypotheses discussed above. In this study, I sampled OSS teams (called repositories in GitHub) from one of these online platforms, GitHub[4]. GitHub is a transparent working environment that records OSS projects' developing activities, interaction history among developers, and projects' quality outcomes. Moreover, all members' profiles and contribution histories in the GitHub community can be easily found (Tsay, Dabbish, & Herbsleb, 2014). Lastly, previous research has used the GitHub platform as the main source of data (e.g., Ortu et al., 2018; Steinmacher, Pinto, Wiese, & Gerosa, 2018; Yu, Wang, Yin, & Wang, 2016).

In order to investigate how OSS team communication influences virtual team performance, I sampled OSS teams that met the following criteria. First, I focused on main-line projects (i.e., not forks[5]) written in the most popular languages on GitHub: Ruby, Python, JavaScript, PHP, Java, Scala, C, and C++. This criterion ensured that the selected project teams could attract sufficient members because fewer developers use uncommon languages. Second, there was a significant amount of communication activity among team members. Members contribute to their OSS projects by submitting pull requests (e.g., a code-revising proposal, a plan to add new features, a possible solution for a bug, etc.), which can generate extended discussions among members (Tsay et al., 2014). Therefore, projects with fewer than 100 pull requests/issues were excluded. Previous OSS teams studies (Gousios et al., 2014; Vasilescu, Yu,

[4] https://github.com/
[5] A fork is a copy of original project; making changes on the fork does not affect the original project.

Wang, Devanbu, & Filkov, 2015; Zou, Xuan, Xie, Chen, & Xu, 2019) have used a similar criterion to make sure that the selected projects truly used the pull request/issue mechanism to perform collaborative development rather than being an infrequent modality adopted by occasional external contributors. Third, the sample was limited in one domain (i.e., open-source internet software projects) to control for possible differences across projects in very different product categories. The selected OSS projects were under the following topics of GitHub: HTTP (Hypertext Transfer Protocol), FTP (File Transfer Protocol), Web, and browser. Fourth, the selected projects had at least three members, and at least two of the team members were core developers. According to previous research (Mockus, Fielding, & Herbsleb, 2000; Setia, Rajagopalan, Sambamurthy, & Calantone, 2012), core developers write more than 12% of the code for the product. In contrast, peripheral developers contribute between 0% to 12% percent of the total code. Suppose only one developer completes most of the tasks. In that case, his/her ability determines project performance rather than the team as a whole, making the team process (i.e., team communication) less relevant to project performance. Thus, having at least two core developers in the selected teams increased the likelihood that team communication would influence team performance. Fifth, the projects selected were active from January to June 2020 regarding contributions to the code repository; requests for bug fixes, support, patches, features, discussion, or page views. This criterion ensured that the sample included ongoing projects that their developers had not abandoned.

The final data set consisted of 99 OSS project teams. Among these teams, 46.47% had 3 to 10 members (i.e., small teams), 39.40% had 11 to 20 members (i.e., medium-sized teams), and the rest had 21 to 31 members (i.e., large teams). Within these teams, 2 to 5 were core

developers. The percentages of these teams under the topics HTTP, FTP, Web, and browser were 57.58%, 8.08%, 23.23%, and 11.11%, respectively.

Measures

This study investigated the impact of virtual team communication content on virtual team performance and explored the effects of the COVID-19 pandemic. According to previous research, the pandemic started to impact software developing virtual teams around mid- to late February 2020, with restrictions and health concerns building in March (Ford et al., 2022; Forsgren, 2020). These teams gradually adapted to the new situation in around one or two months (Ford et al., 2022). To capture the role of virtual team performance and team communication content before, during, and after the main disruption of the COVID-19 pandemic, therefore, all data were measured from January to June 2020. At the end of each month, team performance and communication content of this month were assessed.

Virtual Team Performance

Team performance was measured in two distinct ways. According to TIP theory (McGrath, 1991), the team production function, i.e., team performance here, can be assessed in terms of quantity, quality, or speed of production of some products. Similarly, previous OSS research measured OSS team performance by assessing task completion speed and product quality assessment (e.g., Khomh, Dhaliwal, Zou, & Adams, 2012; Setia et al., 2012; Vasilescu et al., 2015; Zöller, Morgan, & Schröder, 2020).

Task completion speed refers to the number of tasks resolved per unit time (Licorish & MacDonell, 2017). In OSS teams, managing pull requests is the main task. “A pull request is merged” means the task is completed. Thus, following previous studies (Vasilescu et al., 2015;

Zöller et al., 2020), I measured team task completion speed as the number of pull requests merged per month as one form of virtual team performance.

In addition, quality assessment is an indicator of code quality and refers to detecting and reporting issues for improvements in OSS projects (Setia et al., 2012). Because the design and development of software are complex, defects and bugs can be hidden in the software for long periods without being found. They might cause severe problems for software users. Detecting and reporting issues in OSS projects give OSS teams the opportunities to fix defects and bugs and improve code quality in the future (Setia et al., 2012). The more issues are detected and reported, the more likely the code quality will improve. Thus, quality assessment reflects OSS project teams' efforts and potential to improve product quality. More issues reported indicate better OSS team performance. Following previous studies (Khomh et al., 2012; Setia et al., 2012; Vasilescu et al., 2015), quality assessment was measured by the number of issues reported per month as the second type of virtual team performance.

Team Communication Content

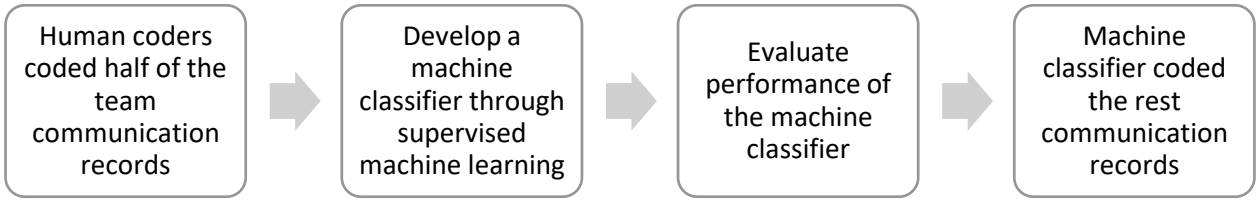
Coding Scheme. I used the validated act4teams coding scheme, developed for observing social interactions (Kauffeld, 2006; Kauffeld & Lehmann-Willenbrock, 2012; Kauffeld et al., 2018), to code team communication content. In particular, communication records of 99 teams were cut into 87,441 utterances or sense units. According to Bales (1950), an utterance or a sense unit is the smallest speech segment that expresses or implies a complete thought. Thus, the utterance can be a sentence or a word (e.g., thanks). Following previous literature (Kauffeld & Lehmann-Willenbrock, 2012; Kauffeld et al., 2018), every utterance was coded into just one communication content category (i.e., mutually exclusive codes): problem-focused, positive

procedural, negative procedural, positive action-oriented, negative action-oriented, positive social-emotional statements, or negative social-emotional statements (see table 1).

Communication Content Coding Process Overview. I chose to have half the utterances coded by human coders and half by a supervised machine learning classifier for the following reasons: 1) the number of utterances was huge, i.e., 87,441 utterances, 2) I had a limited budget to hire human coders, and 3) the machine classifier took a short time to code the same amount of communication records (e.g., five days for machine classifier vs. two months for two human coders). The comparison of the descriptive statistics for the human-coded and the machine-coded teams can be found in Appendix 1. Figure 3 shows the coding process. First, two human coders coded around half of the utterances, which were 52 teams' communication records. These 52 teams were randomly selected. Second, these coded utterances from the first step were then used in a supervised machine learning training process to develop a function that could classify each utterance into one of the categories, just like the two human coders. And then, the performance of the machine classifier was evaluated. After that, the machine classifier coded the rest of the utterances, which were the remaining 47 teams' communication records. Finally, for each virtual team, I calculated the number of each category of communication content for each month. I describe these steps in more detail below.

Figure 3

Communication Content Coding Process



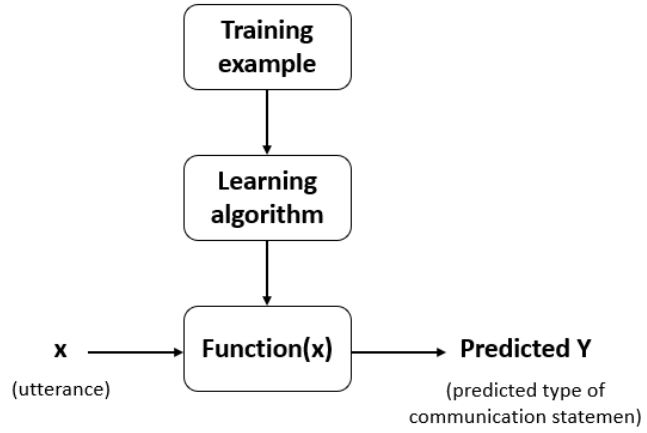
Human Coding Process. Two human coders, blind to the hypotheses, were trained to code around half of the data (52 teams) by assigning a communication content type (i.e., problem-focused, positive procedural, negative procedural, positive action-oriented, negative action-oriented, positive social-emotional statements, or negative social-emotional statements) to each utterance. Following previous studies (Kanawattanachai & Yoo, 2007; Meinecke, Lehmann-Willenbrock, & Kauffeld, 2017), the coding process included the following steps. In step one, the two coders read and learned the act4teams coding manual and separately coded 1% of the data (i.e., one team's communication records, randomly selected). The coders then discussed and resolved any discrepancies between them. In step two, the coders independently coded the same 5% of the data (i.e., seven teams' communication records, again randomly selected) as Hallgren (2012) suggested. I then assessed the agreement between two coders for all types of utterances together; the yielded Cohen's kappa was .73, which was acceptable (Hallgren, 2012). In step three, coders met and resolved inconsistencies in the following way. First, they read the original communication records together and reasoned their coding. Then they aligned the coding maximally to previous coding examples of act4teams until they reached 100 percent agreement. In step four, the remaining data (43 teams' communication records) were divided into two parts, and the coders coded them separately.

Supervised Machine Learning Classifying Process. All communication records coded by human coders were then used in a supervised machine learning training process to develop a function that could classify statements into the above categories (see table 1), just like the two human coders. Supervised machine learning is a machine learning task that learns a function that classifies data or predicts outcomes based on example input-output pairs (Russel, Norvig, & Davis, 2010; see figure 4). In this study, the example input-output pairs are "utterances - human

coded types of communication statement," such as the pair "Issue #4025 has been fixed – problem-focused statement" or "thanks – positive social-emotional statement." These example pairs are also called labeled training data. The label refers to classification results. The supervised machine learning analyzes these labeled training data, and trains (i.e., produces) an inferred function, which can be used for determining the class labels for new instances (i.e., utterances; see figure 4).

Figure 4

Predicting Type of Communication Statement Through Supervised Machine Learning



In this study, all teams' communication records contained 87,441 utterances. Most utterances coded by the human coders were classified into one of the four statements: problem-focused, positive procedural, positive action-oriented, or positive social-emotional statements. Few utterances were coded as negative statements (i.e., zero negative procedural, six negative action-oriented, and four negative social-emotional utterances). Thus, there was insufficient labeled data for the machine learning process to develop a function that can classify statements into these negative communication categories. Because of this, I developed a classifier that classifies statements into four categories that had enough labeled training data: problem-focused, positive procedural, positive action-oriented, and positive social-emotional statements.

I developed this classifier with Pytorch[6] using the pre-trained BERT (Bidirectional Encoder Representations from Transformers) model. Bert was developed in 2018 by Google and is a Transformer-based machine learning model for natural language processing (NLP) applications that outperforms previous language models (e.g., recurrent neural networks) in different benchmark datasets (Devlin, Chang, Lee, & Toutanova, 2019; Vaswani et al., 2017). In this study, I used the "bert-base-uncased" version of BERT, the smaller model[7] trained on lower-cased English text. This model consists of 12 layers of Transformer encoder, 768 hidden size, and 110 M parameters. All transformer encoders are stacked together. Each Transformer encoder contains two sub-layers: a self-attention layer and a feed-forward layer.

Evaluating Machine Classifier's Performance. To evaluate the performance of this classifier, we can count on an AUC - ROC Curve (Fawcett, 2006). The AUC (Area Under the Curve) ROC (Receiver Operating Characteristics) curve can check or visualize the performance of the multi-class classification problem. It is one of the most important evaluation metrics for checking any classification model's performance. It is also written as AUROC (Area Under the Receiver Operating Characteristics). According to Hosmer and Lemeshow (2013, p. 117): "So, what area under the ROC curve describes good discrimination? Unfortunately, there is no "magic" number, only general guidelines. In general, we use the following rule of thumb: 0.5 = this suggests no discrimination, so we might as well flip a coin; 0.5-0.7 = we consider this poor discrimination, not much better than a coin toss; 0.7-0.8 = acceptable discrimination; 0.8-0.9 = Excellent discrimination; and > 0.9 = Outstanding discrimination". The evaluation of AUC also

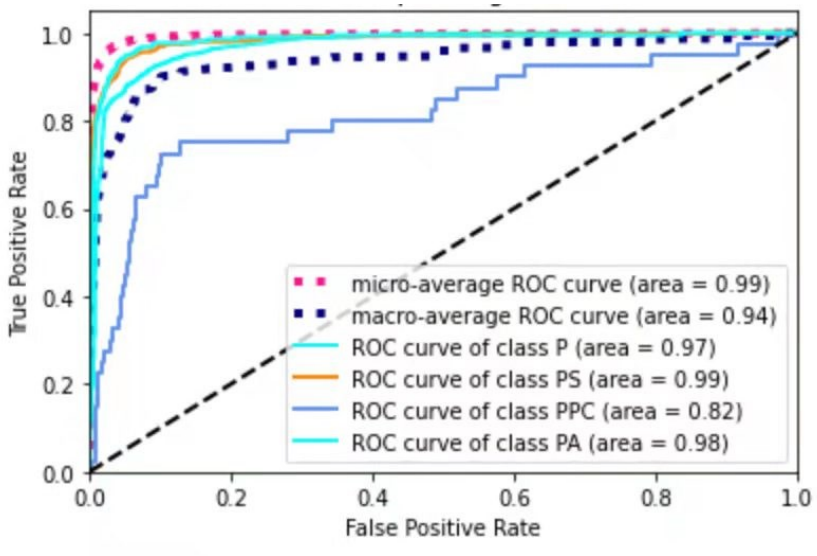
[6] An open-source machine learning framework that accelerates the path from research prototyping to production deployment. https://pytorch.org/.
[7] There are two different BERT models: 1) BERT base, which is a BERT model consists of 12 layers of Transformer encoder, 12 attention heads, 768 hidden size, and 110 M parameters; 2) BERT large, which is a BERT model consists of 24 layers of Transformer encoder, 16 attention heads, 1024 hidden size, and 340 M parameters.

depends on the context. In a medical diagnosis, very high AUCs (.95 or higher) are sought (Amaral, Lopes, Faria, & Melo, 2015). In applied psychology and predicting future behavior, with all the factors that can have an influence, AUC values of .70 and higher would be considered strong effects, such as Rice and Harris (2005).

AUCs in Figure 5 demonstrated the effectiveness of this classifier. Micro-average AUC = 0.99, macro-average AUC = 0.94; AUCs for problem-focused, positive social-emotional, positive procedural, and positive action-oriented statements were 0.97, 0.99, 0.82, and 0.98, respectively. Moreover, I checked whether human-coded and machine-coded data had different "communication content – team performance" relationships. The bootstrapping regression analyses showed similar "communication content – team performance" relationships between human-coded and machine-coded data (see Appendix 2). Thus, the remaining 47 teams' communication records were coded by this classifier.

Figure 5

Performance of the Supervised Marching Learning Classifier



Note. P = problem-focused statement, PS = positive social-emotional statement, PPC = positive procedural statement, and PA = positive action-oriented statement.

In the end, each team's communication content was then measured as the total number of each type of communication content for each month. Table 2 presents the examples of utterances from team communication records for each communication content category. A comparison of descriptive statistics for the human-coded and machine-coded communication content can be found in Appendix 2.

Table 2

Examples of Utterances for Each Communication Content Category

Communication content	Examples
Problem-focused statement	▪ However, it seems like this method has never been added to the README.md. ▪ The first error from modd is fixed by adding /to the path. ▪ This is failing on Node 8 because of the lock file issues we're having.
Positive procedural statement	▪ This will need a test. ▪ Next step would be to announce on Twitter ▪ If not, we should also prioritize #1871 so we don't accidentally ship a breaking change for Node 8
Positive action-oriented statement	▪ I'll just replace all the wiki scraping and DNS lookups with a static list ▪ tomorrow I will fix it ▪ I'll try that
Positive social-emotional statement	▪ Thanks for your pull request! ▪ Good work! ▪ I want to make sure I understand you correctly

Control Variables

OSS License Restriction. Different OSS licenses can impose different degrees of restriction on the users to redistribute software derived or modified from the OSS software (Fershtman & Gandal, 2007). According to OSS literature (Fershtman & Gandal, 2007; Gacek & Arief, 2004), there are three categories of OSS licenses with different degrees of restrictiveness. The Strong-Copyleft licenses (e.g., GNU General Public License or GPL) are the most restrictive licenses. They require that once the software is licensed by a developer, the subsequent derivative programs based on the original must also be licensed similarly. Weak-Copyleft licenses (e.g., GNU Lesser General Public License or LGPL) are moderately restrictive. They require that once a program is licensed by a developer, the subsequent programs based on the

original must also be licensed similarly. Nevertheless, the modified software can be released under a different license under certain conditions. Finally, under Non-Copyleft licenses (e.g., Berkeley Software Distribution or BSD), developers are not obligated to inherit the original license when they redistribute any derivative work.

Given that many OSS project participants prefer to retain the rights to reuse the software code in a way that best serves their objectives, they may be less interested in OSS projects with the Strong-copyleft license (Subramaniam, Sen, & Nelson, 2009). As a result, potential participants may be less likely to complete tasks of OSS projects with the Strong-copyleft license. Previous studies have also shown that restrictive OSS licenses hurt OSS team performance (Fershtman & Gandal, 2007; Stewart, Ammeter, & Maruping, 2006; Subramaniam et al., 2009). Thus, in this study, *OSS license restriction* is used as a control variable in regression models that regress virtual team performance on each communication content category. According to previous research (Subramaniam et al., 2009), *OSS license restriction* is set as a dummy variable that equals 1 when the OSS project team has a Strong-Copyleft license and 0 when OSS has a Weak-Copyleft license or Non-Copyleft license. For the licenses of OSS projects included in this study, GPL licenses were coded as 1; Apache licenses, BSD licenses, LGPL licenses, MIT licenses, MPL licenses, Eclipse Public licenses, ISC licenses, and Artistic licenses were coded as 0.

Autonomous or Firm-sponsored. According to previous literature (Ritvo et al., 2017; West & O'mahony, 2008), there are two types of OSS teams: autonomous and firm-sponsored (see Appendix 1). The autonomous OSS teams are presently independent of any firm and are community-managed. In contrast, the firm-sponsored OSS teams are where one (or more) corporate entities control the community's short- or long-term activities. Further, these two types

of teams may have different resources that influence team members' interactions and performance. For example, Poba-Nzaou and Uwizeyemungu (2019) found that OSS team members who did not earn money from their OSS projects tend to engage less in their projects and be less worried about team communication and software quality than those who were paid. Thus, the autonomous/firm-sponsored OSS team type could be a spurious cause of the relationship between team communication and team performance. In particular, OSS teams sponsored by firms might engage more with certain types of team communication because of firms' policies. At the same time, firms can enhance OSS team performance through wages. Thus, in this study, autonomous/firm-sponsored OSS team type was set as a dummy variable that equaled 1 when the OSS project team was firm-sponsored and 0 when the OSS team was autonomous.

Results

In order to examine the overall correlations among key variables, I calculated the total number of pull requests merged (task completion speed), issues reported (quality assessment), and the total number of each type of communication content for six months (i.e., January to June 2020). Table 3 presents the means, standard deviations, reliability, and correlations for these targeted variables of the 99 virtual teams. According to Shapiro-Wilk normality test results, some variable pairs were not bivariate normal (Jarek, 2015). For instance, for the pair "problem-focused statement – task completion speed," $w = 0.40$, $p < .0001$, thus the null hypothesis 'Ho: distribution of data is multivariate normal' was rejected. Thus, Spearman's and Pearson's correlation were reported. In general, four types of communication content (i.e., problem-focused, positive procedural, positive action-oriented, and positive social-emotional statements)

were positively associated with task completion speed (i.e., number of pull requests merged) and quality assessment (i.e., number of issues reported).

Table 3

Means, Standard Deviations, Reliability, and Correlations

Variable	*M*	*SD*	*Min*	*Max*	Pearson's correlation							
					1	2	3	4	5	6	7	8
1. Strong license [a]	0.04	0.20	0	1	-							
2. Firm [b]	0.79	0.41	0	1	0.00 [c]	-						
3. Problem-focused statement	764.59	1030.87	7	5124	0.18	0.22*	(0.95)[d]					
4. Positive procedural statement	2.93	6.09	0	47	-0.06	0.04	0.30**	(0.72)				
5. Positive action-oriented statement	28.59	37.27	0	223	0.06	0.21*	0.88***	0.40***	(0.92)			
6. Positive social-emotional statement	87.17	139.09	1	1097	0.03	0.13	0.81***	0.35***	0.81***	(0.95)		
7. Number of pull requests merged	87.18	175.86	0	1565	-0.06	0.19	0.44***	0.11	0.31**	0.34***	(0.98)	
8. Number of issues reported	112.98	164.59	2	1106	0.02	0.14	0.54***	0.14	0.45***	0.38***	0.60***	(0.98)

Variable	Spearman's correlation						
	1	2	3	4	5	6	7
1. Strong license [a]	-						
2. Firm [b]	0.00 [c]	-					
3. Problem-focused statement	0.04	0.29**	-				
4. Positive procedural statement	-0.07	0.22*	0.76***	-			
5. Positive action-oriented statement	-0.02	0.28**	0.92***	0.79***	-		
6. Positive social-emotional statement	0.01	0.21*	0.90***	0.72***	0.88***	-	
7. Number of pull requests merged	-0.08	0.34***	0.75***	0.60***	0.73***	0.70***	-
8. Number of issues reported	0.04	0.16	0.75***	0.49***	0.65***	0.70***	0.65***

Note. [a] Strong license: 1 = OSS project team has Strong-Copyleft license, 0 = Weak-Copyleft licenses, or non-Copyleft licenses. [b] Firm: 1 = OSS project team is firm-sponsored, 0 = autonomous. [c] Chi-squared test. [d] Reliability estimates (alpha) for six measurements are in parenthesis.

N = 99.

****p < 0.001. **p < 0.01. *p < 0.05.*

Virtual Team Communication Content and Team Performance

In order to test Hypotheses 1-4, I first conducted an overarching investigation into the role of different communication content on team performance across teams during the six-month period of this study (i.e., between-team differences during January to June 2020 overall). Next, I investigated the disruptive impact of the COVID-19 pandemic on these virtual teams' communication content and performance, looking at differences within the teams during the six-month-time period of this research. Through this latter investigation, I also assessed my hypotheses at the within-team level at three different time points (i.e., differences within the teams in January to February as the "before pandemic period," versus March to April as the "during pandemic period," versus May to June as the "after pandemic period").

To conduct these analyses, I calculated the total number of pull requests merged, issues reported, and the total number of each type of communication content for each of the six months (i.e., January to June 2020). Since the dependent variables (i.e., number of pull requests merged and number of issues reported) were count variables and overdispersed, negative binomial regression analyses were used to test Hypotheses 1- 4 (Beaujean & Morgan, 2016; Blevins, Tsang, & Spain, 2015; Kabacoff, 2011).

Also, following suggestions from previous literature (Becker, Atinc, Breaugh, Carlson, & Edwards, 2015; Carlson & Wu, 2012), I ran tests with and without the control variables and then contrasted the findings. When the standardized coefficients of the independent variables with and without control variables differed by less than 0.1, or when control variables were not

significantly related to any other variables, only the analyses without controls were discussed. All the analyses were conducted using R[8].

Problem-Focused Statements

Hypothesis 1 stated that problem-focused statements are positively related to virtual team performance, which was measured by task completion speed and quality assessment. Given that task completion speed was measured by the number of pull requests merged, I expected that the relationship between the problem-focused statement and the number of pull requests merged would be significantly positive. In addition, quality assessment is an indicator of product quality and was measured by the number of issues reported; the higher the number of issues reported, the better the product quality (Setia et al., 2012). Thus, the relationship between the problem-focused statement and the number of issues reported should be significantly positive.

Hypothesis 1 was supported. First, in Model 1 of Table 4, the coefficient for problem-focused statement was significantly positive ($\beta = 0.09$, $p < 0.001$). Figure 6 shows the negative binomial regression equation of Model 1. One-unit (i.e., 100 utterances[9]) increase in the problem-focused statements was associated with a 0.09 increase in the log mean number of pull requests merged. In other words, if the problem-focused statements increased one unit (i.e., one unit = 100 utterances), the expected number of pull requests merged would change by a factor of $e^{0.09} = 1.10$, or the expected number of pull requests merged would increase $e^{0.09} - 1 = 10\%$. After adding two control variables (see Table 4. Model 2), the effect of problem-focused statement was still significantly positive ($\beta = 0.08$, $p < 0.001$).

[8] https://www.r-project.org/about.html

[9] I used 100 utterances as one unit to make the estimated coefficient of problem-focused statement easy to read, since when using one utterance as one unit, the coefficient was too small.

Figure 6

Relationship Between Problem-Focused Statement and Task Completion Speed

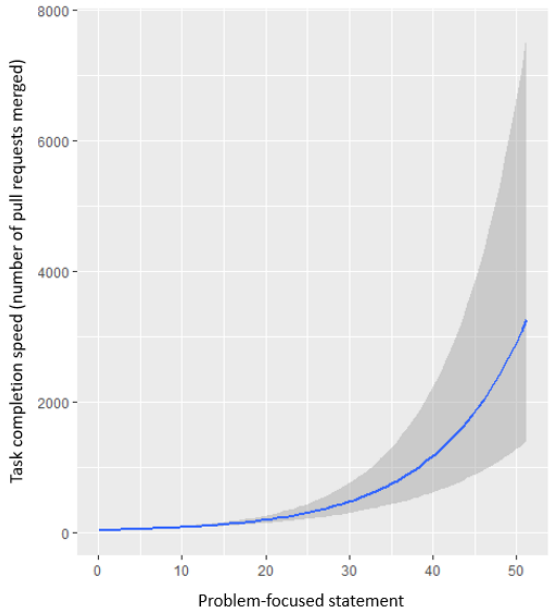


Table 4

Negative Binomial Regression Analyses to Estimate the Relationship Between Problem-Focused Statement and Virtual Team Performance

	Task completion speed (Number of pull requests merged)				Quality assessment (Number of issues reported)			
	1		2		3		4	
Variable	β	exp β	β	exp β	β	exp β	β	exp β
Intercept	3.42***	30.59	2.77 ***	16.00	3.79***	44.35	3.59***	36.25
Problem-focused statement	0.09***	1.10	0.08 ***	1.09	0.09***	1.10	0.10***	1.10
Strong license			-1.06*	0.35			0.92	2.51
Firm			0.87***	2.40			0.14	1.15

*Note. ***p < 0.001. **p < 0.01. *p < 0.05.*

Second, in Model 3 of Table 4, the coefficient of the problem-focused statement was significantly positive (β = 0.09, $p < 0.001$). One unit (i.e., 100 utterances) increase in the problem-focused statement was associated with a 0.09 increase in the log mean number of issues reported. In other words, if problem-focused statement increased one unit (i.e., 100 utterances),

the expected number of issues reported would change by a factor of $e^{0.09} = 1.10$, or the expected number of issues reported would increase $e^{0.09} - 1 = 10\%$.

Positive Procedural Statements

Hypothesis 2 posited that positive procedural statements would be positively related to virtual team performance. In Table 5, Model 1, the coefficient of the positive procedural statement when predicting task completion speed was significantly positive ($\beta = 8.19$, $p < 0.001$). A one-unit (i.e., 100 utterances[10]) increase in the positive procedural statements was associated with an 8.19 increase in the log mean number of pull requests merged. In other words, if the positive procedural statements increased one unit (i.e., one unit = 100 utterances), the expected number of pull requests merged would change by a factor of $e^{8.19} = 3{,}615.50$. The coefficient was still significantly positive after adding two control variables (see Table 5, Model 2; $\beta = 5.72$, $p < 0.01$). Similarly, the relationships between positive procedural statements and quality assessment were significantly positive, too ($\beta = 5.38$, $p < 0.001$; see Table 5, Model 3). The coefficient was still significantly positive after adding two control variables (see Table 5, Model 4; $\beta = 5.23$, $p < 0.01$). Hence, Hypothesis 2 was supported.

[10] I used 100 utterances as one unit to make the estimated coefficient of problem-focused statement easy to read, since when using one utterance as one unit, the coefficient was too small.

Table 5

Negative Binomial Regression Analyses to Estimate the Relationship Between Positive Procedural Statement and Virtual Team Performance

	Task completion speed (Number of pull requests merged)				Quality assessment (Number of issues reported)			
	1		2		3		4	
Variable	β	exp β	β	exp β	β	exp β	β	exp β
Intercept	4.18***	65.69	2.98***	19.73	4.54***	94.05	4.00***	54.77
Positive procedural statement	8.19***	3615.50	5.72**	305.14	5.38***	217.78	5.23**	187.36
Strong license			-0.94	0.39			0.30	1.35
Firm			1.46***	4.32			0.65*	1.91

*Note. ***$p < 0.001$. **$p < 0.01$. *$p < 0.05$.*

Positive Action-oriented Statements

Hypothesis 3 proposed that positive action-oriented statements positively related to virtual team performance. In Table 6, Model 1, the coefficient of the positive action-oriented statement when predicting task completion speed was significantly positive ($\beta = 2.98$, $p < 0.001$). The coefficient was still significantly positive after adding two control variables (see Table 6, Model 2; $\beta = 2.45$, $p < 0.001$). Similarly, the relationships between positive action-oriented statements and quality assessment were significantly positive, too ($\beta = 2.25$, $p < 0.001$; see Table 6, Model 3). The coefficient was still significantly positive after adding two control variables (see Table 6, Model 4; $\beta = 2.39$, $p < 0.001$). Hypothesis 3 was therefore supported.

Table 6

Negative Binomial Regression Analyses to Estimate the Relationship Between Positive Action-oriented Statement and Virtual Team Performance

	Task completion speed (Number of pull requests merged)				Quality assessment (Number of issues reported)			
	1		2		3		4	
Variable	β	exp β	β	exp β	β	exp β	β	exp β
Intercept	3.34***	28.08	2.72***	15.16	3.91***	49.77	3.63***	37.86
Positive action-oriented statement	2.98***	19.64	2.45***	11.8	2.25***	9.50	2.39***	10.92
Strong license			-0.86	0.42			0.91	2.48
Firm			0.92***	2.52			0.25	1.28

Note. ***$p < 0.001$. **$p < 0.01$. *$p < 0.05$.

Positive Social-Emotional Statements

Hypothesis 4 proposed that positive social-emotional statements would be positively related to virtual team performance. In Table 7, Model 1, the coefficient of the positive social-emotional statement when predicting task completion speed was significantly positive ($\beta = 0.78$, $p < 0.001$). The coefficient was still significantly positive after adding two control variables (see Table 7, Model 2; $\beta = 0.66$, $p < 0.001$). Similarly, the relationships between positive social-emotional statements and quality assessment were significantly positive, too ($\beta = 0.69$, $p < 0.001$; see Table 7, Model 3). The coefficient was still significantly positive after adding two control variables (see Table 7, Model 4; $\beta = 0.72$, $p < 0.001$). Hypothesis 4 was therefore supported.

Table 7

Negative Binomial Regression Analyses to Estimate the Relationship Between Positive Social-emotional Statement and Virtual Team Performance

	Task completion speed (Number of pull requests merged)				Quality assessment (Number of issues reported)			
	1		2		3		4	
Variable	β	exp β	β	exp β	β	exp β	β	exp β
Intercept	3.56***	35.06	2.66***	14.25	3.96***	52.43	3.55***	34.81
Positive social-emotional statement	0.78***	2.17	0.66***	1.94	0.69***	1.99	0.72***	2.05
Strong license			-0.89	0.41			0.74	2.10
Firm			1.18***	3.25			0.44	1.55

*Note. ***p < 0.001. **p < 0.01. *p < 0.05.*

Impacts of the COVID-19 Pandemic

Virtual Team Communication Content Before, During, and After the Pandemic

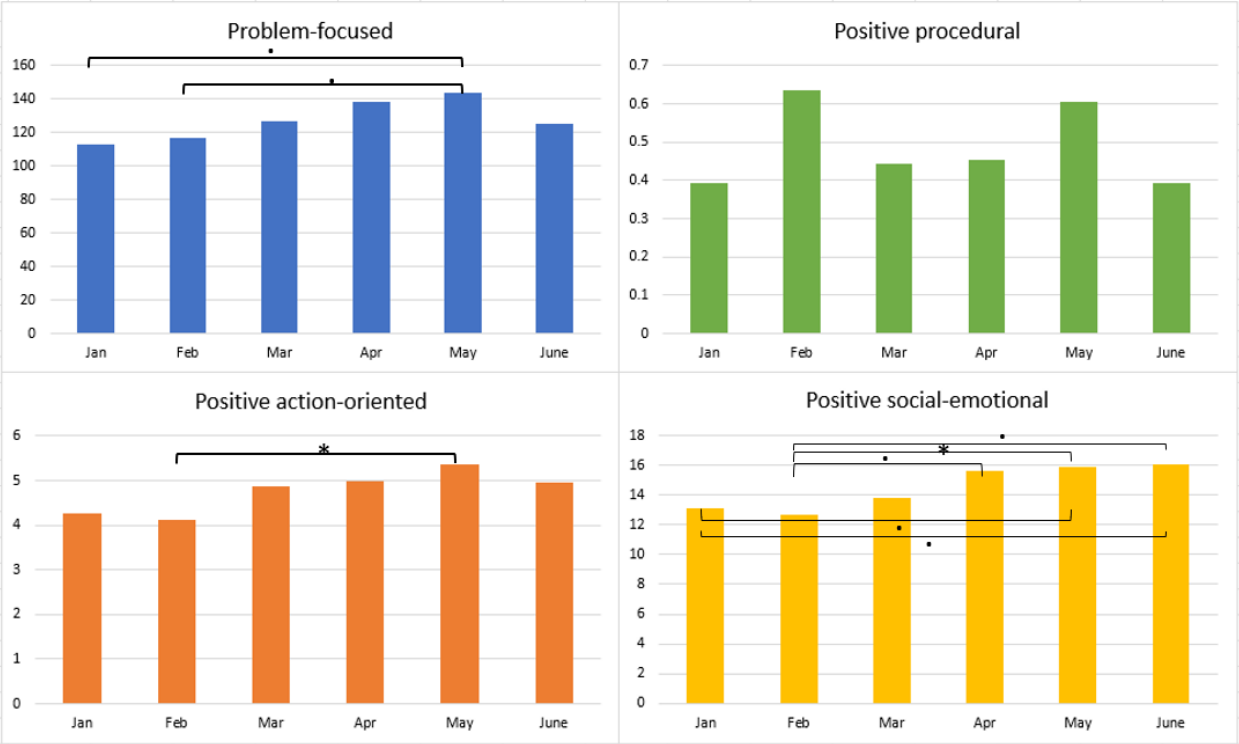
Next, I investigated my research questions about the impact of disruption occurring due to the COVID-19 pandemic, looking at differences within teams during the six-month-time period of this research. As alluded to above, this investigation confirms and extends the overarching view of looking at differences between teams during this time period for Hypotheses 1-4.

Research question 1 asked how virtual team communication content changed before, during, and after the pandemic. Figure 7 shows virtual teams' number of problem-focused communication from January to May. Paired *t*-tests did not show significant differences. Nonetheless, the number of problem-focused communication was marginally significantly smaller in January than in May ($t = -1.82$, $p = 0.072$), and marginally significantly smaller in

February than in May (t = -1.84, p = 0.068). Regarding virtual teams' positive procedural communication, paired t-tests showed that the differences between months were not significant.

Figure 7

Virtual Team Communication Content from January to June 2020



Note. $^{*}p < 0.05$. $^{\cdot}p < 0.1$.

Regarding virtual teams' positive action-oriented communication, paired t-tests demonstrated that the number of positive action-oriented communication was smaller in February than in May (t = -2.05, p = 0.043). Other pairs did not show significant differences. Finally, the number of positive social-emotional communication hit a low point in February, then increased slowly from February to June. Paired t-test demonstrated that the number of positive social-emotional communication in February was smaller than in May (t = -2.13, p = 0.036). Other pairs did not show significant differences, although the number of positive social-

emotional communication in February was marginally significantly smaller than in April (t = -1.69, p = 0.093) and than in June (t = -1.72, p = 0.088). The number of positive social-emotional communication in January was marginally smaller than in May (t = -1.74, p = 0.084), and smaller than in June (t = -1.79, p = 0.077).

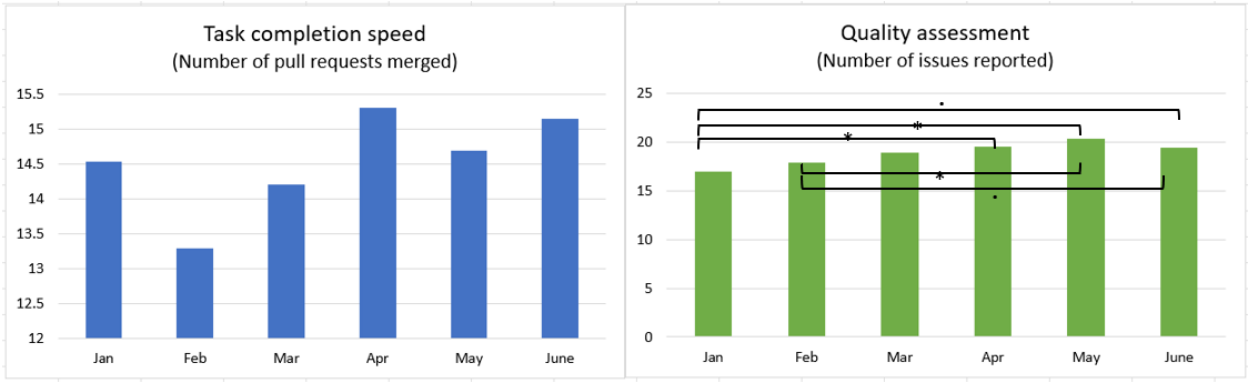
In general, virtual teams' number of problem-focused, positive action-oriented, and positive social-emotional communication hit a low point in February, then increased slowly in the following months. However, the number of positive procedural statements did not show significant changes between months. This finding could indicate that virtual teams were trying to adapt to the disruption of the COVID-19 pandemic by changing their team communication content.

Virtual Team Performance Before, During, and After the Pandemic

Research question 2 asked how virtual team performance changed before, during, and after the pandemic. Figure 8 shows that virtual teams' task completion speed hit a low point in February and peaked in April. However, paired *t*-test demonstrated that differences between months were not significant. Regarding quality assessment, its number increased slightly from January to May, then decreased in June. Paired *t*-tests showed that the number of issues reported in January was smaller than in April (t = -2.01, p = 0.047), May (t = -2.51, p = 0.014), and June (t = -1.84, p = 0.069). Moreover, the number of issues reported in February was smaller than in May (t = -2.19, p = 0.031), and June (t = -1.80, p = 0.075). In general, virtual teams' task completion speed did not change significantly during the pandemic. However, virtual teams' quality assessment decreased at the beginning of the pandemic and gradually recovered in the following months.

Figure 8

Virtual Team Performance from January to June 2020



Note. $^{*}p < 0.05$. $^{\cdot}p < 0.1$.

Relationships Between Team Communication Content and Performance

My third research question asked how the COVID-19 pandemic influenced the relationships between team communication content and performance. To test for such an influence, I built the zero-inflated negative binomial mixed model and negative binomial mixed model with time as a moderator (Blevins et al., 2015; Gill & Torres, 2020; Luke, 2020a). These models can examine the relationship between communication content and team performance while accounting for the fact that multiple observations were nested in each unit (i.e., team) and those dependent variables (i.e., number of pull requests merged and number of issues reported of each month) were count variables, overdispersed, and sometimes zero-inflated. These analyses were conducted using the R-package "glmmTMB" (Brooks et al., 2022, 2017).

Before the analyses, predictors were centered. All between-team predictors were grand-mean centered, whereas the within-team predictors were centered within the team (Enders & Tofighi, 2007). Moreover, intraclass correlation coefficients (ICCs) were computed based on an unconditional random coefficient model (Bliese, 2000). The ICC value for the dependent

variable in the number of pull requests merged was 0.81, in the number of issues reported was 0.90, indicating plenty of the variance can be explained by the model's grouping structure (random effects). Thus, these analyses needed to consider the multilevel data structure (Bliese, 2000).

Model Selection Process

Taking a bottom-up approach, I built a series of negative binomial and zero-inflated negative binomial mixed models (i.e., from simple to complex) and compared their fit to find the best model (Field, Miles, & Field, 2012; Hox, Moerbeek, & Schoot, 2017; Luke, 2020b). I chose negative binomial models since dependent variables (i.e., number of pull requests merged and number of issues reported each month) were count variables and overdispersed (Blevins et al., 2015). I also compared the fitness of negative binomial and zero-inflated negative binomial mixed models because these dependent variables sometimes were zero-inflated (Brooks et al., 2017; Desmarais & Harden, 2013; Wilson, 2015).

In order to explain the model building and selection process, I used the "task completion speed (i.e., number of pull requests merged) ~ problem-focused statement" pair as an example (see Table 8). Models of other variable pairs were built with similar steps. First, a total unconditional negative binomial Mixed model (Model 1) was built. The ICC value for the dependent variable in the number of pull requests merged was 0.81. Thus, the multilevel data structure needed to be taken into account in analyses. Second, in Model 2, problem-focused statement was added as a Level 1 predictor. Then, in Model 3, the problem-focused statement was added as a random term, which allowed the effect of the problem-focused statement to vary across teams. In Model 4, the control variable, firm, was added. In Model 5, another control variable, strong license, was added.

Then, since there were more than 10% zeros in the number of pull requests merged every month, I also built a series of zero-inflated negative binomial mixed models that were similar to the models above (see Table 8, Models 6 to 10). To compare fitness and find the best model, I used the information criteria, AIC and BIC, instead of the classical likelihood-ratio test or Vuong test, according to previous literature (Brooks et al., 2017; Desmarais & Harden, 2013; Wilson, 2015). As demonstrated in Table 8, the AIC and BIC of Model 10 were the smallest. Thus, Model 10 was the best. It was a zero-inflated negative binomial mixed model.

Table 8

Comparing Generalized Mixed Models of Relations Between Problem-Focused Statement and Number of Pull Requests Merged

Model	Type	Regression equation	df	AIC	BIC
1	NB	NPM ~ 1 + (1 | team)	3	3680.5	3693.7
2	NB	NPM ~ PROB+ (1 | team)	4	3565.9	3583.4
3	NB	NPM ~ PROB+ (1 + PROB| team)	6	3533.9	3560.2
4	NB	NPM ~ PROB+ firm + (1 + PROB| team)	7	3524.7	3555.4
5	NB	NPM ~ PROB+ firm + strong license + (1 + PROB| team)	8	3426.3	3461.2
6	ZINB	NPM~1 + (1| team), zi=~PROB,	5	3679.8	3701.7
7	ZINB	NPM~ PROB+ (1| team), zi=~PROB	6	3564.2	3590.5
8	ZINB	NPM~PROB + (1+ PROB| team), zi=~PROB	8	3524.0	3559.1
9	ZINB	NPM~PROB+firm+ (1+ PROB| team)	9	3513.9	3553.4
10	**ZINB**	**NPM~PROB+firm+ strong license + (1+ PROB| team), zi=~PROB,**	**10**	**3414.2**	**3457.8**

Note. NB = negative binomial mixed model; ZINB = zero-inflated negative binomial Mixed model; NPM = number of pull requests merged; PROB = problem-focused statement.

Zi was used in zero-inflated models. It described how the probability of an extra zero (i.e., structural zero) would vary with predictors. Zi = ~ PROB meant that zeros varied by PROB (problem-focused statement).

Interaction Between Virtual Team Communication Content and Covid-19 Pandemic

According to previous literature, the pandemic started to impact software developing virtual teams around mid- to late February 2020 (Forsgren, 2020). Then, these teams gradually adapted to the new situation in the following one or two months (Ford et al., 2022). In order to investigate the changes in the relationship between virtual team communication content and performance before, during, and after the pandemic, I treated the data from January to February as the "before pandemic period," the data from March to April as the "during pandemic period," and the data from May to Jun as the "after pandemic period" (also see Figure 2).

Problem-Focused Statement. The Model 10 results presented in Table 9 showed that the problem-focused statement ($\beta = 0.60$, $p < 0.001$), firm ($\beta = 1.02$, $p < 0.001$), and strong license ($\beta = -1.07$, $p < 0.05$) were positively associated with number of pull requests merged. This result suggested that, for each virtual team, its task completion speed would be higher if it engaged in more problem-focused communication. Thus, similar to my earlier investigation of the relationship between problem-focused communication and team performance between teams, I found further support for Hypothesis 1 in that this hypothesis was also supported at the within-team level.

Table 9

Problem-Focused Statement and Task Completion Speed (Number of Pull Requests Merged)

	Model 4			Model 2 Jan-Feb vs Mar-Apr			Model 3 Mar-Apr vs May-Jun		
Random effects									
Team	Variance	SD	Corr	Variance	SD	Corr	Variance	SD	Corr
Intercept	1.56	1.25		1.61	1.27		1.53	1.24	
PROB	0.10	0.32	-0.84	0.12	0.34	-0.88	0.04	0.19	-0.81
Conditional model									
	Estimate	SE	*p*	Estimate	SE	*p*	Estimate	SE	*p*
Intercept	1.72***	0.13	0.000	1.73***	0.14	0.000	1.78***	0.14	0.000
Level 1									
PROB	0.60***	0.07	0.000	0.63***	0.10	0.000	0.48***	0.07	0.000
P1 [a]				-0.11	0.06	0.087			
PROB *P1 [a]				-0.03	0.09	0.732			
P2 [b]							-0.04	0.06	0.538
PROB *P2 [b]							-0.02	0.09	0.815
Level 2									
Firm	1.02***	0.28	0.000	1.14***	0.32	0.000	1.01**	0.30	0.001
Strong license	-1.07*	0.48	0.026	-1.29*	0.57	0.024	-1.00	0.5	0.066
Zero-inflation model									
	Estimate	SE	*p*	Estimate	SE	*p*	Estimate	SE	*p*
Intercept	-5.23***	1.04	0.000	-20.53	2570.73	0.994	-4.85***	1.06	0.000
PROB	0.64	0.39	0.104	-0.24	1798.37	1.000	0.66	0.42	0.114

Note. PROB = problem-focused statement. [a] P1 is a dummy variable for time, 1= January to February, 0 = March to April. [b] P2 is a dummy variable for time, 1 = March to April, 0 = May to June.

****p* < 0.001. ***p* < 0.01. **p* < 0.05.*

In order to examine the effect of the COVID-19 pandemic (Research Question 3), I first compared the before and during the pandemic periods. I selected data from January to April, and then set a dummy variable P1 for time (P1 = 1 when time = January to February; P1 = 0 when time = March to April). After that, an interaction term "P1*Problem-focused statement" was added to the model to compare the impacts of problem-focused statements in different periods

(i.e., Jan-Feb vs. Mar-Apr). The coefficient for the interaction term was not significant, $\beta_{(P1*PROB)} = -0.03$, $p = 0.732$ (see Table 9, Model 2), which indicated the relationship between problem-focused statement and team task completion speed was not significantly different between January-February and March-April. Thus, the pandemic did not significantly influence the impact of problem-focused communication content on virtual team task completion speed.

In addition, I compared the during and after the pandemic periods. I selected data from March to June, and set another dummy variable P2 for time (P2 = 1 when time = March to April; P1 = 0 when time = May to June). After that, another interaction term, "P2*Problem-focused statement," was added to the model to compare the impacts of problem-focused statements in different periods (i.e., Mar-Apr vs. May-Jun). The coefficient for the interaction term was not significant, $\beta_{(P2*PROB)} = -0.02$, $p = 0.815$, which indicated that the relationship between problem-focused statement and team task completion speed was also not significantly different between March-Apr and May-June. Thus, these results suggest that the pandemic did not have a moderating effect on the relationship between problem-focused statements and team task completion speed.

Negative binomial generalized mixed models for the relation between problem-focused statements and the quality assessment (i.e., number of issues reported) were built and selected using the same approach discussed above. I did not build zero-inflated models since zeros in the number of issues reported every month were fewer than 10%. The best model (see Table 10, Model 1) showed that the problem-focused statement ($\beta = 0.13$, $p < 0.001$) was positively associated with the number of issues reported. This result suggested that, for each virtual team, its quality assessment would be higher if it engaged more in problem-focused communication. Thus, Hypothesis 1 was supported also at the within-team level.

Table 10

Problem-Focused Statement and Quality Assessment (Number of Issues Reported)

	Model 1			Model 2 Jan-Feb vs Mar-Apr			Model 3 Mar-Apr vs May-Jun		
Random effects									
Team	Variance	*SD*		Variance	*SD*		Variance	*SD*	
Intercept	1.70	1.30		1.69	1.30				
Conditional model									
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	2.16***	0.14	0.000	2.17***	0.14	0.000	2.19***	0.14	0.000
Level 1									
PROB	0.13***	0.02	0.000	0.13**	0.05	0.006	0.11***	0.03	0.000
P1 [a]				-0.07	0.04	0.094			
PROB *P1 [a]				-0.02	0.07	0.800			
P2 [b]							-0.03	0.03	0.460
PROB *P2 [b]							-0.05	0.05	0.315

Note. PROB = problem-focused statement. [a] P1 is a dummy variable for time, 1= January to February, 0 = March to April. [b] P2 is a dummy variable for time, 1 = March to April, 0 = May to June.

****p* < 0.001. ***p* < 0.01. **p* < 0.05.*

I also compared the impacts of problem-focused statements on quality assessment (i.e., number of issues reported) in different periods (i.e., Jan-Feb vs. Mar-Apr; and Mar-Apr vs. May-Jun), using the same approach described above. However, no significant difference was found between these periods: $\beta_{(P1*\ PROB)} = -0.02$, $p = 0.800$, $\beta_{(P2*\ PROB)} = -0.05$, $p = 0.315$. Thus, I did not find a significant interaction effect of the pandemic on the relationship between problem-focused statements and quality assessment.

Positive Procedural Statement. The negative binomial generalized mixed model (see Table 11, Model 1) showed that positive procedural statement ($\beta = 9.54$, $p < 0.001$) and firm ($\beta =$

1.10, $p < 0.001$) were positively associated with number of pull requests merged. This result suggested that a virtual team's task completion speed would be higher if it engaged in more positive procedural communication. Thus, looking at within-team effects, Hypothesis 2 was further supported.

Research question 3 indicated that there may be a moderating effect of the pandemic on the relationship between positive procedural statement and team completion speed. Results showed that the relationship was different in March-April than in January-February, $\beta_{(P1*\ PROCE)} = 16.39$, $p = 0.015$ (see Table 11, Model 2). This result suggested a negative impact of the pandemic since the relation between positive procedural statement and the number of pull requests merged decreased after February 2020. I also compared the impacts of positive procedural statement on task completion speed in Mar-Apr and May-Jun. However, no significant difference was found between these latter periods ($\beta_{(P2*\ PROCE)} = -9.50$, $p = 0.175$).

Table 11

Positive Procedural Statement and Task Completion Speed (Number of Pull Requests Merged)

	Model 1			Model 2 Jan-Feb vs Mar-Apr			Model 3 Mar-Apr vs May-Jun		
Random effects									
Team	Variance	*SD*		Variance	*SD*		Variance	*SD*	
Intercept	1.54	1.24		1.53	1.23		1.54	1.24	
Conditional model									
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	1.78***	0.13	0.000	1.81***	0.14	0.000	1.84***	0.14	0.000
Level 1									
PROCE	9.54***	2.36	0.000	-0.27	4.50	0.952	10.62*	4.81	0.027
P1 [a]				-0.19**	0.07	0.008			
PROCE *P1 [a]				16.39*	6.74	0.015			
P2 [b]							-0.04	0.07	0.61
PROCE *P2 [b]							-9.50	7.00	0.175
Level 2									
Firm	1.10***	0.32	0.000	1.17***	0.32	0.000	1.10***	0.33	0.000
Strong license	-0.46	0.66	0.491	-0.84	0.68	0.216	-0.39	0.67	0.561

Note. PROCE = positive procedural statement. [a] P1 is a dummy variable for time, 1= January to February, 0 = March to April. [b] P2 is a dummy variable for time, 1 = March to April, 0 = May to June.

****p* < 0.001. ***p* < 0.01. **p* < 0.05.*

Positive procedural statement (β = 10.70, $p = 0.001$) was positively associated with the number of issues reported (quality assessment, see Table 12, Model 1). This result suggested that a virtual team's quality assessment would be higher if it engaged more in positive procedural communication. Thus, Hypothesis 3 was also supported when looking at within-team effects.

The relationship between positive procedural statement and quality assessment was not significantly different between March-Apr and January-February, $\beta_{(P1*\ PROCE)} = 4.44$, $p = 0.250$

(see Table 12, Model 2). However, the relationship was stronger in May-Jun than in March-Apr, $\beta_{(P2*\ PROCE)} = -9.32$, $p = 0.025$ (see Table 12, Model 3). As per Research question 3, this result indicated a negative, moderating impact of the pandemic because the relation between positive procedural statement and the number of issues reported increased after Apr 2020.

Table 12

Positive Procedural Statement and Quality Assessment (Number of Issues Reported)

	Model 1			Model 2 Jan-Feb vs Mar-Apr			Model 3 Mar-Apr vs May-Jun		
Random effects									
Team	Variance	*SD*	*Corr*	Variance	*SD*	*Corr*	Variance	*SD*	*Corr*
Intercept	1.70	1.30		1.69	1.30		1.75	1.32	
PROCE	85.43	9.24	-0.78	16.57	4.07	-1.00	48.35	6.96	-0.56
Conditional model									
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	2.16***	0.14	0.000	2.18***	0.14	0.000	2.19***	0.14	0.000
Level 1									
PROCE	10.70**	3.37	0.001	3.53	3.86	0.361	11.30**	3.80	0.003
P1 [a]				-0.10*	0.05	0.031			
PROCE *P1 [a]				4.44	3.8	0.250			
P2 [b]							-0.03	0.04	0.393
PROCE *P2 [b]							-9.32*	4.15	0.025

Note. PROCE = positive procedural statement. [a] P1 is a dummy variable for time, 1= January to February, 0 = March to April. [b] P2 is a dummy variable for time, 1= March to Apr, 0 = May to Jun.

****p* < 0.001. ***p* < 0.01. **p* < 0.05.*

Positive Action-oriented Statement. The negative binomial generalized mixed model (see Table 13, Model 1) showed that positive action-oriented statement ($\beta = 12.56$, $p < 0.001$) and firm ($\beta = 0.87$, $p = 0.002$) were positively associated with number of pull requests merged. This result suggested that a virtual team's task completion speed would be higher if it engaged in

more positive action-oriented communication. Thus, this test of within-team differences offered further support for Hypothesis 3.

However, the impacts of positive action-oriented statement on task completion speed were not different between these periods, i.e., Jan-Feb vs. Mar-Apr; and Mar-Apr vs. May-Jun. Thus, as per Research question 3, the relation between positive action-oriented statement and task completion speed was stable over time.

Positive action-oriented statement ($\beta = 2.18$, $p < 0.001$) was positively associated with number of issues reported (see Table 13, Model 2). This result suggested that a virtual team's quality assessment would be higher if it engaged in more positive action-oriented communication. Thus, Hypothesis 3 was supported looking within-teams.

The impacts of positive action-oriented statement were not different between Jan-Feb and Mar-Apr, Mar-Apr and May-Jun. Thus, the relationship between positive action-oriented statement and quality assessment was stable over time, suggesting there was no significant interaction effect as per Research question 3.

Table 13

Positive Action-Oriented Statement, Task Completion Speed, And Quality Assessment

	Model 1 Task Completion Speed (Number of pull requests merged)			Model 2 Quality Assessment (Number of issues reported)		
Random effects						
Team	Variance	*SD*	*Corr*	Variance	*SD*	
Intercept	1.62	1.27		1.70	1.30	
PACT	59.61	7.72	-0.89			
Conditional model						
	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept	1.72***	0.13	0.000	2.16***	0.14	0.000
Level 1						
PACT	12.56***	1.59	0.000	2.18***	0.43	0.000
Level 2						
Firm	0.87**	0.28	0.002			
Strong license	-0.77	0.53	0.147			

Note. PACT = positive action-oriented statement.

****p* < 0.001. ***p* < 0.01.

Positive Social-Emotional Statement. Positive social-emotional statement (β = 6.20, $p < 0.001$) and firm (β = 1.05, $p < 0.001$) were positively associated with number of pull requests merged (see Table 14, Model 1). This result suggested that a virtual team's task completion speed would be higher if it engaged in more positive social-emotional communication. Thus, Hypothesis 4 was also supported when looking at within-team effects.

To answer Research question 3, I also compared the impacts of positive social-emotional statements on task completion speed (i.e., number of pull requests merged) in different periods (i.e., Jan-Feb vs. Mar-Apr; and Mar-Apr vs. May-Jun). However, no significant difference was found between these periods.

Positive social-emotional statement (β = 0.95, $p < 0.001$) was positively associated with number of issues reported (see Table 14, Model 2). This result suggested that a virtual team's quality assessment would be higher if it engaged in more positive social-emotional communication. Thus, this lends further support to Hypothesis 4 (within-teams). Again, however, the impacts of positive social-emotional statement were not different between periods (i.e., Jan-Feb vs. Mar-Apr; and Mar-Apr vs. May-Jun), suggesting the pandemic did not serve as a moderator for this relationship between positive social-emotional statement and quality assessment.

Table 14

Positive Social-Emotional Statement, Task Completion Speed, And Quality Assessment

	Model 1 Task Completion Speed (Number of pull requests merged)			Model 2 Quality Assessment (Number of issues reported)		
Random effects						
Team	Variance	SD	Corr	Variance	SD	
Intercept	1.59	1.26		1.70	1.30	
PSE	15.17	3.90	-0.84			
Conditional model						
	Estimate	SE	*p*	Estimate	SE	*p*
Intercept	1.69***	0.13	0.000	2.16***	0.14	0.000
Level 1						
PSE	6.20***	0.67	0.000	0.95***	0.16	0.000
Level 2						
Firm	1.05***	0.26	0.000			
Strong license	-0.59	0.48	0.213			
Zero-inflation model						
	Estimate	SE	*p*			
Intercept	-4.81***	0.83	0.000			
PSE	0.73	4.73	0.877			

Note. PSE = positive social-emotional statement.

****p < 0.001. **p < 0.01. *p < 0.05.*

Discussion

This empirical study aimed to investigate the impact of team communication content (i.e., problem-focused, procedural, action-oriented, and social-emotional statements) on virtual team performance. Based on the TIP theory (McGrath, 1991), I developed hypotheses regarding the relationships between these types of virtual team communication content and virtual team performance. To test these hypotheses, I used a sample of 99 virtual teams during the first six months of 2020. Moreover, given that the COVID-19 pandemic happened during this period and may have significantly influenced virtual teams, I also investigated how virtual teams' communication content, performance, and their relationship changed during the pandemic. In the following section, I summarize and elaborate on the results. Then, theoretical, practical contributions, limitations, and future research directions are discussed in the end.

Summary of Results

The results demonstrate that four types of team communication content (i.e., problem-focused, positive procedural, positive action-oriented, and positive social-emotional communication) can facilitate virtual team performance. The between- and the within-team effects of positive team communication content on virtual team performance were both significantly positive. In other words, if a virtual team engaged in more problem-focused and positive communication content than other virtual teams, it would perform better in terms of increased quality and task completion speed. At the same time, if a virtual team engaged in more problem-focused and positive communication content than before, it would also perform better. This finding supports the TIP theory (McGrath, 1991) that task-oriented and social-emotional activities can facilitate team performance. While this finding is consistent with previous research examining the effect of problem-focused communication on virtual team performance (e.g.,

Bradley et al., 2013; Curtis et al., 2017; Espinosa et al., 2015), it further reveals that the other three types of team communication content (i.e., positive procedural, positive action-oriented, and positive social-emotional communication) also positively impact virtual team performance. Therefore, this research both replicates and extends the current literature on communication content for virtual teams' performance.

Moreover, the results demonstrate that virtual teams' communication content, performance, and their relationships changed during the pandemic. Virtual teams' number of problem-focused, positive action-oriented, and positive social-emotional communication hit a low point in February, then increased slowly in the following months. In contrast, although the number of positive procedural statements did not show significant changes between months, it might suggest a change pattern different from other types of communication content: it peaked in February, decreased in the following months, and hit a second peak in May. Overall, this finding might reveal an adapting process of virtual teams during the disruption of the pandemic. At the beginning of the pandemic, virtual team members reduced communication contents that solved task-related problems, expressed willingness to take action to improve work, and communication that maintained team relationships. However, at the same time, they seemed to engage in more positive procedural communication that highlighted team goals, discussed further courses of action, and managed time. In the following months, virtual teams gradually adapted to the new situations; consequently, they engaged in communication that facilitated task completion and built good team relationships again.

Regarding virtual teams' performance, team task completion speed did not change significantly during the pandemic. Meanwhile, although virtual teams' quality assessment decreased at the beginning of the pandemic, it gradually recovered in the following months. This

finding is reasonable given that virtual teams may have adjusted their communication content to adapt to the disruption of the pandemic. This finding is also consistent with a previous longitudinal study by Ford et al. (2020), which found that software developers were less productive at the beginning of the pandemic, but the percentage of developers being less productive consistently dropped from March 2020 to May 2020.

In terms of the relationship between virtual team communication content and performance, the pandemic did not significantly influence the impact of problem-focused, positive action-oriented, and positive social-emotional communication content on virtual team task completion speed. In other words, the relations between these types of communication content and virtual team performance were stable over time. However, the relationship between positive procedural communication and virtual team performance did change during the pandemic. The results demonstrate that the relationship between positive procedural communication and team completion speed was weaker during the pandemic than before the pandemic. Also, the relationship between positive procedural communication and quality assessment was weaker during the pandemic than after the pandemic. This finding suggests that the COVID-19 pandemic may have negatively impacted the effect of positive procedural communication on virtual team performance, which supports the TIP theory. According to the TIP theory (McGrath, 1991), because of the COVID-19 pandemic, teams' external environment changed substantially. In order to implement the production function, teams must engage in extra positive procedural communication to solve new-arising problems or conflicts, such as questioning team members about further course of action and weighing the costs and benefits of possible solutions. Because the extra procedural communication was meant to solve the new-arising issues, but did not directly perform team tasks immediately, the relationship between

positive procedural communication and performance became weaker at the beginning of the pandemic. However, these extra communicative activities can help teams gradually adapt to the new working mode, overcome difficulties in the pandemic, and contribute to long-run team performance (McGrath, 1991). Thus, after overcoming the initial shock of the disruption from COVID-19, virtual teams could perform tasks well by engaging in the default simplest positive procedural communication again, such as communication that highlights team goals, manages time, distributes tasks, and summarizes what has been reached. Thus, the relationship between positive procedural communication and performance became stronger after the pandemic.

Theoretical and Practical Contributions

Despite consistent findings across many studies that problem-focused statements can significantly impact virtual team performance (e.g., Bradley et al., 2013; Curtis et al., 2017; Espinosa et al., 2015), research has not systematically examined how other types of team communication content influences virtual team performance. The results of this study enrich our knowledge about the effects of different team communication contents on virtual team performance, which is increasingly important for organizations today. This research also contributes to the literature on virtual team management under a disruptive external environment. Previous research has focused mainly on individuals' performance changes during the pandemic (e.g., Feitosa & Salas, 2020; Ford et al., 2022; Ralph et al., 2020; Russo, Hanel, Altnickel, & van Berkel, 2021). Results of this study reveal how virtual teams deal with external environmental challenges by engaging in different communication behaviors, extending the literature on virtual working during times of disruption (i.e., the pandemic).

Moreover, at first glance, the results of this study seem to suggest that there are no appreciable differences among certain types of communication content (i.e., problem-focused,

positive procedural, positive action-oriented, and positive social-emotional communication), given that they all positively impact virtual team performance. However, during the COVID-19 pandemic, the fluctuations of virtual team communication content and their impacts on virtual team performance reveal that these various communication content types indeed play a different role for virtual teams and deserve further attention by scholars moving forward. In particular, it is important to recognize that these results emerged in virtual teams consisting of team members who were used to working virtually, well before the pandemic. Hence, it is possible that these different communication contents may have even more meaningful and diverse effects for teams with less virtual working experience.

As elaborated above, the present study suggests that using TIP theory (McGrath, 1991) as a framework for investigating the impacts of virtual team communication content could be fruitful. For example, in line with this theory, it is also possible that certain combinations of communication content are particularly important for virtual teams, depending on their task and context. For mature virtual teams to complete routine tasks, frequent action-oriented communication that plans actions may be sufficient for them to perform well. However, when facing new challenging tasks, problem-focused communication may be more important than other types of communication for them to solve technical problems. In contrast, when unfamiliar virtual team members complete new tasks together, they may need both problem-focused and positive social-emotional communication to perform well. Although problem-focused communication facilitates problem-solving, it is positive social-emotional communication that helps unfamiliar members develop trust, enabling team members to depend on each other to reach the team's collective goal (Greenberg et al., 2007). Apart from virtual team performance, the TIP theory (McGrath, 1991) also suggests that various types of team communication content

are related to other virtual team outcomes, such as team trust, satisfaction, and learning. Thus, this study demonstrates that the TIP theory can be a useful framework for future virtual team communication content research.

In addition, it is always challenging to measure and analyze communication content. Following calls from previous studies, I measured virtual team communication content via textual analyses of actual communication records. This approach can reveal how language use and naturally occurring interactions within virtual teams affect team performance. These findings can be used to corroborate previous work that has mostly relied on self-reported, subjective assessments. Moreover, in this study, team communication content was coded by human coders and a supervised machine learning algorithm. This approach can quickly analyze a massive amount of communication records. Thus, it provides a promising future direction and guidance for team communication content research.

From a practical perspective, the results of this study demonstrate that problem-focused, positive procedural, positive action-oriented, and positive social-emotional team communication are critical for virtual team performance over time, even during times of disruption. Thus, organizations can improve virtual team performance by providing virtual communication training or managing virtual team communication to facilitate these four types of team communication content. Having said that, it is important to point out that I investigated the impacts of team communication content on performance in open-source software (OSS) teams. Thus, this research not only offers theoretical and practical guidance for virtual team communication in general, but for the OSS team literature and OSS practitioners' team interactions in particular.

Finally, when facing the challenges of a disruptive external environment, this research suggests that organizations can help virtual teams adapt by asking them to engage in extra procedural communication to solve new-arising problems or conflicts, such as communication that suggests new and further courses of action. Although this extra procedural communication does not directly perform team tasks immediately, it can help teams gradually adapt to the new working mode, overcome difficulties in uncertain times, and contribute to long-run team performance as per the results here.

Limitations and Future Directions

Because most team communication records coded by the human coders were classified into one of the four statements: problem-focused, positive procedural, positive action-oriented, or positive social-emotional communication; few communication records were coded as negative statements (i.e., negative procedural, negative action-oriented, and negative social-emotional utterances). Thus, there was insufficient labeled data for the machine learning process to develop a function that can classify statements into these negative communication categories. Because of this, I could not examine how these types of negative communication content impact virtual team performance. It is also unclear how these types of negative communication content and their relationships with virtual team performance changed before, during, and after the pandemic. One possible reason why only a few negative communications content was found is that these team communication records were collected from the online publicly available platform, GitHub. Since these communication records can be seen by anyone, team members are less likely to engage in negative communication content (e.g., complaining, criticizing, or blaming others). Nevertheless, more private virtual team communication may include negative communication content that could largely affect team performance. Thus, I suggest future studies collect

communication records from more private virtual teams and examine the impact of negative communication content on virtual team performance.

Besides, although the present study measured two aspects of virtual team performance (i.e., task completion speed and quality assessment), their relationships with virtual team communication are similar. However, the performance of OSS project teams can also be measured as system and information quality, popularity, user satisfaction, and community service quality (Crowston et al., 2012). It is possible that team communication content may impact other aspects of virtual team performance differently. For example, positive procedural communication may be positively related to a project's system and information quality but less likely to relate to user satisfaction since positive procedural communication is to manage the virtual team communication process. Future studies can investigate the impact of virtual team communication content on these crucial aspects of virtual team performance. Then, we can have a more comprehensive understanding of the effects of virtual team communication content.

Another limitation of this study is that the sample was limited in one domain of OSS projects (i.e., open-source internet software projects) to control for possible differences across projects in very different product categories. Future studies would benefit from sampling OSS project teams from multiple domains to enhance generalizability. In addition, the OSS team is a type of virtual team with several unique characteristics: its team members mainly communicate through texts to develop open-source software and some team members voluntarily participate in team projects without payment. Given that these characteristics may impact virtual teams' communication and production function, it is possible that virtual teams with different features may demonstrate different "team communication-performance" relationships, such as software development teams that communicate through multiple virtual tools and are paid regularly

according to performance. In addition to the field of software development, it is also meaningful for future studies to explore how the impacts of communication content on virtual team performance change in different settings. For instance, virtual surgical teams in hospitals or drone navigation teams in the military, composed of highly trained personnel with very high stakes outcomes, may need more problem-focused communication but less positive-social emotional communication to complete challenging tasks and perform well. In contrast, virtual design teams may need more positive social-emotional communication to encourage team members to develop and express new ideas. For e-sports teams composed of skillful members who often train together, frequent positive action-oriented communication helps them plan actions and win an intense battle. Positive procedural communication may slow the speed of their teams and cause failure. Given that virtual teams have become more prevalent and crucial for our lives, future studies investigating the impact of communication content on virtual team performance in different OSS project domains, types of virtual teams, and fields can help us more effectively manage virtual teams.

Finally, this research measured virtual teams' communication content and performance for six months to examine the impact of the COVID-19 disruption and set one month as the interval to observe the fluctuations of team communication content and performance based on prior work. However, these approaches could be problematic. Mitchell and James (2001) argue that when investigating a causal relationship, the time when an independent variable and a dependent variable are measured is crucial for determining whether the independent variable influences the dependent variable and its strength. For example, regarding the relationship between virtual team communication content and team performance, it is unclear how long it takes for certain types of communication content to influence virtual team performance. The

communication content of January may not impact January's team performance but February's performance. Moreover, its effect might last for the whole six months. Alternatively, its effect might gradually diminish over time. To date, there are few theoretical or empirical guides about when to measure virtual team communication content and team performance during a disruptive event, and therefore I followed current trends and recommendations for how I measured and analyzed my data (i.e., one month intervals as well as an overall analysis over a six month period). Moving forward, I suggest that future studies about the causal relationship between virtual team communication content and performance over time use Mitchell and James (2001) as a guide to consider the time issues more seriously.

Conclusion

Although virtual teams are increasingly used in organizations, the impacts of communication content on virtual team performance remain under-investigated. This research accordingly investigated the impacts of virtual team communication content on virtual team performance, and explored how virtual teams' communication content, performance, and their relationship changed from before to during the pandemic. The results of the present study demonstrate that problem-focused, positive procedural, action-oriented, and social-emotional communication content could help virtual teams perform well and even adapt to the disruption of the COVID-19 pandemic.

General Discussion and Future Research

This thesis aimed to answer the question: how can virtual teams communicate effectively to achieve positive outcomes? To answer this question, I first examined the relationships between different dimensions of team communication and virtual team outcomes by reviewing and synthesizing previous empirical articles (Study 1). Then, I explored the impact of specific communication content on virtual team performance in the context of the COVID-19 pandemic (Study 2). The overall theoretical, methodological, and practical implications of the results of these complementary studies are discussed here.

The purpose of Study 1 was to delineate the relationship between team communication and team outcomes in virtual teams. The result of this systematic literature review showed that team communication is a profile multidimensional construct that has different and context-specific outcomes for teams, highlighting the need for more clarity as well as diversity in the conceptualization of virtual team communication and its outcomes. To build on this, Study 2 focused on the impacts of one aspect of team communication – team communication content — on virtual team performance, which has been under-investigated in previous research, according to Study 1. The results of Study 2 demonstrated that four types of team communication content (i.e., problem-focused, positive procedural, positive action-oriented, and positive social-emotional communication) could facilitate virtual team performance at between- and within-team levels, also during times of disruption.

In terms of theoretical contributions, Study 1 identified virtual team communication as a profile multidimensional construct – consisting of the five dimensions of communication frequency, quality, content, style, and structure – that alone or in combination affects virtual team outcomes mainly through two theoretical mechanisms - relational and informational.

Specifically, various profiles of team communication can impact virtual team outcomes by developing social relationships necessary for team coordination and trust-building, and also by sharing task-related information that fosters shared mental models and TMS. However, the results also indicated that contextual variables moderate these relationships. According to my analysis, many theories and theoretical perspectives underpin these mechanisms, such as the TIP theory (McGrath, 1991), which argues that task-oriented and social-emotional activities can facilitate team performance. The findings of Study 2 supported both these mechanisms identified in Study 1 and the TIP theory (McGrath, 1991). It showed that problem-focused, positive procedural, positive action-oriented communication (task-oriented activities, informational mechanism) and positive social-emotional communication (social-emotional activities, relational mechanism) could facilitate virtual team performance. Furthermore, Study 2 also demonstrated that the relationship between positive procedural communication and virtual team performance changed during the pandemic, indicating that external disruption from COVID-19 can moderate the relationship between team communication and performance in virtual teams.

In terms of methodological contributions, in Study 1, I classified the broad concepts of team communication and team outcomes into smaller and more nuanced categories as recommended in previous literature (Marlow, Lacerenza, Paoletti, et al., 2017; Marlow, Lacerenza, & Salas, 2017; Roberson & Colquitt, 2005; Schaubroeck & Yu, 2017). This approach enabled me to delineate and shed more light on the specific relationships between different aspects of team communication and various virtual team outcomes. In Study 2, I took a different approach to measuring virtual team communication (compared to previous work that has mostly relied on self-reported, subjective assessments; e.g., Altschuller & Benbunan-Fich, 2010; Walther & Bunz, 2005) by measuring virtual team communication content through textual

analyses of actual communication records. This approach can reveal how language use and naturally occurring interactions within virtual teams affect team performance. Moreover, communication records were analyzed by human coders and a supervised machine learning algorithm. This method helped me analyze a massive amount of communication records in a short amount of time. Accordingly, this research offers future researchers methodological guidance for team communication content research moving forward.

In terms of practical contributions, the results of Study 1 and Study 2 provide a very good basis for organizations to develop interventions and policies that aim to foster effective team communication that facilitates good virtual team outcomes, given that this research has examined the impacts of different aspects of team communication on various virtual team outcomes. In addition, individuals working in virtual teams can also use the results of this research as a guide to overcoming challenges in virtual working by engaging in more effective communication with their teammates while recognizing the impact of moderating factors such as team development stage, the types of communication tools used, and the role of external factors such as COVID-19.

Overall, the research findings of this thesis also shed light on several promising directions for future research. First, most previous research has focused on the impacts of one dimension of team communication. However, communication is a nuanced process, and different dimensions of team communication can impact virtual team outcomes in different or interactive ways. Given the recent rise of virtual work in organizations, future research can examine how these aspects of virtual team communication interact and influence virtual team outcomes by conceptualizing virtual team communication as a profile multidimensional construct, looking for more or less effective communication profiles in virtual teams. Second, future research about communication content can use supervised machine learning algorithms to analyze massive amounts of team

communication records quickly. Currently, many virtual communication tools, such as Zoom, can automatically record communication content containing both verbal and nonverbal information. Using supervised machine learning algorithms can make the most of these data since it can analyze not only natural languages, but also other non-verbal communication content, such as facial expressions and body movements (Abdulrazaq et al., 2021; Narayanan, Desai, Stewart, Duncan, & MacKay, 2020).

Finally, with the development of technology, especially in light of COVID-19, various advanced virtual communications tools have become available to teams. Virtual team members now use a much broader set of communication tools, including emails, messages, phone calls, and many other more advanced tools, such as Trello, a project management app that streamlines virtual team communication, collaboration, and project tracking; and Zoom, which blends video meetings and group messaging. Thus, it is also meaningful to investigate how virtual team members can communicate effectively when simultaneously using several communication tools with different features. Future research can also explore the impacts of these newly developed virtual communication tools on the relationship between virtual team communication and team outcomes. For example, virtual team members can use emoticons during Zoom meetings to express feelings. They can use the whiteboard feature[11] to share, interact, develop, and organize ideas with remote teammates. They also can add closed captions and live transcriptions during the Zoom meeting, which can be very handy for people who cannot turn on the volume (e.g., in a noisy train station). However, many important questions remain about the impact of these tools for virtual team communication. For example, will using these features in video meetings make virtual team communication more productive? How will they impact the relationships between

[11] https://explore.zoom.us/en/products/online-whiteboard/

various aspects of virtual communication and team outcomes? How can virtual teams structure their online meetings to benefit from these new features? Another example is that, in January of 2022, the chief executive officer of Columbia Shipmanagement Ltd, Mark O'Neil, showed up at a conference and interacted with the audience as a life-size hologram (Ha, 2022). Technology companies, such as Google and Microsoft Corp, are seeking to make virtual meetings more authentic by using 3D holographic technology, allowing virtual teammates to engage in real-time communication as if they are in the same room (Ha, 2022). Will this technology blur the lines between virtual meetings and face-to-face meetings? Or is it still unnatural and will hurt virtual team performance? More studies are clearly needed to answer these questions.

Conclusion

In conclusion, this thesis aimed to answer the question: how can virtual teams communicate effectively to achieve positive outcomes? Results revealed a comprehensive and complex picture of the relationships between virtual team communication and team outcomes. In particular, they showed that the impacts of five dimensions of team communication are different and context-specific, demonstrating the need for a clearer and more nuanced conceptualization of virtual team communication – i.e., communication as a profile multidimensional construct – and its outcomes. Furthermore, this thesis also provided a testable framework to help us better understand the impacts of virtual team communication on virtual team outcomes and contingencies of these relationships; and highlights many exciting research questions yet to be addressed. I hope this thesis will inspire researchers to advance our understanding of virtual team communication and its effects and make further headway in this area.

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Appendix

1. Autonomous and Firms Sponsored OSS Teams (Ritvo et al., 2017)

	Autonomous OSS teams	**Firms sponsored OSS teams**
Definition	is presently independent of any one firm and is community managed	is one where one (or more) corporate entities control the community's short- or long-term activities
	Both offer access to code that is guaranteed by an open-source license, which fits the definition set by the Open Source Initiative. Both also offer a high degree of transparency of access to that code — without which the right to use the code would be useless.	
Goals	improving the capabilities of the shared technology	profiting from its investment
Uniqueness		face a fundamental tension (openness and control) between two conflicting goals: sponsoring the organizations and win external participation and technological adoption.
Organization of Production	Transparent and accessible	Transparent but not that accessible to outsiders
Governance	More accessible	By creating a membership organization and the opportunity to elect leaders, a few sponsors offered potential contributors the ability to develop a sense of belonging and

		become more vested in the community's future. However, most sponsors did not create an independent form of governance, retained exclusive release authority, and final say on all key community decisions
Intellectual Property (the most dramatic difference)		the sponsor in nearly all cases retained ownership of the core (if not subproject) code.
Types		1. communities either had achieved or were seeking levels of community participation comparable to those of individually-founded communities; in 2. communities (the three firm-sponsored dual- licensed communities) offered what we term a "fishbowl" development pattern — with the sponsor offering transparency to outsiders, but not accessibility to software development. 3. communities lay somewhere in between: experimenting with the provision of access but not willing to give up key points of control.

2. Comparison of Human-Coded and Machine-Coded Teams, Communication Content, And "Communication Content – Team Performance" Relationships

There were 52 teams' communication records were coded by two human coders. Among these teams, 42.30% had 3 to 10 members (i.e., small teams), 46.15% had 11 to 20 members (i.e., medium-sized teams), and the rest had more than 20 members (i.e., large teams). Within these teams, 2 to 6 were core developers. The percentages of these teams under the topics HTTP, FTP, Web, and browser were 59.62%, 7.69%, 23.08%, and 9.62%, respectively.

In comparison, 47 teams' communication records were machine-coded. Among these teams, 51.06% had 3 to 10 members (i.e., small teams), 31.91% had 11 to 20 members (i.e., medium-sized teams), and the rest had more than 20 members (i.e., large teams). The percentages of these teams under the topics HTTP, FTP, Web, and browser were 55.32%, 8.51%, 23.40%, and 12.77%, respectively. Similar portions of human-coded teams and machine-coded teams were firm-sponsored or had Strong-Copyleft licenses.

	Teams coded by human ($N = 52$)	Teams coded by machine ($N = 47$)
Team size		
3-10	22	24
11-20	24	15
21-31	6	8
Topic		
HTTP	31	26
FTP	4	4
Web	12	11
Browser	5	6
Firm-sponsored	38	40
Strong-Copyleft license	1	3

Then, I compared the human-coded and machine-coded communication content. Their descriptive statistics were similar.

Human coded communication content

	N	*M*	*SD*	*Min*	*Max*	*Skew*	*Kurtosis*	*Shapiro-Wilk's test(w)*
Problem-focused statement	52	474.02	430.95	29.00	1558.00	1.18	0.33	0.84***
Positive procedural statement	52	3.81	7.88	0.00	47.00	4.06	17.61	0.46***
Positive action-oriented statement	52	21.12	18.50	1.00	80.00	1.32	1.21	0.86***
Positive social-emotional statement	52	60.62	56.62	4.00	245.00	1.62	2.47	0.82***

*Note. ***p < 0.001. **p <0.01. *p<0.05.*

Machine coded communication content

	N	*M*	*SD*	*Min*	*Max*	*Skew*	*Kurtosis*	*Shapiro-Wilk's test(w)*
Problem-focused statement	47	1086.06	1362.74	7.00	5124.00	1.33	0.85	0.78***
Positive procedural statement	47	1.96	2.91	0.00	13.00	2.21	4.81	0.68***
Positive action-oriented statement	47	36.85	49.47	0.00	223.00	1.89	3.45	0.74***
Positive social-emotional statement	47	116.55	189.68	1.00	1097.00	3.25	12.94	0.60***

*Note. ***p < 0.001. **p <0.01. *p<0.05.*

Finally, to evaluate the performance of the supervised machine learning classifier, I also checked whether human-coded, and machine-coded data have similar "communication content – team performance" relationships by using bootstrapping regression analyses. I used bootstrapping regression analyses because the sample sizes were small when communication data were separated into human coded and machine coded data. Moreover, distributions of variables were unclear. According to Fox (2008), bootstrapping does not require distributional assumptions (such as normally distributed errors); it can provide more accurate inferences when the data are not well behaved or small sample size. Besides, it is also possible to apply the bootstrap to statistics with sampling distributions that are difficult to derive, even asymptotically. The confident intervals produced by bootstrapping regression analyses showed that three data

sets have similar relationships between four types of communication and two team performance measurements.

	Communication data coded by	Number of pull requests merged	Number of issues reported
Problem-focused statement	human	0.03, 0.12	0.06, 0.19
	machine	0.02, 0.18	0.05, 0.16
	all	0.03, 0.16	0.06, 0.15
Positive procedural statement	human	0.51, 19.74	0.77, 7.44
	machine	7.41, 52.79	17.70, 71.78
	all	0.61, 22.18	0.57, 18.89
Positive action-oriented statement	human	0.69, 3.89	0.97, 4.23
	machine	0.49, 3.92	1.36, 3.90
	all	0.64, 3.65	1.52, 3.50
Positive social-emotional statement	human	0.20, 0.96	0.58, 1.23
	machine	0.23, 1.53	0.15, 1.59
	all	0.25, 1.36	0.20, 1.44