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# Communication and Trust in Virtual and Face-to-Face Teams

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# COMMUNICATION AND TRUST IN VIRTUAL AND FACE-TO-FACE TEAMS

by

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A Thesis Submitted to the Department of Human Factors in the College of Arts and Science
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This dissertation was prepared under the direction of the candidate's Dissertation Committee Chair, Dr. Joseph R. Keebler and has been approved by the members of the Dissertation Committee. It was submitted to the College of Arts and Sciences and was accepted in partial fulfillment of the requirements for the degree of

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# DEDICATION

To Mom, with love.

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# Abstract

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Virtual teams (VTs) accomplish shared goals by relying on technology-mediated communication to counteract geographic disparities. Rapid advances in technology have led to the near-ubiquity of VTs within modern organizations, but gaps in existing research designs afflict extant empirical VT research. This experiment evaluates the constructs of trust, communication, and effectiveness in VTs. Two-hundred six participants (103 teams) completed an interdependent task either face-to-face, mediated by a videoconferencing telepresence robot, or mediated by a voice call. I collected measures of cognitive trust, trust propensity, communication quality, and team effectiveness, and conducted in-depth communication analyses. Results suggest that while virtual teamwork does not result in effectiveness decrements, it does result in team trust decrements, but video teams demonstrated smaller trust decrements than voice-only teams. The expansive communication analyses utilized in the study produced inconclusive findings. Given the large sample size used and the breadth of constructs assessed, this experiment sets a milestone in empirical virtual teamwork research for future work to build upon.

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# CHAPTER ONE: INTRODUCTION

## Statement of the Problem

The spread of technology into every facet of our lives is inexorable, and the workplace is no exception. Technology has long enabled companies to reap the benefits of geographically distributed talent, spanning the implementation of the telegraph in the 1830s, the telephone in the 1870s, e-mail in the 1970s, and the World Wide Web from the 1980s to the present (Burns, 2004; Peter, 2004). The latter technologies provided the platform upon which businesses began to develop virtual teams (VTs). VTs are generally defined as geographically dispersed teams that rely primarily on technology-mediated communication (Gibson & Cohen, 2003; Powell, Piccoli, & Ives, 2004; Schweitzer & Duxbury, 2010). Technology has rapidly advanced, outpacing our understanding of exactly how it affects team communication and trust, especially among the diversity of workplaces that exist (Marlow, Lacerenza, & Salas, 2017).

As technology becomes more widespread, so does the use of virtual teamwork; industry use of technology to enable distributed work has exploded in recent years, and an estimated 80 to 85 percent of the workforce participates in virtual teamwork on a frequent basis (Siemens Enterprise Communications, 2012; C. Solomon, 2014, 2016). Industries that see widespread VT use include education, accounting, travel, healthcare, IT, news/media, human resources, and more (Shin, 2016). Certain positions lend themselves well to virtual work, such as those involved with marketing, finances, public relations, app/web development, and more. The ubiquity of VTs means that the stakes for effectively managing and understanding virtual teamwork are global.

Communication is fundamental to teamwork; it is vital to a team's ability to coordinate collective efforts toward a shared goal (Salas, Rosen, Burke, & Goodwin, 2009). Broadly, communication improves team performance by allowing for other team processes and outcomes to develop more effectively (Kozlowski & Ilgen, 2006). Arguably, communication is the most significant predictor of team success, as without effective communication, a team cannot coordinate to complete interdependent tasks. Critically, however, communication is a very broad construct. Researchers argue that a more nuanced understanding of VT communication is needed in order to better understand team functioning, especially in virtual teams (Marlow et al., 2017). A clearer understanding of exactly *how* different facets of communication affect team performance can have arguably global effects on international business, given the universal prevalence of virtual teamwork.

Communication serves a critical role in trust development, and generally, trust and communication in VTs are positively related (Crisp & Jarvenpaa, 2013; Henttonen & Blomqvist, 2005). Trust is critical to the effectiveness of teams (de Jong, Dirks, & Gillespie, 2015), and is positively related with VT performance (Furumo, 2009), so a clear understanding of team trust enables a clear understanding of team performance. When a team goes virtual, the loss of face-to-face contact undermines team members' ability to provide full context for communication, and makes it more difficult to establish trust (C. Solomon, 2016). Regarding trust in VTs, Foster (2015) said the following:

> "Remote work stops working when you can't trust the person on the other end of the line. If you continually find yourself worrying what someone is doing, then you are spending brain cycles focusing on something other than the product. Trust is key."

Despite the broad consensus that trust is important, generalizing research findings across studies of trust is often difficult (Mooradian, Renzl, & Matzler, 2006). This is because trust can be conceptualized and measured in many different ways. In addition, the geographically dispersed nature of VTs makes it difficult for team members to establish trust in traditional ways given the obstacles to face-to-face interaction. As with communication, the worldwide use of virtual teamwork means that any improvement in our understanding of how VT trust affects performance has tremendous implications for global business.

It is evident that the state of VT research is changing perhaps as rapidly as the technology that enables it. Recently, the amount of research being conducted on virtual teamwork has increased rapidly over the past few years (Gilson, Maynard, Jones Young, Vartiainen, & Hakonen, 2015), and this body of research is rising to the challenge of understanding how the newest technologies are changing what we understand about virtual teamwork (Marlow et al., 2017). However, much work remains to be done, and this study was designed to provide insight into some of the most critical areas requiring research.

**Purpose of the Current Study**

This study contributes to the virtual teamwork literature by comprehensively analyzing the relationships between inputs, processes, and outputs critical to virtual teamwork. The purpose of this study is to empirically examine the effects of virtuality and propensity to trust on cognitive trust, team communication quality, and team effectiveness in two-person teams. Specifically, the study assesses how cognitive trust, communication quality, and team effectiveness vary when face-to-face interactions are compared to interactions mediated by a video call or a voice call. These constructs were selected due to their fundamental importance to virtual teamwork, which is discussed below. Overall, this study contributes to the literature in several ways.

First, it continues in the relatively new and critical line of research that assesses the effects of differing degrees of virtuality on teamwork (Gilson et al., 2015). Rich communication methods such as video calling closely simulate face-to-face interaction (Martínez-Moreno, González-Navarro, Zornoza, & Ripoll, 2009), and VT workers employed in industry widely recommend the use of face-to-face interactions to increase later VT performance (C. Solomon, 2016). Thus, it is pertinent to assess whether video call interactions can be just as effective as co-located interactions at positively influencing later virtual teamwork. If so, this would serve as a useful recommendation to industry members, indicating that VTs could save travel costs intended for face-to-face interactions by allowing for video call interactions. Further, it has been noted that there is very little research that empirically investigates the relationship between virtuality and team outcomes (Breuer, Hüffmeier, & Hertel, 2016; Schweitzer & Duxbury, 2010). Therefore, this study addresses some of that gap, and sheds light on how organizations should appropriately utilize different communication media.

Second, this study develops our understanding of how cognitive trust affects the effectiveness of a VT. Cognitive trust involves a belief that someone is reliable or competent at a task (McAllister, 1995). The trust displayed in early phases of virtual team interactions is primarily based on cognitive trust because there is little other information available about the team (Crisp & Jarvenpaa, 2013). A recent meta-analysis by Breuer and colleagues (2016) suggested that virtual teamwork moderated the relationship between team trust and task performance. However, the authors acknowledge that only one of the studies included in their analysis (Zornoza, Orengo, & Peñarroja, 2009) compared trust effects in virtual and co-located teams directly while controlling for other variables. In addition, this meta-analysis evaluated team trust as a singular concept, without consideration for the separate affective and cognitive components of trust. It is therefore apparent that more empirical research is needed to demonstrate the relationship that cognitive trust has with team effectiveness. A clearer understanding of the role of cognitive trust in virtual teamwork will provide useful recommendations for managing and forming VTs in a way that bolsters the cognitive trust between its members, eventually resulting in increased organizational productivity.

Third, this study will also allow for a novel look into how VT members' propensity to trust affects their team effectiveness. Propensity to trust is a significant correlate of trust (Colquitt, Scott, & LePine, 2007), and research suggests that one's propensity to trust positively affects one's ability to work in VTs (Jarvenpaa, Knoll, & Leidner, 1998). Given that VTs are often ad hoc in nature, propensity to trust is a critical component of VT interactions as it allows VT members to have a baseline level of trust for each other in the absence of knowledge about each other (Meyerson, Weick, & Kramer, 1996; Robert, Denis, & Hung, 2009). However, much extant research into propensity to trust in virtual teams is theoretical in nature, and there is a need to understand how propensity to trust interacts with task-irrelevant socialization, team communication, and team trust, given the importance of each of these factors to VT performance.

Fourth, this study will contribute to our understanding of the relationship between communication quality and team effectiveness in VTs. Communication is key to teamwork, as it allows team members to exchange information (Pinto & Pinto, 1990). It serves a critical coordinating function for teams (Salas et al., 2009) and is a key predictor of VT effectiveness (Wong & Burton, 2000). Problematically, very few studies have comprehensively analyzed the communication of a VT in order to draw conclusions about how specific communication patterns affect VT performance (Gilson et al., 2015; Marlow et al., 2017). Therefore, this study will comprehensively analyze team communication in order to draw actionable conclusions about how virtuality and cognitive trust affect the communication used by team members.

To improve the applicability of results, the quality of the team communication is the construct of interest. Marlow et al. (2017) argue that communication quality is significantly more important to VT outcomes than other elements of team communication, such as communication frequency or timeliness. Narrowing down to the construct of communication quality will make this study's results more specifically actionable than a broader, diffuse look at communication. Given that approximately 2/3rds of multinational organizations use VTs (Society for Human Resource Management, 2012), any guidelines that result in improvements in VT communication quality can result in millions of dollars in increased productivity across the world.

To address all the gaps outlined above, this study will evaluate the relationships between the constructs of virtuality, cognitive trust, propensity to trust, communication quality, and team effectiveness. Figure 1 depicts a model of the proposed relationships between these constructs.

The following chapter delves into greater detail regarding each of the proposed relationships and outlines the study hypotheses as well as the literature in support of the proposed model.

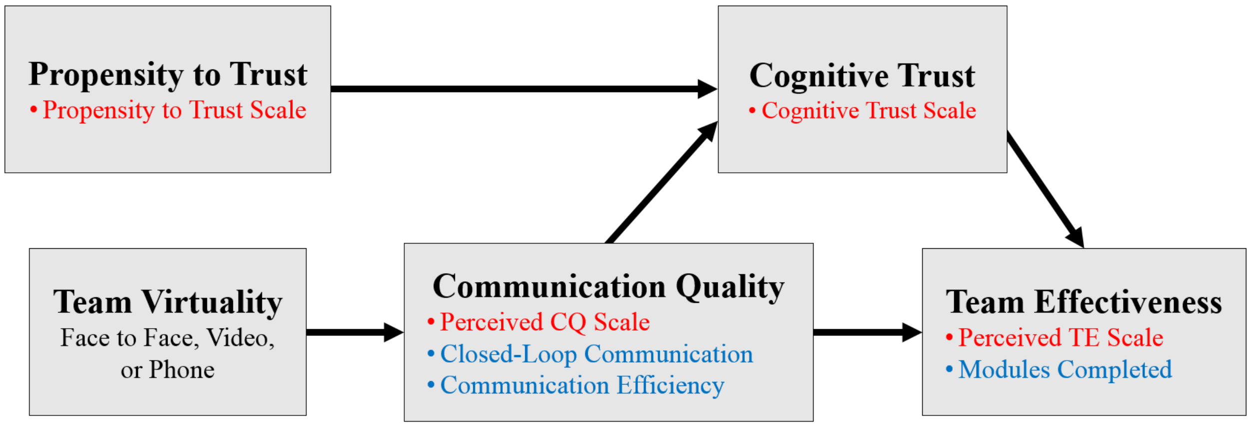



*Figure* 1. Relationships between constructs and proposed hypotheses.

# CHAPTER TWO: LITERATURE REVIEW

How do VTs differ from co-located teams? This is the fundamental question underlying VT research. Due to the exponential growth of available technologies and the limitless number of potential team configurations, this question may never be completely answered, but research continues to shed light on this domain. In order to inform our discussion of VTs, it would be prudent to first understand teams in general. The following section delves into the concept of teamwork, dissecting the constructs that comprise it and discussing the state of research into the teamwork domain. After that, additional sections address the constructs of virtuality, communication, and trust.

## Teamwork

**Definitions**. The concept of a team is familiar to us, as much social interaction involves working with others as part of a team. However, we will ground our definition of a team in literature. One of the more enduring definitions was put forth by Dyer (1984), who defined a team as consisting of "at least two people, who are working towards a common goal, where each person has been assigned specific roles or functions to perform, and where completion of the mission requires some form of dependency among the group members" (p. 286). A fairly similar definition was laid out by Hackman (1987) and later supported by other authors (e.g. Cohen & Bailey, 1997; Sundstrom, de Meuse, & Futrell, 1990). They describe a team as a group of interdependent individuals "who share responsibility for outcomes, [and] who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems" (Cohen & Bailey, 1997, p. 239). Both definitions share the concept of interdependency among team members, and both definitions share the orientation of a team towards a goal. Thus, for the purposes of this study, I will define a team as *two or more interdependent individuals working toward a common goal*.

The concept of teamwork is somewhat more complicated; defining it is easier than understanding what it is and how it works. Salas, Rosen, Burke, and Goodwin (2009) define teamwork as “the means by which individual task expertise is translated, magnified, and synergistically combined to yield superior performance outcomes, the wisdom of the collectives” (p. 43). A more elaborate definition was offered by Salas, Stagl, Burke, & Goodwin (2007), who described teamwork as the “dynamic, simultaneous, and recursive enactment of process mechanisms which inhibit or contribute to team performance and performance outcomes” (p. 190). These definitions can be distilled down to their fundamentals; teamwork can thus be understood as *the mechanisms by which a team moves toward its goals.*

**Models.** As ways of thinking about teamwork have changed, teamwork models have undergone several paradigm shifts over the years. While a large variety of teamwork models have been designed to account for different aspects of teamwork, many of them lie outside the scope of this research. As such, this section will detail a small selection of teamwork models that are most relevant to this study.

Early seminal works conceptualized teamwork using a model with three stages: inputs, processes, and outputs (Hackman, 1987; McGrath, 1984; Steiner, 1972). The IPO model was important as it provided researchers with a framework for understanding how team inputs (such as knowledge, skills, and attitudes) lead to processes (such as mutual performance monitoring or closed-loop communication) which then lead to outcomes (such as performance or satisfaction). However, the IPO model fails to characterize teamwork in several ways.

First, it oversimplifies teamwork, and fails to account for emergent states. The IPO model considers that processes are the primary linkage between inputs and outputs, but emergent states can also link inputs and outputs. Processes involve the nature of the team's interaction, and reflect things that team members *do*, such as closed-loop communication (CLC). Emergent states refer to the cognitive or affective states that a team experiences, such as team member attitudes (Marks, Mathieu, & Zaccaro, 2001). The exclusion of emergent states from the IPO model limits its ability to account for the breadth of mediators that can link team inputs and team outputs.

Second, the IPO model does not account for the cyclical nature of teamwork. It models the way that inputs lead to outputs via processes, but it does not explain how outputs can affect subsequent inputs. For example, a team can review their performance outcomes on a task (output), and based on their shortcomings, they can plan for future iterations of the task (input). This means that within the constraints of the traditional IPO model, team development over time cannot be represented.

This shortcoming was addressed by (Marks et al., 2001), who argued that the IPO model was better represented in brief "episodes and sub-episodes, rather than the entire life cycle of the team" (p. 360). The authors posited that teams experience *action phases* and *transition phases*; in the former, the team is working directly toward its goal, and in the latter, the team is evaluating and/or planning their strategies for accomplishing their goals. It is in these phases, they argued, that the IPO model can be represented. For example, in completing Task A, a team may undergo an alternating sequence of four action and transition phases, and each phase would have its own set of inputs, processes, and outputs. Figure 2 graphically represents this process.

However, this solution still fails to address the fact that the IPO model does not account for emergent states. In response to this and other shortcomings, Ilgen, Hollenbeck, Johnson, & Jundt (2005) proposed the IMOI model of teamwork.

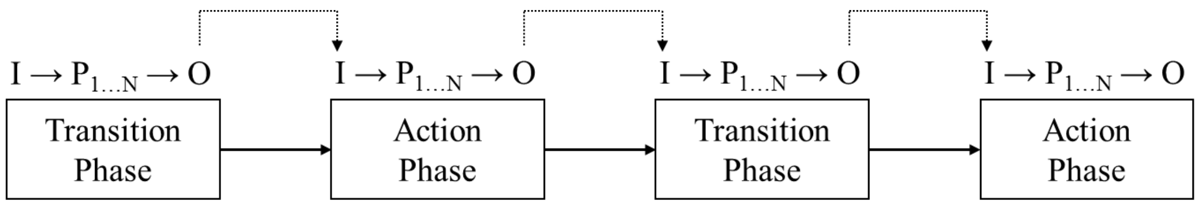



*Figure 2.* Phases of teamwork over time. Adapted from Marks, Mathieu, and Zaccaro (2001).

The IMOI model represents teamwork in a different manner from previous models. Ilgen and colleagues (2005) argued that extant teams research could be best captured by understanding teamwork as a set of inter-related phases of inputs, mediators, outputs, and inputs. Their use of a second input phase after output is meant to reflect the cyclical nature of teamwork. Their replacement of processes (used in the IPO model) with mediators is meant to capture a greater extent of variables and constructs that can link inputs to outputs. Finally, they argued that the IMOI model accommodates potential interactions between its phases, rather than serving as a solely linear flow from inputs to outputs, as in the IPO model.

Notably, one study validated a variant of the IMOI model in virtual teams (Algesheimer, Dholakia, & Gurău, 2011). To do so, the authors investigated more than 600 professional video game teams. Using structural equation modeling, they found that the model that best explained the collected data was an Input-Process-Emergent State-Output-Input model. In a sense, it synthesizes Marks et al's (2001) distinction between processes and emergent states, and the IMOI model proposed by Ilgen et al. (2005). Critically, however, Algesheimer et al. (2011) note that their findings represent only a single type of VT, and recommend that more research is carried out to verify whether this variant of the IMOI model applies to other VTs. Until more research supports their model, the IMOI model stands as the best way to conceptualize virtual teamwork due to its broad acceptance across the fields of organizational and teams research.

**What is a virtual team?** Recall that a team is defined as *two or more interdependent individuals working toward a common goal*. Therefore, a virtual team is a team with an added dimension of virtuality. Many authors have attempted to define virtuality, resulting in some inconsistencies between these definitions. The following section addresses this, providing a clear definition of a virtual team and discussing the measurement of virtuality

## Virtuality

**Defining virtuality and VTs.** Definitions of virtuality traditionally include some combination of six distinct criteria: space/geographic dispersion; boundary/organization spanning; asynchronicity; limited lifespan; cultural/national diversity; and reliance on communication technology (Schweitzer & Duxbury, 2010). Table 1 contains a variety of definitions for virtuality, collected by Schweitzer and Duxbury (2010). I have expanded the table to include additional definitions as well as definitions from manuscripts that have been published more recently. Interestingly, while most definitions prior to about 2006 seem to include more than two criteria, the definitions proposed after that time seem to coalesce around the two criteria of spatial/geographic dispersion and a reliance on communication technology.

Logically, these are the only criteria that are fundamentally required for virtual teamwork. Boundary/organization spanning is not a sufficient criterion for a VT; a team whose members work in the same location at the same time but belong to different organizations is not considered virtual. Asynchronicity is not a sufficient criterion for a VT; in fact, many VTs work synchronously while separated geographically. Limited lifespan is not a sufficient criterion for a VT; the length of a team's commitment has no relation to its virtual nature. Cultural/national diversity is not a sufficient criterion for a VT; it is irrational to say that a homogeneous team cannot be virtual.

What remains are the two criteria that form the definition of virtuality: spatial/geographic dispersion and a reliance and communication technology. A team that is spatially dispersed cannot communicate face-to-face, and must rely on technology to communicate and coordinate team tasks. Thus, VTs are geographically dispersed teams that rely primarily on technology-mediated communication (Gibson & Cohen, 2003; Peñarroja, Orengo, Zornoza, & Hernández, 2013; Schweitzer & Duxbury, 2010). Combining this with the definition of a team, therefore, a VT is defined as *two or more interdependent individuals who work towards a common goal and who rely primarily on technology mediated communication to counteract geographic disparities*.

**Measuring virtuality.** In earlier years, VTs were considered to be conceptually distinct from teams that worked exclusively face to face (Bouas & Arrow, 1995; Lurey & Raisinghani, 2001). Since then, however, authors have sought to reconceptualize this, instead considering the extent of a team's virtuality (Bell & Kozlowski, 2002; Martins, Gilson, & Maynard, 2004). In other words, the current thinking is that virtuality is a continuum. Teams can have zero virtuality, in which they conduct all of their work face-to-face. Teams can also have complete virtuality, in which they complete all work without ever meeting in person. However, most teams have some degree of virtuality because teams rarely complete entire tasks in shared spaces and across synchronous times (Griffith, Sawyer, & Neale, 2003). This does little to clarify the dimensions upon which virtuality is measured; is it reflected in the proportion of work completed in separate spaces? Or at separate times? Or via technology-mediated communication? This has been the subject of debate in literature. How, then, can one measure the degree of a team's virtuality?

In the same way that definitions of virtuality have several criteria, the degree to which a team is virtual has been characterized by several dimensions. In most cases, authors have characterized a team's degree of virtuality as being based in: the amount of distance/spatial dispersion; the proportion of time spent co-located; the degree of asynchronous work; the extent of face-to-face contact; and the degree of dependence on electronic communication.

Unlike how definitions of virtuality coalesced upon two distinct criteria, a method to measure virtuality has not coalesced into an agreed-upon subset of the five dimensions described above. Most authors opt for some combination of three dimensions, and the most popularly included dimension is a VT's degree of spatial dispersion (Schweitzer & Duxbury, 2010). However, the other four dimensions are about equally distributed. For example, Griffith et al. (2003) argue that virtuality can be measured by assessing a team's spatial dispersion, extent of face-to-face contact, and degree of dependence on electronic communication. O'Leary & Cummings (2007) argue that it can be measured via a team's spatial dispersion, proportion of time spent co-located, and degree of asynchronous work.

In a broad meta-analysis of virtuality and information sharing in teams, Mesmer-Magnus, DeChurch, Jimenez-Rodriguez, Wildman, & Shuffler (2011) support a view put forth by Kirkman & Mathieu (2005) in which team virtuality can be measured via a team's extent of face-to-face contact as well as via the informational value and synchronicity afforded by their communication tools. In this context, informational value refers to the richness of a communication medium; richness is discussed in detail in the following section on Communication. When measured in this manner, a team that relies completely on videoconferencing tools has no face-to-face contact, high informational value, and high synchronicity. Therefore, this type of team can be said to be low in virtuality. In contrast, a team that relies on voice communication has no face-to-face contact, moderate informational value, and high synchronicity. Therefore, this type of team can have moderate virtuality. The present study will compare low-virtual, moderate-virtual, and face-to-face teams to investigate how they differ in communication, trust, and team effectiveness patterns. These teams will use video calls, voice calls, and co-located performances, respectively. The following section discusses the construct of communication, relates it to virtuality, and expands on how media richness affects the communication of virtual teams.

*Table 1. Summary of research that includes criteria for defining virtuality. Adapted from Schweitzer and Duxbury (2010).*

| Authors | Space/ geographic dispersion | Organization/ boundary-less | Time/ asynchronicity | Term/ lifespan | Cultural/ national diversity | Rely on communication technology |
|---|---|---|---|---|---|---|
| Kristof, Brown, Simps, & Smith (1995) | | X | | | | |
| Jarvenpaa & Leidner (1999) | X | | | X | X | X |
| Bal & Teo (2000) | X | X | | | | X |
| Chudoba & Maznevski (2000) | X | | | | X | X |
| Wong & Burton (2000) | X | X | | X | X | |
| Lurey & Raisinghani (2001) | X | | | | | |
| Watson-Manheim, Chudoba, & Crowston, (2002) | X | X | | X | X | |
| Bell & Kozlowski (2002) | X | | | | | X |
| Espinosa, Cummings, Wilson, & Pearce (2003) | X | X | X | | | |
| Griffith et al. (2003) | X | | | | | X |
| Gibson & Cohen (2003) | X | | | | | X |
| Martins et al. (2004) | X | X | X | X | | X |
| Powell et al. (2004) | X | X | X | | | X |
| Kirkman, Rosen, Tesluk, & Gibson (2004) | X | | X | | | X |
| Hertel, Geister, & Konradt (2005) | X | X | X | | | X |
| Powell, Galvin, & Piccoli (2006) | X | X | X | | | X |
| Gibson & Gibbs (2006) | X | X | | | X | X |
| Saunders & Ahuja (2006) | X | | X | | | X |
| Staples & Webster (2007) | X | | | | | X |
| O'Leary & Cummings (2007) | X | | X | | | |
| Schweitzer & Duxbury (2010) | X | | | | | X |
| Pridmore & Phillips-Wren (2011) | X | | | | | X |
| de Guinea et al. (2012) | X | | | | | X |
| Crisp & Jarvenpaa (2013) | X | | | X | | X |
| Peñarroja, Orengo, Zornoza, & Hernández (2013) | X | | | | | X |
| Charlier et al. (2016) | X | X | | | | X |

## Communication

Communication is a critical aspect of teamwork, as it allows team members to share information (Pinto & Pinto, 1990). Communication is vital to a team's ability to coordinate collective efforts toward a shared goal (Salas et al., 2009). Specifically, communication improves team performance by allowing for other team processes and outcomes to develop more effectively (Kozlowski & Ilgen, 2006). For example, communication aids in the development of team shared mental models of the task, which are related with improvements in team processes and performance (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999). With respect to VTs, communication is a key predictor of VT effectiveness (Wong & Burton, 2000).

Communication itself is a broad construct, and can be broken down into components that are more suitable for assessment, such as the quality, frequency, content, and timeliness of the communication. In VTs, Marlow et al. (2017) argue that communication quality is significantly more important to team outcomes than other elements of team communication, such as communication frequency or content. Hence, the proposed study will assess the construct of communication quality.

**Media richness.** Different communication technologies have differing levels of media richness, which refers to the types of information cues that the medium can transmit (Daft & Lengel, 1984). According to media synchronicity theory (Dennis, Valacich, Speier, & Morris, 1998), a communication medium can have its richness categorized on five dimensions: feedback, symbol variety, concurrency, persistence, and rehearsability (referring to how easily replayed a medium is). Similarities between face-to-face communication and video calling, two of the media of interest in this study, are revealed by their similarities across these dimensions. For example, both media have high feedback, symbol variety, and concurrency, but they also have low rehearsability and persistence. Compared to face-to-face communication, video calls have slightly less feedback, due to the lack of colocation between parties which limits the quality of nonverbal cues that can be transmitted. Therefore, video calls have slightly less richness than face-to-face communication.

Voice calls, the third medium of interest in the study, have slightly less feedback than video calls, less symbol variety, and the same concurrency. Voice calls also have similarly low rehearsability and persistence. Therefore, the richest medium is face to face communication, which is followed by video calling. Of the three media used in this study, the least rich medium (which is still moderately rich) is voice calling.

Going one step further, these media can be compared to e-mail conversations. E-mail conversations have very low feedback and concurrency, moderate symbol variety (due to the lack of nonverbal cues), and high rehearsability and persistence. E-mail conversations provide fairly little information compared to very rich media such as video calls. However, the low concurrency and high rehearsability and persistence of e-mail conversations means that they are very useful for asynchronous conversations.

Media richness is fairly similar to the degree of a team's virtuality, which was discussed in the previous section. For example, a rich medium such as videoconferencing provides high informational value, and provides high concurrency/synchronicity, while simulating face-to-face contact. This means that a team that uses this type of rich communication method has low virtuality. A team that uses a communication method very low in richness, such as e-mail conversations, is likely to be highly virtual, due to significant drops in the informational value and synchronicity provided by this medium. However, these drawbacks are acceptable to a team that is highly spatially dispersed, and perhaps even beneficial to a team that works in vastly different time zones, or that places high value on independent, asynchronous work.

In the context of teamwork, rich communication reduces ambiguity and uncertainty between parties (Peñarroja et al., 2013). As discussed earlier, video calls simulate the richness of face-to-face communication by allowing for the perception of some nonverbal cues such as body language (Goman, 2014). Despite the similar richness levels of these two media, authors generally agree that videoconferencing is not a perfect substitute for face-to-face communication (Straus & Olivera, 2000), leading to potential issues with a team's communication due to the lack of colocation between parties. One author argues that technology has increasingly served to disrupt the quality of our communication with others, and that managers and other business leaders should make greater use of face-to-face time (Turkle, 2016). Building on this, Turkle notes that employees may avoid uncomfortable one-on-one encounters such as apologies in favor of carrying them out via technology, and contends that workers should encourage their colleagues to avoid these cop-outs in favor of the increased richness offered by face-to-face interaction (Turkle, 2016). Altogether, while technology can simulate many aspects of rich communication, it cannot completely replace the richness of face-to-face communication.

**Communication quality.** Rich communication is not necessarily *quality* communication. Richness is a factor of a communication medium, whereas quality is a factor of the information being communicated. Communication quality is a construct that captures the usefulness and effectiveness of communication. Hoegl and Gemuenden (2001) defined it as the extent to which communication is sufficiently frequent, informal, direct, and open. It has also been argued that quality is represented via timely communication as well as by the use of closed-loop communication (CLC; Marlow et al., 2017). González-Romá and Hernández (2014) argue that communication quality encompasses the "extent to which communication among team members is clear, effective, complete, fluent, and on time" (p. 1046), a definition supported by Marlow and colleagues (2017). Inconsistencies in defining constructs like communication often hamper the generalizability of VT research findings; in other words, it can be difficult to extrapolate results across studies when communication aspects are operationalized inconsistently (Gilson et al., 2015). In order to ensure that the results of this study conform to existing work and can be compared to future work, the definitions proposed by Marlow et al. (2017) and González-Romá and Hernández (2014) form the basis of the communication analyses conducted for this study.

**Communication process framework.** Recent groundbreaking work by Marlow et al. (2017) integrates existing VT literature trends into a framework intended to inform future research into VT performance and communication. Many of the arguments posed by the authors have been discussed so far in the current manuscript, as much of their work informs the proposed research study. Essentially, Marlow et al. (2017) argue that many trends in VT research findings (e.g. the link between communication and performance outcomes) tend to be founded on inconsistent team structures, construct operationalizations, and definitions of communication. Despite this, their evaluation of extant VT research resulted in the development of a framework that synthesizes various VT constructs (see Figure 3). This framework parallels the IMOI model; in this case, the mediators are separated into Communication and Emergent States, echoing the importance of communication as a process of VT performance. Importantly, it also provides a set of team and task characteristics, such as virtuality, which are hypothesized to mediate and moderate various relationships between constructs in the framework.

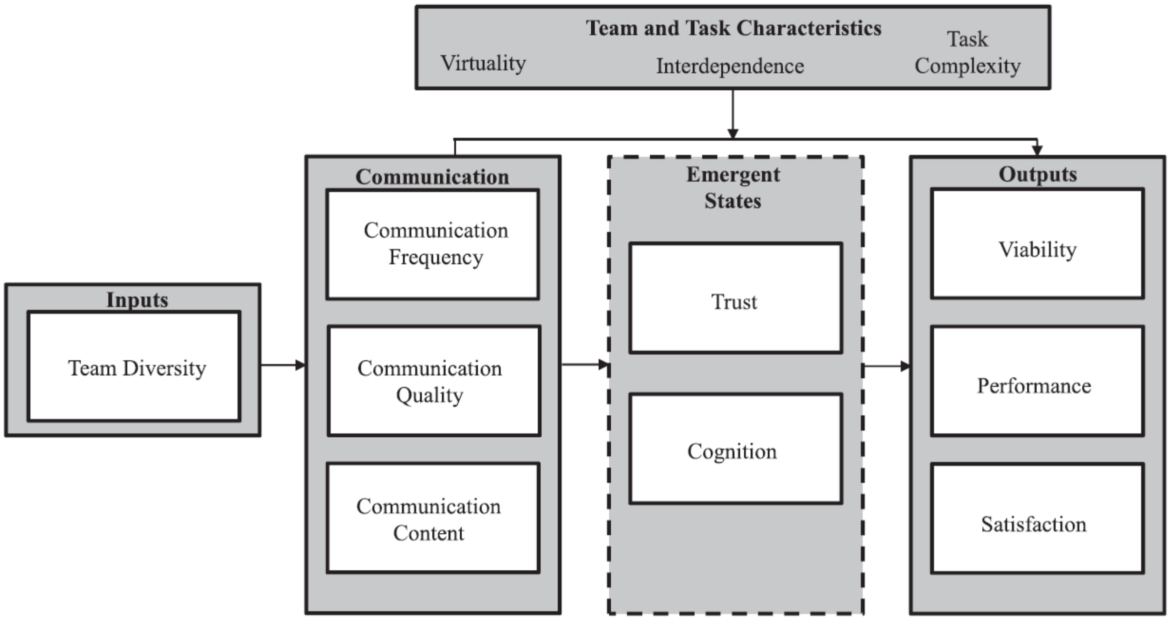



*Figure 3.* Communication process framework proposed by Marlow, Lacerenza, and Salas (2017).

As discussed earlier, media richness is tightly linked to virtuality, and both play large roles in the potential quality of communication that a team can use. Co-location improves team activity awareness and coordination (Gutwin, Greenberg, & Roseman, 1996), and leads to better communication between team members by allowing teams to share gestures and nonverbal communication (Wallace, Scott, Stutz, Enns, & Inkpen, 2009). Thus, virtuality and media richness are fairly similar, and differing degrees of virtuality/co-location have different implications for the communication quality of teams.

Videoconferencing, a rich medium, provides high informational value and high concurrency/synchronicity. This means that it should allow for timely communication and CLC, indicators of communication quality according to Marlow et al. (2017). In addition, the high informational value and high concurrency/synchronicity of videoconferencing means that it should allow communication that is clear, effective, complete, fluent, and on time, all indicators of communication quality according to González-Romá and Hernández (2014).

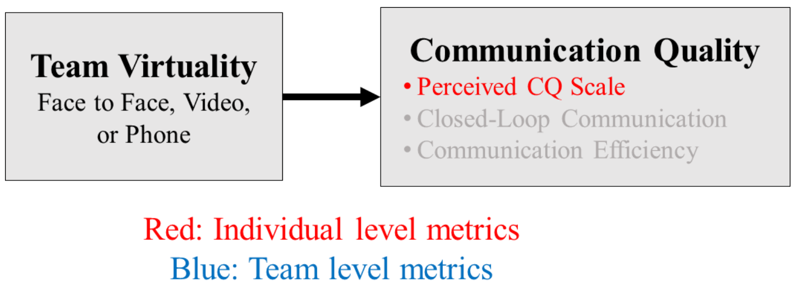
However, recall that videoconferencing is not a perfect substitute for the richness of face-to-face communication (Straus & Olivera, 2000). Suboptimal camera positioning can lead to decreases in trust and communication effectiveness (Bekkering & Shim, 2006). This occurs because people expect eye contact patterns during a conversation to match face-to-face communication, but camera positioning that does not recreate this and leads to feelings of distrust. Beyond this, the lack of colocation between video call participants can also lead to difficulties when deictic expressions such as “here” or “that” are used, reducing the communication effectiveness of the team (Nguyen & Canny, 2007). This occurs because deictic expressions rely on contextual information that can be more difficult to understand clearly when speakers are not in shared spaces. Therefore, videoconferencing is more virtual and slightly less rich than face-to-face communication.

Compared to videoconferencing, voice calls are slightly more virtual and slightly less rich. Without a visual component, voice calls lead to slightly lower communication comprehension between speakers, as they lose the ability to read facial expressions. Seeing a speaker’s face improves detection of speech noise and speech intelligibility (Grant, 2001; Grant & Seitz, 2000; Schwartz, Berthommier, & Savariaux, 2004). In situations where communication is ambiguous, we rely on facial expressions to help us understand what a speaker means. Furrowed brows reveal worry, anger, or questioning. Sly smiles reveal sarcastic jokes. Without these important indicators, words become slightly more difficult to understand. Thus, voice calls are slightly less rich than videoconferencing, which is slightly less rich than face-to-face communication. Compared to face-to-face communication, voice calls are a moderately rich medium.

This study compares face-to-face teams, video call teams, and voice call teams, in descending order of media richness (Daft & Lengel, 1984). Media richness theory suggests that voice call teams will have the most communication issues, due to the inability of teams to see each other's faces, which helps to resolve communication ambiguities (Grant & Seitz, 2000). Media richness theory also suggests that video call teams should communicate similarly to, but not quite as well as, face-to-face teams. This is because both media allow people to see each other's faces. However, as discussed earlier, the lack of co-location between video call participants introduces several small drawbacks to communication, such as difficulties when using deictic phrases (Nguyen & Canny, 2007). Face-to-face teams have the highest richness and the lowest virtuality. The richness afforded to a face-to-face team avoids many drawbacks of voice or video calls, suggesting that participants in the former condition should perceive their communication to be of a higher quality than participants in the other conditions (Gutwin et al., 1996; Wallace et al., 2009).

Voice call teams are the most virtual of the three, due to the moderate informational value of voice communication compared to the high informational value provided by face-to-face communication. Without being able to see each other's faces, voice call participants are less able to intuitively resolve communication ambiguities by looking at each other's faces. This should lead participants of these teams to have the lowest subjective ratings of communication quality. Video call teams gain the ability to see each other's faces, which should lead to a higher perception of communication quality compared to voice call teams. Face-to-face teams, with the richest medium of communication and no obstacles to clear communication, should have the highest subjective ratings of communication quality.

Given that teams with less media richness and higher virtuality should experience the most communication issues due to the difficulty of resolving ambiguities without seeing each other's faces, and given that videoconferencing is slightly less rich and slightly more virtual than face-to-face communication, I hypothesize the following:

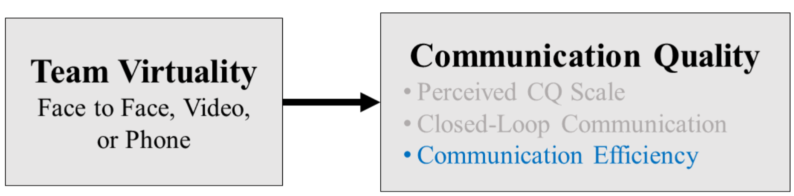



**Hypothesis 1a.** Virtuality will have a negative effect on participants' perceived communication quality scores, such that co-located participants will have the highest communication quality scale scores, voice call participants will have the lowest, and video call participants will be in between.

Recall that communication quality is reflected in the extent to which communication is clear, effective, fluent, complete, and on time (González-Romá & Hernández, 2014). In this way, high-quality communication involves the timely transmission of useful, clear information that is directly relevant to the task at hand. Providing unnecessary information risks overloading the listener with irrelevant information, reducing comprehension (Cruse, 2006). Thus, it can be said that communication efficiency is a facet of communication quality: transmitting the same information in a more efficient manner improves the overall quality of the message.

In our previous discussion of co-location, virtuality, and communication, parallels were drawn between the richness of a medium and the quality of the communication it should afford. Face-to-face communication is the richest medium, allowing teammates to resolve some communication ambiguities by seeing each other's faces; the ability to see another's face provides critical diagnostic information that helps in understanding their speech (Grant & Seitz, 2000; Schwartz et al., 2004). In this manner, working in a shared physical environment is likely to bolster communication efficiency by enabling non-verbal communication (Wallace et al., 2009).

In contrast, working via a less-rich medium such as a voice call is likely to reduce communication efficiency, as voice calls are a more limited form of communication than face-to-face speech. Participants using voice calls do not have the ability to resolve communication ambiguities by seeing each other's faces, and so they will likely have to ask more clarifying questions. Ultimately, given the limited richness of voice communication, participants in the voice call condition are likely to speak more to transmit the same amount of information as face-to-face teams. Video call participants are likely somewhere in between, perhaps closer to face-to-face teams. This presents the possibility of an inverse relationship between virtuality and communication efficiency, which is a facet of communication quality. As such, I hypothesize the following:



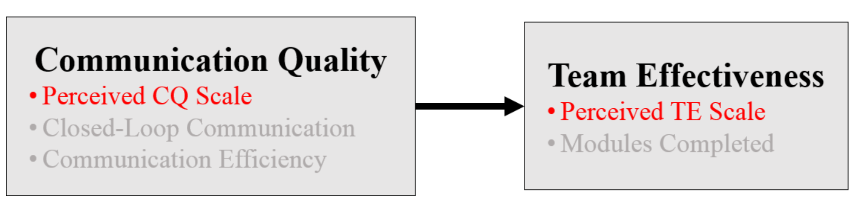

**Hypothesis 1b.** Virtuality will have a negative effect on participants' communication efficiency, such that co-located participants will have the highest communication efficiency, video call participants will have a moderate amount, and voice call participants will have the lowest.

**Communication and Team Outcomes**

Communication is fundamental to a team's coordination and collaboration efforts, as it allows for the distribution of task-relevant information (Pinto & Pinto, 1990; Salas, Sims, &

Burke, 2005). Broadly, research supports the link between communication and team performance; a meta-analysis of 72 studies by Mesmer-Magnus and Dechurch (2009) revealed a significant positive relationship between information sharing and team performance. Communication positively influences team performance because it allows other team processes and outcomes to develop more effectively (Kozlowski & Ilgen, 2006). Wong and Burton (2000) suggest that communication is a key predictor of VT performance because it enables effective team coordination. Empirical research also supports the link between communication and team performance in VTs (Campion, Papper, & Medsker, 1996; González-Romá & Hernández, 2014). Overall, research trends generally support the notion that communication is strongly linked with teamwork (Dinh & Salas, 2017).

Fundamentally, a team that communicates effectively is able to transmit task-related information more effectively; as a result, this information can be more easily applied to the task at hand, leading to improved team outcomes. The experimental task used in this study was selected because it elicits a considerable amount of communication within teams that perform it. Given the strong relationships between team communication and team performance outlined above, it seems that participants that believe their team has high quality communication may subsequently be likely to perceive their team as being effective at the experimental task. As such, I hypothesize the following:




**Hypothesis 2a.** Perceived communication quality will be positively related with participants' perceived team effectiveness scores, such that teams that report higher communication quality scale scores will also report higher team effectiveness scale scores.

Closed-loop communication (CLC) is a process by which two speakers exchange information to ensure that a message is delivered correctly. For example, consider the following discussion:

Alex: It says to cut the red wire.

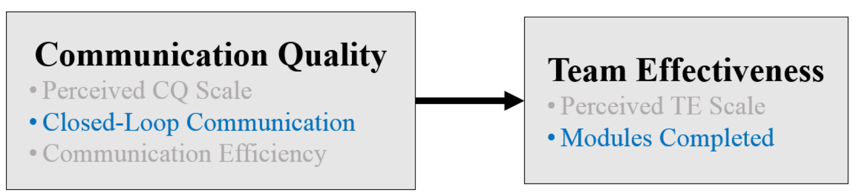
Betty: Cut the red wire?

Alex: Yup, that's correct.

Here, Alex delivers information. Betty sends a message back acknowledging the information she received. Alex then 'closes the loop', signaling to Betty that she received the information and interpreted it correctly. CLC helps teams to ensure that information is sent, processed, and received accurately (McIntyre & Salas, 1995). Broadly, teamwork literature associates CLC with improvements in accurate information transmission. (Salas et al., 2005) argue that CLC is a critical coordinating mechanism of teams, improving the quality of communication between speakers. Marlow et al. (2017) additionally suggest that CLC can mitigate some of the problems associated with virtual teamwork. If team members verify the correct transmission and receipt of messages using CLC, they encounter more opportunities to clarify ambiguities and thus improve team functioning.

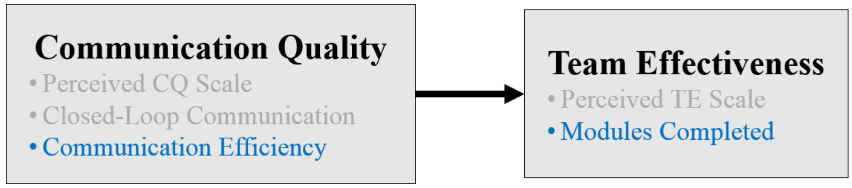
The use of CLC in real-world teams extends to several domains; medicine is one example, and in that domain, literature supports the ability of CLC to improve team outcomes. TeamSTEPPS is a widely used evidence-based set of teamwork tools designed to help healthcare professionals improve communication, teamwork, and patient safety; one component of TeamSTEPPS involves training healthcare workers how to use CLC. The latest research in this direction suggests that CLC improves task completion times, speed, and efficiency in pediatric trauma resuscitation (El-Shafy et al., 2017). Other research into the occurrence of foreign body entrapment in thoracic surgery suggests that the implementation of CLC can reduce the prevalence of this medical error (Schuenemeyer et al., 2017).

In the context of this study, CLC may translate to improved team functioning by reducing the error rate and increasing the success rate of teams. Participants that communicate with fewer errors should perform with fewer errors, so CLC is likely to improve team effectiveness on the experimental task. Effectiveness will be encapsulated by Modules Completed (MC), which reflects the number of task modules successfully completed by a team. Teams will be tasked with completing four tasks, each with a 5-minute timer. There are 16 modules divided among the four tasks. Thus, teams that complete the task more effectively will have a higher MC. Given that CLC reduces communication errors and is argued to improve team functioning by smoothing the transmission of information between teammates, I hypothesize the following:




**Hypothesis 2b.** The use of closed-loop communication will be positively related with teams' number of modules completed, such that teams that use more CLC will have a greater MC.

To build upon the previous hypothesis, there may be a similar relationship between a team's communication efficiency and its MC. Recall that communication efficiency is a facet of communication quality. Providing too much information can overload the listener and reduce comprehension (Cruse, 2006). However, teams that can convey the same amount of information in less time and using fewer words should be able to complete the timed task more effectively. Each task module has a set solution that teams are tasked with discovering. Every team must discover the same set of solutions in the same allotted time. Ergo, teams that are able to find the solutions with less communication should, on average, be finishing more modules in the allotted time. Hence, I hypothesize the following:




**Hypothesis 2c.** Higher communication efficiency will be positively related with a team's number of completed modules, such that teams with higher communication efficiency will have a greater MC.

**Trust**

Research into trust first began in the 1950s and 60s, with seminal articles that investigated the nature of trust and cooperation between individuals. These early works sought to evaluate how various factors related to trust, such as suspicion and trustworthiness (Deutsch, 1958, 1960), cooperative behavior (Solomon, 1960), and communication (Loomis, 1959; Mellinger, 1956). However, until Rotter's work in the late 1960s (Rotter, 1967), there was not a foundational definition and description for the construct of trust. As such, many earlier works that investigated trust inconsistently operationalized it. Once authors began researching the construct of trust directly, various definitions began to emerge, but there were consistencies tying them together.

Rotter (1967) defined trust as an "expectancy held by an individual that the word, promise, or written communication of another can be relied upon" (p.651). Rempel, Holmes, and Zanna (Rempel, Holmes, & Zanna, 1985) defined it as "expectation related to subjective probability an individual assigns to the occurrence of some set of future events" (p. 96). As perhaps the most widely cited definition of trust, Mayer, Davis, & Schoorman (1995) conceptualized it as "the willingness of a party to be vulnerable to the actions of another party based on the expectations that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (p. 712). Thus, while several different definitions have risen to prominence, they tend to share a theme of one's expectations of another.

Trust has a variety of definitions due to its depth as a construct. Trust can be thought of in terms of a person's dispositions, attitudes, decisions, behavior, and more (Rousseau, Sitkin, Burt, & Camerer, 1998). And while it can be conceptualized as a singular dimension (e.g. "do you trust Bob?"), researchers agree that trust is multi-dimensional. In other words, there are different types of trust, suitable for different contexts and relationships.

On the broadest level, authors have conceptualized trust in two ways: as a trait or as a state (Mooradian et al., 2006). When thought of as a trait, trust is considered to be a personality-based construct that reflects a general predisposition to trust others, independent of specific situations or contexts. When thought of as a state, trust is considered something that emerges over the course of one's interactions with others, and based in specific situations or contexts.

Trait definitions of trust have taken several forms. Rotter's (1967) definition of interpersonal trust reflected one's generalized expectancy that others can be relied on. Similar definitions have been put forth by other authors who have applied different names to the concept, such as trust propensity to trust (Mayer et al., 1995), dispositional trust (Roderick M. Kramer, 1999), and generalized trust (Stack, 1978). These definitions are meant to encompass the trusting dimension of one's personality, which reflects the base level of trust that a person brings into a new encounter. For example, someone with a low level of propensity to trust will likely have a lower base level of trust for a new coworker.

State definitions of trust have taken many more forms. One type is affective trust, also known as relational trust (Rousseau et al., 1998) or traditional trust (Lewis & Weigert, 1985; McAllister, 1995). This is the familiar conception of trust as something that develops between people over time and after multiple shared experiences. This type of trust is built across repeated interactions and is strengthened when parties behave predictably in situations of uncertainty and ambiguity (Rempel et al., 1985). Affective trust tends to be based in emotion rather than reason or logic, serving the social side of interactions. In contrast to this is cognitive trust, which is described in the following section, and serves as a construct of interest in the proposed study.

**Cognitive Trust**

Cognitive trust stands in addition to affective trust, and together, these two form the foundations for the various types of state trust (McAllister, 1995). Cognitive trust is based in cognitive choices of "whom we will trust in which respects and under which circumstances, and we base the choice on what we take to be 'good reasons,' constituting evidence of trustworthiness" (Lewis & Weigert, 1985, p. 970). In other words, cognitive trust tends to be based in reason and logic rather than emotion. By evaluating the logic associated with trusting another, cognitive trust provides an early basis upon which one can trust new team members with whom one does not have a shared history of experience. In a work context, cognitive trust is primarily rooted in one's rational assessment that another party is competent, reliable, and able to work effectively (Erdem & Ozen, 2003; Greenberg, Greenberg, & Antonucci, 2007; McAllister, 1995). Given evidence that another party has these characteristics, one can develop cognitive trust in them.

Cognitive trust is reflected in several other conceptions of trust spanning business and organizational literature. In some cases, the construct is called competence trust, reflecting the basis of this type of trust in the perception of another's competence (Barber, 1983; Ibrahim & Ribbers, 2009). In business environments, Lui and Ngo (2004) suggest that trust is based on goodwill trust and competence trust, which appear to mirror McAllister's affective and cognitive trust constructs. Whatever the terms used, perceptions of competence are arguably a critical foundation of trust (Das & Teng, 2001; Sako, 2002). In healthcare, competence based trust between administrators and physicians plays a large role in successful strategic decision making, and is related to decision quality, commitment, and understanding (Parayitam, 2010). At least one study has found that cognitive trust and competence perceptions can be applied to devices, largely forming the basis for how we decide to continue using smartphones throughout their usable lifespan (Idemudia & Raisinghani, 2014). Competence based trust and cognitive trust thus appear to address the same construct: a rational judgment that another can be relied on based on their perceived competence.

In VTs, cognitive trust is related to swift trust, which occurs when temporary group members must rapidly develop interpersonal trust in order to accomplish some team function (Meyerson et al., 1996). In VTs, swift trust involves two components: the first is an initial presumption that the ad hoc team is trustworthy, and the second is the execution of goal-oriented normative actions like team planning (Crisp & Jarvenpaa, 2013). Swift trust, while easily formed, is also easily broken in the face of the types of communication disruptions that can commonly occur in VTs, especially those that are highly geographically dispersed (Cramton, 2001).

Swift trust is different from cognitive trust in that swift trust stems from a team's temporality, surface-level cues, and imported information about others (Wildman et al., 2012), whereas cognitive trust stems from a rational basis for trusting others based on perceptions of competence or reliability (McAllister, 1995). The two are related in that cognitive trust makes up a significant portion of a team's swift trust; without initial reasons to believe that an ad hoc team is trustworthy (i.e. cognitive trust), swift trust cannot exist. Thus, cognitive trust forms the foundation of a VT's early interactions, and serves as a construct of interest in the proposed study.

Cognitive trust was selected for this study to the exclusion of other types of state trust (such as affective trust) primarily due to the scope of interaction between participants in this study. Participants are allotted a maximum of 20 minutes of interaction on this task. This amount of time is fairly limited, and within that span, it is unlikely that any meaningful amount of affective trust will develop among participants. However, cognitive trust forms quickly among early team interactions (Meyerson et al., 1996), and given its importance to ad hoc teams, analysis of cognitive trust will provide important insights into how it is affected by team communication and how it affects team outcomes.

Authors have argued for additional types of trust in the literature, such as role-based trust (Barber, 1983) or deterrence-based trust (Rousseau et al., 1998), but these are outside the scope of the present research, which will primarily investigate a team's cognitive trust as well as each team member's initial propensity to trust. By evaluating both trait-based and state-based trust, this study can better capture the variety of effects that trust has on a VT's interactions. While distinctions between trait and state trust are sometimes difficult to operationalize (Rotter, 1967), it is critical to the process of clear and effective trust evaluation (Mooradian et al., 2006).

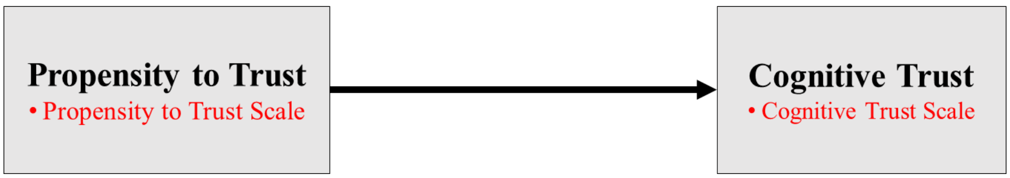
**Propensity to Trust**

Propensity to trust is a dispositional trait reflecting a general willingness to trust others. Within the context of a team, it reflects one's general willingness to trust teammates, and provides one with a baseline level of trust before they even have any information about their teammate (Mayer et al. 1995). Early work by Deutsch (1958, 1960) revealed that participants tended to either be generally trusting or untrusting of their anonymous counterparts. Later work by Rotter (1967) would concretely establish this dispositional aspect of trust as well as the first scale for its measurement. Hofstede (1980) found that people with different cultures and personality experiences varied in their propensity to trust.

Propensity to trust is a critical precursor for trust and collaboration (Brown, Poole, & Rodgers, 2004). Alone, propensity to trust is not sufficient for later trust development, but it does positively influence one's odds of eventually trusting another (Greenberg et al., 2007). A meta-analysis by Colquitt et al. (2007) supported the positive relationship between propensity to trust and later trust among groups.

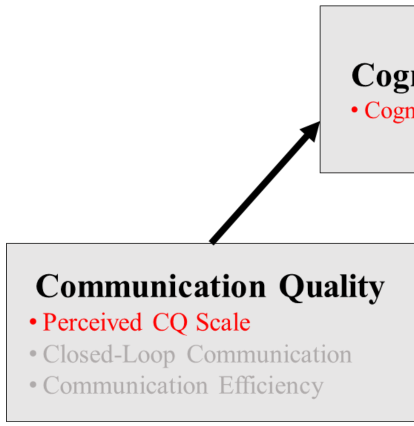
Some research suggests that one's propensity to trust positively affects one's ability to work in VTs (Jarvenpaa et al., 1998). This is likely due to the ad hoc nature of VTs; propensity to trust is a critical component of VT interactions as it allows VT members to have a baseline level of trust for each other in the absence of knowledge about each other (Meyerson et al., 1996; Robert et al., 2009). However, much extant research into propensity to trust in virtual teams is theoretical in nature, and there is a need to understand how propensity to trust interacts with other teamwork constructs. To address this gap, this study will analyze participants' propensity to trust as it relates to their cognitive trust of their teammates. Colquitt et al. (2007) found a positive relationship between participant propensity to trust and later overall trust among their groups. Other researchers have demonstrated the importance of propensity to trust as a prerequisite for later perceptions of trust, implying that low or high propensity to trust relates to subsequently lower or higher levels of trust in future interactions (Greenberg et al., 2007;

McKnight, Cummings, & Chervany, 1998). The findings in these studies suggest that participants that come into the present study with a high propensity to trust will report a higher trust of their partner due to the relationship between propensity to trust and later trust perceptions. While cognitive trust is primarily based in perceived competence, and lacks an affective component, it is likely that this pattern of results should still follow the trends in the aforementioned studies. Therefore, I hypothesize the following:




**Hypothesis 3.** Propensity to trust will be positively related with participants' cognitive trust scale scores, such that participants with high propensity to trust will report higher cognitive trust scale scores.

Communication and trust are critical to effective teamwork. Communication is a critical coordinating function for teams (Salas et al., 2005), and effective communication is a foundation for trust development in teams (Chowdhury, 2005). The experimental task in this study involves a considerable amount of interdependency, as teams will be working together to defuse virtual bombs. If one participant does not communicate well, the team's performance will suffer, because the other participant will be unable to receive the information they need to complete their portion of the task. Communicating information with teammates promotes trust and cohesion among group members (Mesmer-Magnus & Dechurch, 2009), and some researchers have demonstrated that, in virtual teams, communication behaviors such as response timeliness and provision of feedback can promote or damage trust (Henttonen & Blomqvist, 2005; Jarvenpaa & Leidner, 1999). Thus, in a situation involving poor communication, a participant would likely perceive their poorly-communicating teammate as unreliable or not competent enough to complete the task well, because the team's outcomes depend on effective coordination of efforts. Given the previously-discussed literature that supports that notion, I hypothesize the following:

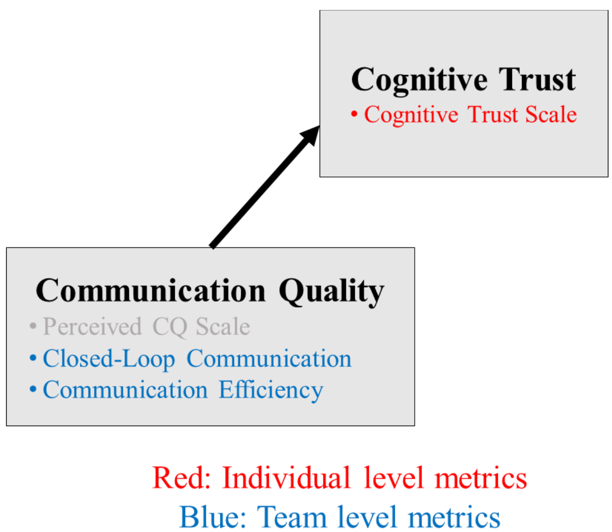



**Hypothesis 4a.** Perceived communication quality will be positively related with participants' cognitive trust scale scores, such that teams that report higher communication quality scale scores will also report higher cognitive trust scale scores.

As discussed previously, CLC helps teams to ensure that information is sent, processed, and received accurately (McIntyre & Salas, 1995), and is associated with improved transmission of information (Marlow et al., 2017; Salas et al., 2005). The verification process of CLC allows teams more opportunities to clarify ambiguities and thus improve team functioning.

Hypothesis 2b predicts that CLC will be positively related with teams' total number of modules completed (MC), a measure of effectiveness. This is because CLC should reduce the number of communication errors that occur between teammates, improve the communication quality of the team and resulting in more modules being completed. In a similar vein, it is likely that participants that use more CLC will be perceived as more reliable and competent because of their lower error rate. This should be reflected by higher cognitive trust scale ratings.

Relatedly, I posited earlier in Hypothesis 2c that a team's communication efficiency will be related with MC. Teams that communicate the same information more efficiently, i.e. in fewer words and less time, will have an advantage over their less-efficient counterparts due to the interdependent and timed nature of the experimental task. Given the communication-heavy nature of the experimental task, and the task's high level of interdependence, a participant that believes their partner is an inefficient communicator is not likely to believe that their partner is competent or reliable, leading to lower cognitive trust scale scores. Conversely, a team of highly efficient communicators, seeing more task success, should consider each other to be more competent and reliable, leading to higher cognitive trust scale scores. Given the relationships that CLC and communication efficiency may share with cognitive trust, I hypothesize the following:



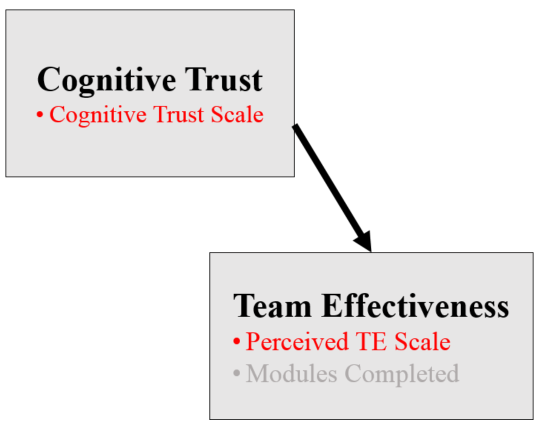

**Hypothesis 4b.** The use of closed-loop communication will be positively related with teams' cognitive trust scale scores, such that teams that use more closed-loop communication will report higher cognitive trust scale scores.

**Hypothesis 4c.** Higher communication efficiency will be positively related with teams' cognitive trust scale scores, such that teams with higher communication efficiency will report higher cognitive trust scale scores.

The consequences of trust in teamwork have been extensively studied. Broadly, much research indicates that trust is critical to the performance of teams (see an extensive meta-analysis by de Jong, Dirks, & Gillespie, 2015). Trust and team performance are inherently linked because trust forms the basis upon which team interactions can occur, allowing team members to rely on each other to complete their share of tasks. Without this trust, team members cannot rely on each other to complete assigned tasks, crippling the interdependence that forms the very definition of a team. When team trust is strong, however, teams are able to take risks that facilitate coordination, cooperation, and team effectiveness (Colquitt et al., 2007).

Much research has also been conducted to evaluate the role that trust plays in VTs (Gilson et al., 2015). In line with other teamwork literature, studies suggest that trust is positively related with VT performance (Furumo, 2009; Hayzak & Suchan, 2001). Research by Crisp and Jarvenpaa (2013) suggests that cognitive trust in ad hoc VTs has the effect of increasing the team's confidence, leading to higher subsequent trust and performance. A recent and comprehensive meta-analysis of trust in VT research supports the link between trust and team effectiveness (Breuer et al., 2016). However, the authors note that that much of the empirical research included in their meta-analysis did not compare trust effects in virtual and face-to-face teams directly while controlling for other variables.

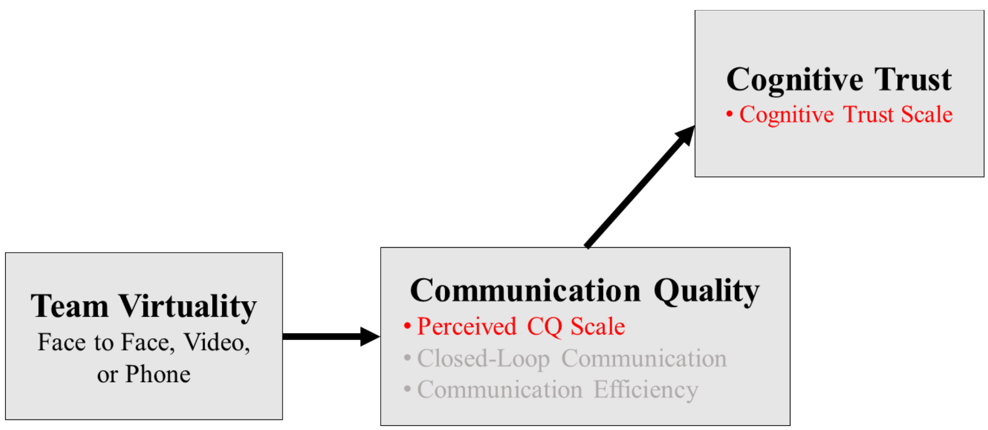
Recall that cognitive trust is a type of trust characterized by a belief that another party is competent or reliable at performing some task, and that it stems from a rational choice to trust another based on that competence. Compared to the rest of the literature discussed in this section, the body of literature specifically linking cognitive trust to team performance is smaller. Erdem and Ozen (2003) conducted a study of fifty work-based teams, concluding that both cognitive and affective dimensions of trust were related to overall team outcomes. Teams that showed higher cognitive and affective trust ratings performed better than those that showed lower ratings on those. Research by Webber (2008) supported that link, and demonstrated a similar relationship between cognitive/affective trust and eventual team outcomes. While little research exclusively considers the relationship between cognitive trust and team performance, given the research supporting the broad relationship between trust and team outcomes, it is likely that teams that display higher cognitive trust will also display higher perceived team effectiveness. In this study, this means that participants that rate their teammates as more reliable and competent are more likely to believe that their team was effective at the given task. Conversely, participants that believe their teammates were unreliable are more likely to believe that their team performed poorly, which would reflect in lower team effectiveness scale ratings. Consequently, I hypothesize the following:




**Hypothesis 5.** Cognitive trust scale scores will be positively related with participants' team effectiveness scale scores, such that teams that report higher cognitive trust scores will also report higher team effectiveness scale scores.

A decrease in virtuality has the potential to increase communication quality in that highly virtual teams should have the lowest communication quality, less virtual teams should have better communication quality, and co-located teams should have the best communication quality.

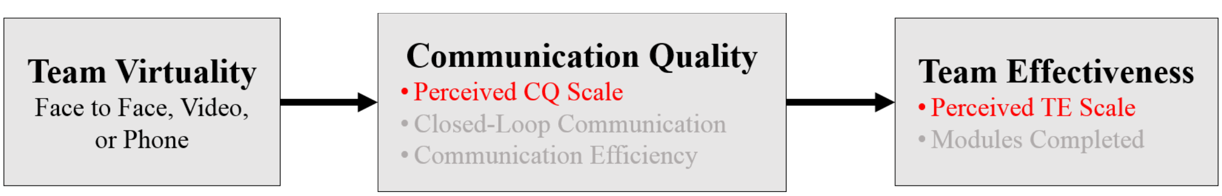
Further, better communication quality should lead to a higher level of cognitive trust among participants. This implies that communication quality could mediate the relationship between a team's virtuality and the cognitive trust of its members. For this to occur, team virtuality would have to be related to the cognitive trust scale ratings provided by team members. It is likely that the lower media richness of voice call teams will eventually result in lower team cognitive trust scale scores due to the communication quality drawbacks inherent to the medium. Conversely, it is likely that the high richness of co-located teams will result in higher cognitive trust scores, which would conceivably due to the better communication quality of that medium. Thus, it is plausible that communication quality mediates the relationship between a team's virtuality and its effectiveness. Accordingly, I hypothesize the following:




**Hypothesis 6.** Perceived communication quality will mediate the relationship between team virtuality and cognitive trust scale scores, such that co-located teams with high communication quality scale scores will have the highest cognitive trust.

As argued earlier, a decrease in virtuality has the potential to increase perceived communication quality in that participants in voice call teams should have the lowest perceived communication quality ratings, video call participants should have better communication quality ratings, and co-located participants should have the best communication quality ratings. Further, Hypothesis 2a posits that participants with a higher perception of communication quality will have a higher perception of their team effectiveness. This implies that perceived communication quality ratings could mediate the relationship between a team's virtuality and their participants' perceptions of the team's effectiveness.

For this to be true, a team's virtuality would have to be related to the perceived team effectiveness ratings. Research discussed in the previous sections generally suggests that, due to the communication limitations and lower media richness of virtual teams, face-to-face teams are superior to virtual teams in situations where either can be used. It is reasonable to imagine that given those limitations, voice call teams in this study will have the lowest perceived team effectiveness ratings, video call teams will have higher perceived team effectiveness, and face-to-face teams will have the highest ratings; this serves as a prerequisite condition for investigating a mediation effect between the three constructs of virtuality, communication quality, and team effectiveness. If there is a relationship between virtuality and perceived team effectiveness ratings, it is plausible that perceived communication quality ratings mediate the relationship between a team's virtuality and the perceived team effectiveness ratings provided by participants. Hence, I hypothesize the following:




**Hypothesis 7.** Perceived communication quality will mediate the relationship between team virtuality and team effectiveness scale scores, such that collocated teams with high communication quality scale scores will have the highest TE scale scores.

Ultimately, this study will offer extensive insight into the processes, performance, and outcomes of virtual versus face-to-face teams. The preceding hypotheses are represented in model form in Figure 4 and in text form in Table 2. In addition, Table 3 on page 68 contains the study constructs as well as the proposed measurement methods. The next chapter details the methods, materials, and measurements that will be utilized by the study.

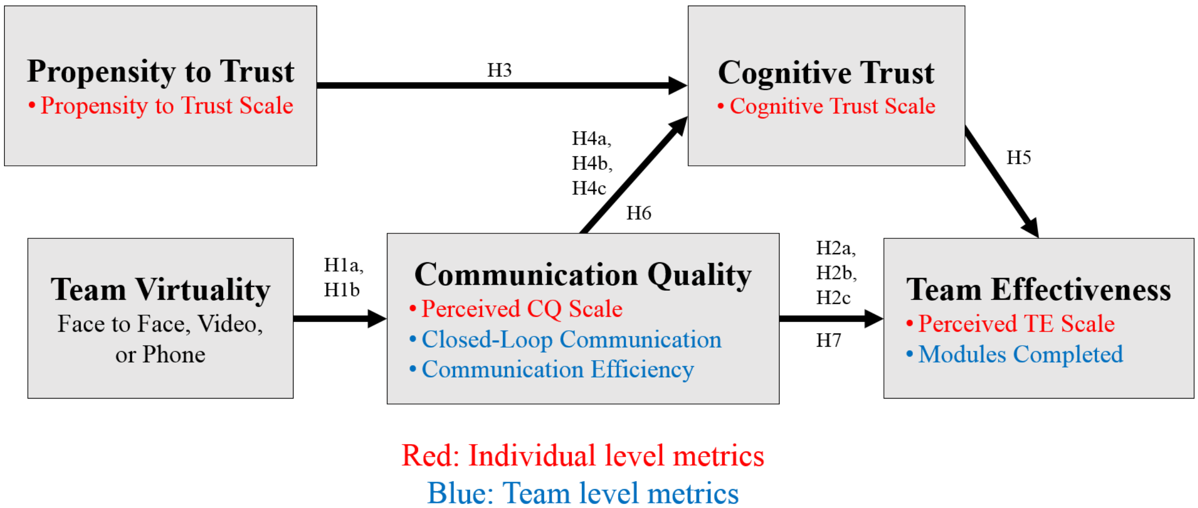



Figure 4. *Model of proposed relationships between study constructs*

*Table 2. List of proposed hypotheses*

| | |
|---|---|
| H1a: | Virtuality will have a negative effect on participants' perceived communication quality scores, such that co-located participants will have the highest communication quality scale scores. |
| H1b: | Virtuality will have a negative effect on participants' communication efficiency, such that co-located participants will have the highest communication efficiency, video call participants will have a moderate amount, and voice call participants will have the lowest. |
| H2a: | Perceived communication quality will be positively related with participants' perceived team effectiveness scores, such that teams that report higher communication quality scale scores will also report higher team effectiveness scale scores. |
| H2b: | The use of closed-loop communication will be positively related with the number of modules completed (MC) by teams, such that teams that use more CLC will have a greater MC. |
| H2c: | Communication efficiency will be positively related with the number of modules completed by teams, such that teams with higher communication efficiency will have a greater MC. |
| H3: | Propensity to trust will be positively related with participants' cognitive trust scale scores, such that participants with high propensity to trust will report higher cognitive trust scale scores. |

| | |
|---|---|
| H4a: | Perceived communication quality will be positively related with participants' cognitive trust scale scores, such that teams that report higher communication quality scale scores will also report higher cognitive trust scale scores. |
| H4b: | The use of closed-loop communication will be positively related with teams' cognitive trust scale scores, such that teams that use more closed-loop communication will report higher cognitive trust scale scores. |
| H4c: | Communication efficiency will be positively related with teams' cognitive trust scale scores, such that teams with higher communication efficiency will report higher cognitive trust scale scores. |
| H5: | Cognitive trust scale scores will be positively related with participants' team effectiveness scale scores, such that teams that report higher cognitive trust scores will also report higher team effectiveness scale scores. |
| H6: | Perceived communication quality will mediate the relationship between team virtuality and cognitive trust scale scores, such that co-located teams with high communication quality scale scores will have the highest cognitive trust. |
| H7: | Perceived communication quality will mediate the relationship between team virtuality and team effectiveness scale scores, such that collocated teams with high communication quality scale scores will have the highest TE scale scores. |

# CHAPTER THREE: METHODS AND MATERIALS

This section discusses the participants, study design, and materials used.

## Participants

Two-hundred six participants completed the study. The mean age of participants was 21 with a standard deviation of 3.95 years. Participants ranged from 18 to 56 years old. Participants were recruited from around the Embry-Riddle campus using a mix of flyers, classroom recruitment visits, and posts on the campus website. All participants provided informed consent and were offered their choice of course credit or $10 cash as compensation. Specific demographic data about the sample is provided in Chapter Four (Results).

**Participation requirements.** Participants were required to be 18 years of age or older and were required to have normal or corrected vision with no color vision impairments. A pre-screen was used to filter out participants that have previously played the game used in the experiment, Keep Talking and Nobody Explodes.

## Design

A mixed model design was employed for this study in order to evaluate the effects of several sets of factors. One between-subjects factor is assessed. This IV reflects the virtuality level of the team during the experimental task. For Level 1, called face-to-face (F2F), teams were co-located. For Level 2, called video, teams worked virtually and communicated via a Double, a telepresence robot developed by Double Robotics (see Figure 5). This device allows participants to communicate via a video call. The Double was placed in one participant's room, and the other participant joined the video call using a computer and webcam. For Level 3, called voice, the team communicated using a voice call. This voice call was enabled by the voice chat application called Discord, which connected both participant PCs using their microphones and speakers. Thus, the three experiment conditions are F2F, video, and voice.

While one IV was manipulated, another IV was captured as an individual difference variable: propensity to trust (PTT). As discussed in the literature review in Chapter 3, PTT assesses a participant's generalized trust attitude toward others.

Broadly, the DVs and covariates are represented by three variables: cognitive trust, communication quality, and team effectiveness. All three were measured at the individual level, and the latter two were also measured at the team level. Specific metrics and measurement methods are outlined in the two upcoming sections called Self-Report Measures and Effectiveness Measures.

*Figure 5.* Double Robotics telepresence device.

**Procedure**

Teams were randomly assigned to levels of virtuality. To begin the study, team members were shown to their appropriate workstations based on their randomly assigned condition. Co-located participants were in the same computer laboratory. Participants in video and voice teams were in separate computer labs. All seating locations are indicated in Figure 6.

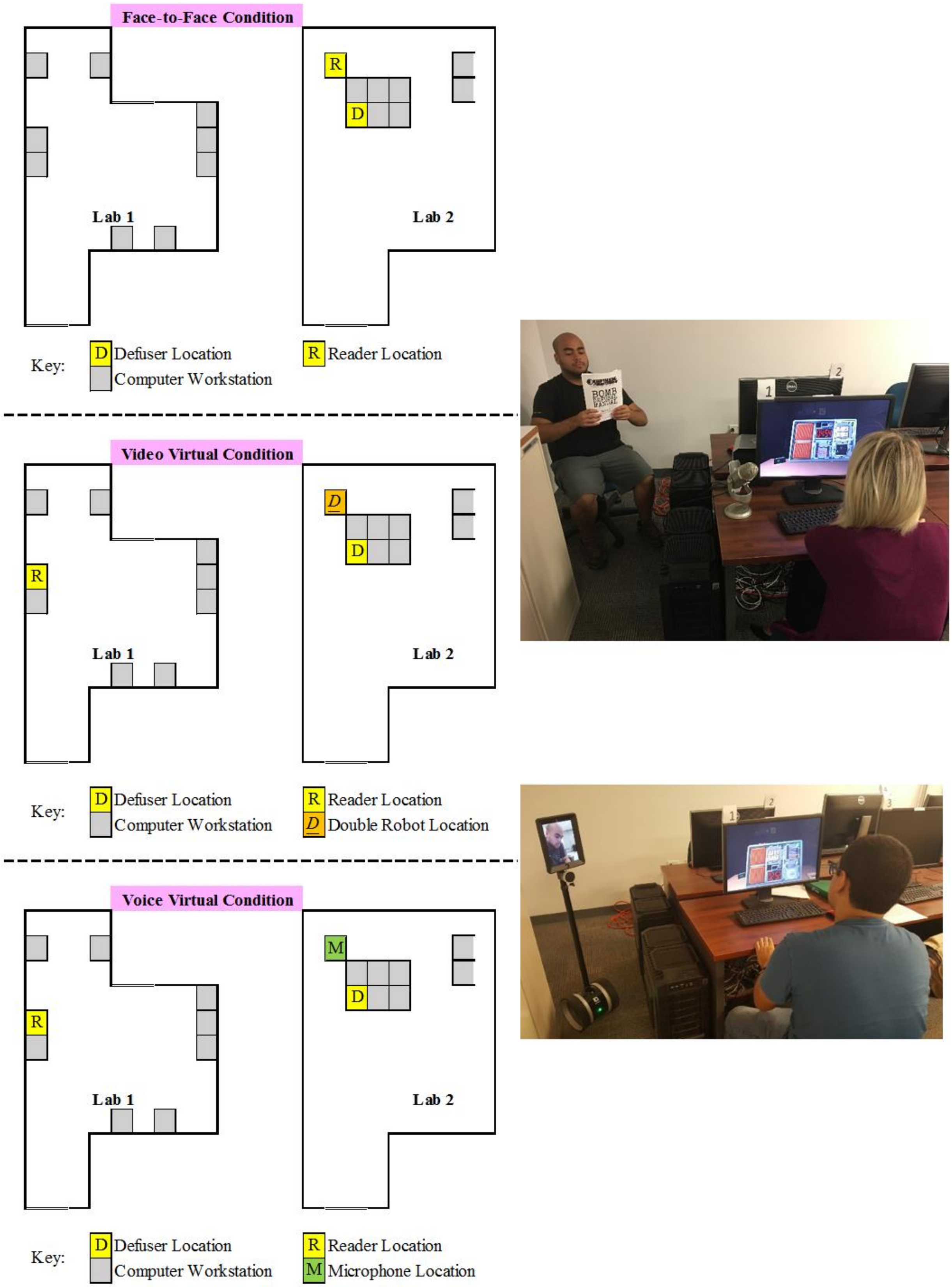



*Figure 6.* Participant seating locations and experimental conditions.

After completing the informed consent process, participants completed a set of pre-task measures, which are outlined in the following section of this chapter. Next, participants were introduced to the experimental task. They were tasked with playing the game Keep Talking and Nobody Explodes (KTANE), a two-player game in which one player defuses a bomb while a second player relays instructions for defusing the bomb’s components (Kane, Fetter, & Pestaluky, 2015; instruction manual available at http://www.bombmanual.com/). The participant that is defusing the bomb is called the defuser, and the player that is reading the instructions is called the reader.

Importantly, neither player can see the other’s materials. In other words, the defuser cannot read the instructions, and the reader cannot see the bomb. As such, this task dictates a high level of interdependency among participants. Figure 7 represents the defuser’s view of the game, and Figure 8 depicts one of the pages in the defusal manual. Appendix H contains the bomb manual pages used in this study, and Appendix I contains images of each bomb that participants encountered.

Participants were first given a training exercise to help them acclimate to the demands of the task. The reader was given a few minutes to read through the developer-created game instructions, which offered guidelines on how the task worked and how to successfully defuse bombs (pages 1 through 3 shown in Appendix H). The defuser was given a few minutes to perform the in-game tutorial, which instructed them on how to interact with the game and the bombs. Both participants performed their training simultaneously but separately. After the training exercise was completed, the reader was given a period of 30 seconds to briefly look through the defusal manual which contains instructions for solving bomb modules (pages 4 through 23 in Appendix H). This step was meant to prevent floor effects among teams; pilot testing with two teams indicated that the 30 second review period somewhat reduced the odds that a team would completely fail all modules, but no so much that teams would hit a ceiling effect.

Following the training, teams were moved to the experimental phase. In this phase, teams were tasked with defusing a series of four bombs, each with a 5-minute timer. With assistance from the developers, the game was modified to produce a consistent series of bombs, such that each team of participants experienced the same series of bombs, with the same panels and the same solutions. Also, in the normal, unmodified game, the bomb timer counts down more rapidly after accruing each strike, which would have made data inconsistent and led to possible floor effects. To remedy this, an additional developer’s help was solicited to modify the game so that the timer counted down at the same rate regardless of the number of strikes that teams accrued.

After completing this series of bombs, participants completed the post-task measures, described in the following section which addresses the measurement and evaluation methods used in the study.

For face-to-face teams, participants were led through the study by one researcher. For the video and voice conditions, two researchers were needed (one in each lab). In those conditions, researchers coordinated with each other silently using an instant-messaging app called Glip to ensure that any communication did not disturb participants or otherwise affect their performance. Using this app, researchers in the video and voice conditions were able to move participants through the study at the same pace despite the physical separation between participants.


*Figure 7.* The defuser’s view of a bomb in KTANE. On this bomb, the three modules must be correctly completed to defuse the bomb; the fourth module displays the time until detonation.

**Self-Report Measures**

**Pre-task.** Upon completing the informed consent process, participants completed a battery of self-report measures meant to assess several constructs. A demographics measure was taken to collect information about participants’ age, ethnicity, and video game experience. See Appendix A for the full set of demographics measures.

The propensity to trust measure developed by Couch, Adams, & Jones (1996) was administered in order to gauge participants’ trusting dispositions. The Generalized Trust subscale of this measure was utilized for this study. It contains 20 items (e.g. “I have few difficulties trusting people”) and participants rated how strongly they agree with each statement on a 1 (strongly disagree) to 7 (strongly agree) scale. See Appendix B for the full scale. The full trust inventory by Couch et al. (1996) also contains a Partner Trust subscale, but this was not relevant to the study as it pertains to trust of one’s romantic partner.

**During task.** After each bomb was completed (successfully or not), participants filled out a cognitive trust scale developed by Wildman et al. (2009) and based on the trust theory of Lewicki, McAllister, & Bies (1998). This 8-item scale taps into participants’ trust attitudes and each item is rated on a 5-point scale from “not at all” to “very much so”. While this measure has not yet been published, it has been validated in both lab and field samples and has shown utility in prior teamwork research (Lazzara, 2013; Wildman, 2011). Appendix C contains the full scale.

**Post-Task.** After the experimental portion was completed, participants completed another set of measures. First, participants completed the Communication Quality Scale developed by González-Romá & Hernández (2014). This scale contains 5 items that assess participants’ perceptions of their team’s communication quality, rated on a 1 to 5 scale. The full measure is available in Appendix D.

Next, participants completed a 5-item team effectiveness measure. This measure is comprised of the Quality subscale from Gibson, Zellmer-Bruhn, and Schwab's (2003) Team Outcome Effectiveness survey. Participants rated their agreement with each of the five items on a 1 to 7 scale. The team effectiveness measure is available in Appendix E.

Last, participants indicated whether or not they were already familiar with their teammate. If so, they were also asked to indicate approximately how many years they had known their teammate, and how often they communicated with the teammate. Finally, teams were prompted to write a few sentences about why they thought their team performed the way it did.

## Effectiveness Measures

**Communication quality: CLC.** In addition to the self-report measure described above, communication quality was assessed based on criteria outlined in Marlow et al. (2017). The authors argue that a critical facet of communication quality involves CLC. As such, all participant communication during the experimental tasks was recorded. The Sound Record function of Windows 7 was used to record participant audio. Audio files were transcribed by a team of trained human factors undergraduate and graduate students using a protocol designed to produce consistent transcriptions; for example, any laugher was coded as “haha”, and any unintelligible words were replaced with “xxxx” to ensure word counts would still remain accurate. Once the files were transcribed, I developed a codebook for CLC, which was based in available CLC coding practices. The codebook was augmented with positive and negative examples of CLC drawn from participant audio transcriptions. CLC was coded for frequency based on each instance that participants closed the loop in a conversation. For example, the following exchange would be coded as one instance of CLC:

Alex: It says to cut the red wire.

Betty: Cut the red wire?

Alex: Yup, that’s correct.

Again, CLC occurs when one party transmits a message, the other repeats it back, and the first party either confirms the accuracy of the message or corrects it. This produced a team-level metric, allowing for comparison of teams across experiment conditions (face to face, video, voice).

Notably, in some cases, CLC occurred among teams in which each step was separated by other sentences. In other words, the communication loop was closed, but it was not in three subsequent sentences. In these instances, CLC was counted and coded as a separate variable. Thus, two CLC variables are recorded: “conservative” CLC and “liberal” CLC, with the former following the tight rule of three consecutive sentences and the latter allowing for loops closed over time. For hypotheses involving CLC, the sum of conservative and liberal CLC counts was used.

**Communication quality: Efficiency.** Communication efficiency is represented by the amount of communication it takes to transmit some amount of information. Every team will encounter the same four bombs, and every bomb will have the same solution. Therefore, there exists a minimum amount of information that can be transmitted in order to defuse each bomb. Teams that perform with higher communication efficiency will speak fewer words while achieving the same outcomes as teams with lower communication efficiency, which will speak more words to achieve those outcomes. For example, a team with high communication efficiency might complete one “Wires” module by speaking 150-200 words, while a team with low efficiency may take 750-800 words to complete the same module. Time is also considered, because a team that speaks less often to achieve the same performance outcomes is communicating more efficiently. Finally, the number of modules completed by teams is also counted. Using these three factors, an equation was developed to objectively measure the efficiency of team communication, reflecting the clarity, effectiveness, and overall quality of the team’s communication in a single number. The equation for communication efficiency is as follows:

$$Efficiency = \frac{Modules\ Completed}{Words\ Spoken\ /\ Seconds\ Taken}$$

Where:

- *Modules Completed* is the total number of bomb modules solved by teams while dealing with each of the four bombs
- *Words Spoken* is the total number of words spoken during all four of a team’s bomb defusals, excluding any communication before the task begins or after it ends
- *Seconds Taken* is the total amount of time spent defusing each of the four bombs, which can be reduced when teams either detonate the bomb by accruing three strikes or defuse it before time expires

There are three ways to increase efficiency. A team can:

1. Speak fewer words (while completing the same number of objectives in the same amount of time)
2. Complete more objectives (while speaking the same number of words in the same amount of time)
3. Take less time (while speaking the same number of words and completing the same number of objectives)

In essence, efficiency is greater when a team extracts more value from the words it speaks – whether it results in more objectives completed, fewer words spoken, or less time taken, all else being equal. The equation is robust to teams that might detonate bombs too early (reducing the number of words spoken and seconds taken); in such situations, efficiency decreases considerably because of the reduced number of modules that a team can eventually solve.

As originally proposed, this study would evaluate communication efficiency in the following manner:

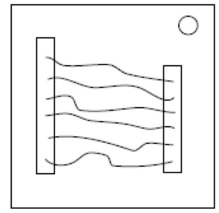
$$E = \frac{Modules\ Completed}{Words\ Spoken}$$

However, this usage does not account for time, and thus cannot account for teams that either run out of time or detonate bombs too early. In other words, this equation would produce the same result whether a team speaks 500 words and solves 5 modules due to delayed, infrequent communication or due to significant errors that lead to early bomb detonations. The adjusted equation detailed earlier in this section accounts for time and serves as a better observed proxy for communication efficiency.

**Team Effectiveness.** In KTANE, each bomb has three to six modules that must be solved in order to defuse each bomb. Since module completion is the primary objective of teams, the number of modules completed by teams was recorded. The first two bombs each had 3 modules, the third bomb had 6 modules, and the last bomb had 4 modules. Thus, each team has a total of 16 modules that can be completed. The more modules a team completes, the better their overall performance. Thus, a team's total number of modules completed (MC) was recorded and assessed as an objective outcome metric.

Keep Talking and Nobody Explodes v. 1 — Wires

## On the Subject of Wires



*Wires are the lifeblood of electronics! Wait, no, electricity is the lifeblood. Wires are more like the arteries. The veins? No matter...*

- A wire module can have 3-6 wires on it.
- Only the one correct wire needs to be cut to disarm the module.
- Wire ordering begins with the first on the top.

| |
|---|
| **3 wires:**<br>If there are no red wires, cut the second wire.<br>Otherwise, if the last wire is white, cut the last wire.<br>Otherwise, if there is more than one blue wire, cut the last blue wire.<br>Otherwise, cut the last wire. |
| **4 wires:**<br>If there is more than one red wire and the last digit of the serial number is odd, cut the last red wire.<br>Otherwise, if the last wire is yellow and there are no red wires, cut the first wire.<br>Otherwise, if there is exactly one blue wire, cut the first wire.<br>Otherwise, if there is more than one yellow wire, cut the last wire.<br>Otherwise, cut the second wire. |
| **5 wires:**<br>If the last wire is black and the last digit of the serial number is odd, cut the fourth wire.<br>Otherwise, if there is exactly one red wire and there is more than one yellow wire, cut the first wire.<br>Otherwise, if there are no black wires, cut the second wire.<br>Otherwise, cut the first wire. |
| **6 wires:**<br>If there are no yellow wires and the last digit of the serial number is odd, cut the third wire.<br>Otherwise, if there is exactly one yellow wire and there is more than one white wire, cut the fourth wire.<br>Otherwise, if there are no red wires, cut the last wire.<br>Otherwise, cut the fourth wire. |

Page 5 of 23

*Figure 8.* The reader's view of a page in the KTANE reader manual.

*Table 3. Summary of study constructs and measurement methods.*

| Construct | Definition | Operational Definition | Authors |
|---|---|---|---|
| Virtuality | Combination of the team's spatial dispersion and reliance on technology-mediated communication | Level 1: Face-to-face teamwork during defusal<br>Level 2: Video call teamwork<br>Level 3: Voice call teamwork | Schweitzer & Duxbury (2010) |
| Communication Quality | Communication that is clear, effective, complete, fluent, and on time | **Individual Metric**<br>• Perceived Communication Quality (PCQ) scale<br>**Team-Level Metrics**<br>• Number of instances of CLC<br>• Communication efficiency (modules completed / words per second) | González-Romá & Hernández (2014); Marlow et al. (2017) |
| Cognitive Trust | Trust based in a person's perceived competence or reliability | **Individual Metric**<br>• Cognitive Trust (CT) Scale | McAllister (1995); Wildman et al. (2009) |
| Propensity to Trust | One's general disposition toward trust of others | **Individual Metric**<br>• Generalized Trust Scale (referred to as PTT, for Propensity to Trust) | Colquitt et al. (2007); Couch et al. (1996) |
| Team Effectiveness | Extent to which a team accomplishes its goals | **Individual Metric**<br>• Perceived Team Effectiveness (PTE) Scale<br>**Team-Level Metric**<br>• Modules Completed (MC) | Gibson et al. (2003); Crisp & Jarvenpaa (2013) |

# CHAPTER FOUR: RESULTS

This chapter details the statistical analyses that were conducted on the various metrics and constructs outlined in Chapter 3. In addition, the hypotheses associated with each analysis are also outlined. Reliability statistics for all self-report measures are provided in Appendix F, and Appendix G contains normal P-P plots and residual scatter plots for the regression analyses.

## Study Sample and Data Screening

Two-hundred six participants (103 teams) were run through the study. One participant indicated partway through the study that they had prior experience playing the game, and one participant accidentally closed the game during the experiment; as such, data from both of those teams was discarded, and the final data pool accounts for 202 participants (101 teams). In 13 of the teams, participants indicated that they were familiar with each other before arriving at the study; analyses indicated no significant differences in performance between familiar and unfamiliar teams, even in the trust measures. Study participants provided information about their racial/ethnic background as well as their video game experience; bar charts reflecting these are provided in Figure 9 and Figure 10, respectively. Neither subject variable significantly affected any of the factors of interest in the study.

In all, more than 208,000 words of spoken audio were transcribed by research assistants, and more than 20,000 points of performance and survey data were collected. Some of the analyses in the Hypotheses section use team-level data (e.g. comparing effectiveness based on virtuality levels) while other analyses involve individual-level data (e.g. comparing perceived communication quality to perceived cognitive trust). Analyses can be discriminated by their $n$ or $df$ values; numbers around 100 indicate a team-level analysis, while numbers around 200 suggest an individual level analysis. This split was done to ensure that statistical effects were not spuriously inflated for team-level analyses.

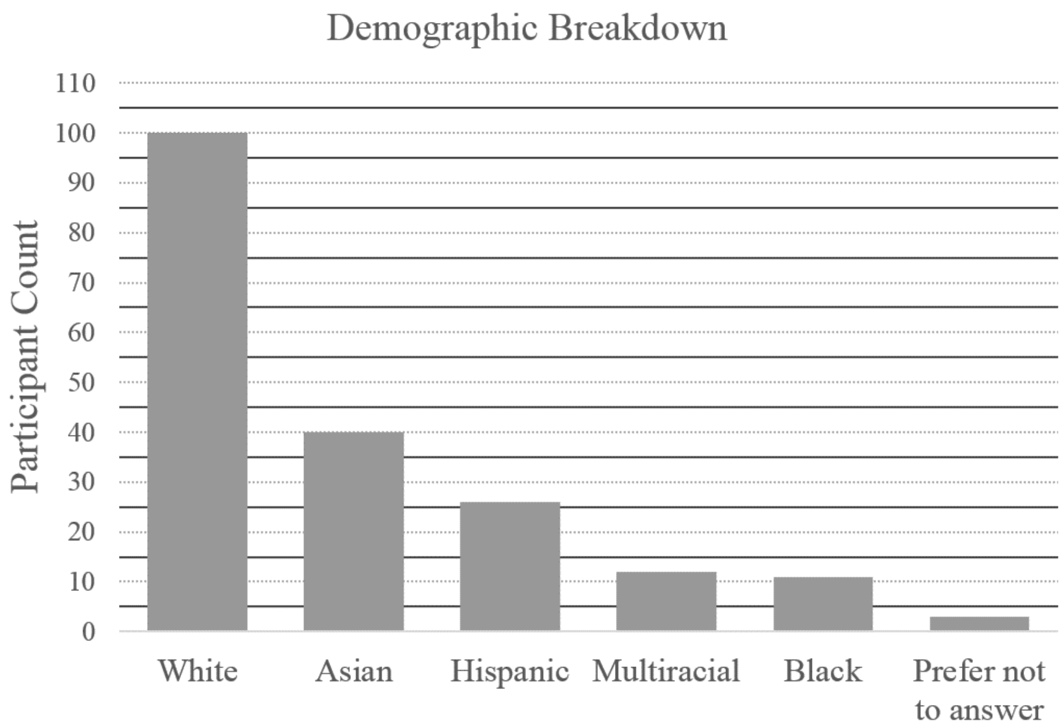



*Figure 9.* Participant racial/ethnic backgrounds.

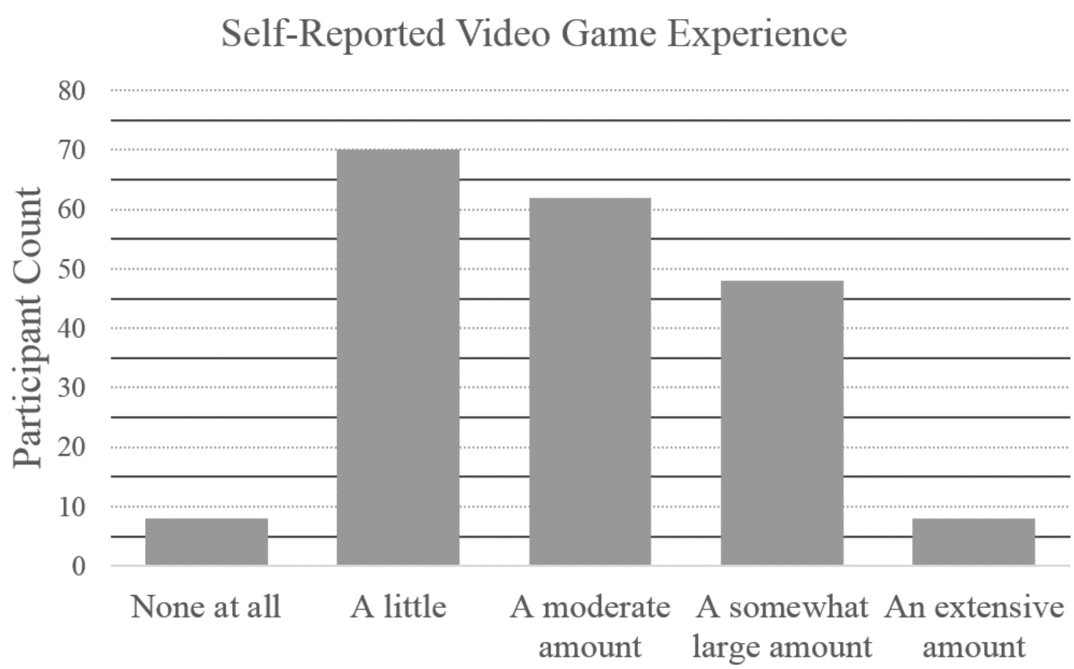



*Figure 10.* Participant video game experience.

## Hypotheses

This section details each of the hypotheses posed for the study as well as the statistics used to evaluate them. Table 4 provides descriptive statistics for the primary variables of interest in the study, followed by Figure 11 which revisits the proposed model.

*Table 4. Variables, means, and standard deviations.*

| Variable | Variable Label | Mean | Std. Deviation | N |
|---|---|---|---|---|
| Number of instances of closed-loop communication | CLC | 12.49 | 6.99 | 98 |
| Modules completed divided by words per second | Communication Efficiency | 3.54 | 2.01 | 89 |
| Score on Propensity to Trust measure | PTT | 99.57 | 13.11 | 202 |
| Sum of scores on Cognitive Trust surveys | CT_Total | 154.94 | 34.42 | 202 |
| Score on Perceived Communication Quality scale | PCQ | 17.42 | 4.45 | 202 |
| Score on Perceived Team Effectiveness scale | PTE | 14.58 | 6.72 | 202 |
| Number of modules completed during task | Modules Completed | 7.04 | 4.06 | 98 |

Note: Slight variations in sample size occurred due to cleaning/ screening procedures and errors in data collection.

## Treatment of Individual Level and Team Level Data

For this study, several variables were measured at the team level (e.g. CLC) and several were at the individual level (e.g. perceived communication quality). Variables can be identified by their sample sizes in Table 4. In that table, N values below 100 indicate a variable measured at the team level and all other variables are measured at the individual level. All hypotheses were analyzed so as to maintain the same measurement levels; in other words, team-level variables were used to predict team-level variables, and individual-level variables were used to predict individual-level variables. The only exceptions are the regression analysis conducted for Hypotheses 4b and 4c and the correlation presented in the following subsection.

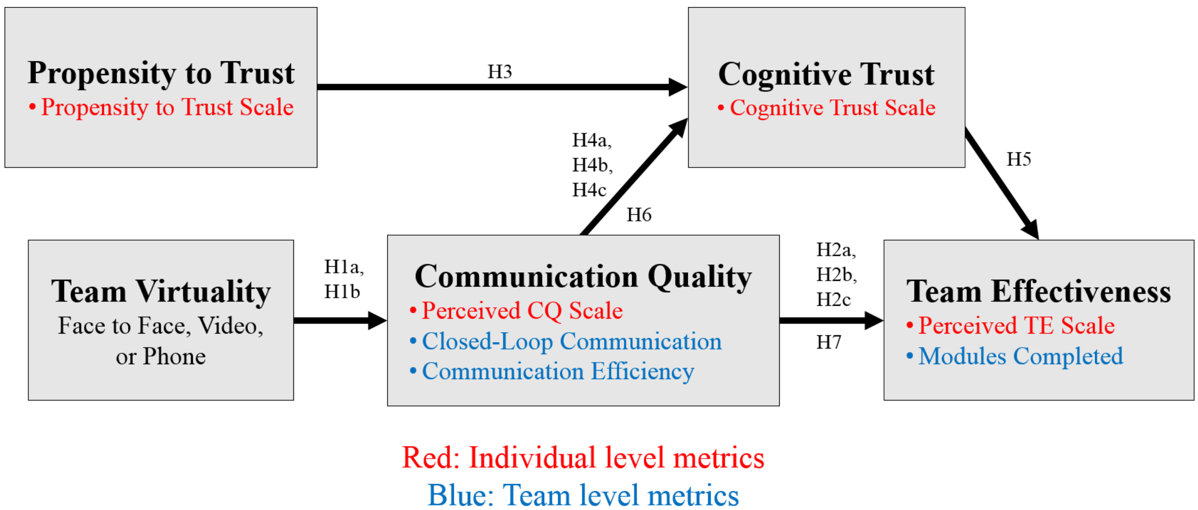



*Figure 11*. Hypothesized relationships between constructs

**Relating self-report measures to outcomes**. To evaluate the relationship between the various self-report measures (PTT, PCQ, PTE, CT) and team effectiveness, a correlation matrix was calculated between those factors and the number of modules each participant completed. The results of the correlations are reported in Table 5. Notably, all of the perception measures were considerably correlated with team outcomes.

*Table 5. Correlations between self-report measures and outcomes.*

| | | PTT | PCQ | CT | PTE |
|---|---|---|---|---|---|
| Modules Completed | Pearson correlation | .122 | **.509** | **.393** | **.553** |
| | P value | .084 | **<.001*** | **<.001*** | **<.001*** |
| | $R^2$ | .014 | **.259** | **.154** | **.306** |

*Note*. Differences marked with * are significant at the 0.05 level

## Hypothesis Testing

**Hypothesis 1a**. Virtuality will have a negative effect on participants' perceived communication quality scores (PCQ), such that co-located participants will have the highest communication quality scale scores.

To compare the three levels of virtuality groups on PCQ, a one-way ANOVA was conducted. Recall that virtuality was classified into three groups: face-to-face (F2F) ($n$ = 68), video virtual ($n$ = 66), and voice virtual ($n$ = 68). There were no outliers, as assessed by boxplot, and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances. PCQ scores in the F2F condition were the highest video ($M$ = 18.22, $SD$ = 4.38), while scores in the video condition were the lowest ($M$ = 16.71, $SD$ = 4.73), with scores in the voice condition falling somewhat in the middle ($M$ = 17.31, $SD$ = 4.18). The differences between the virtuality levels on PCQ scores were not statistically significant, $F(2, 199) = 1.976$, $p = .141$.

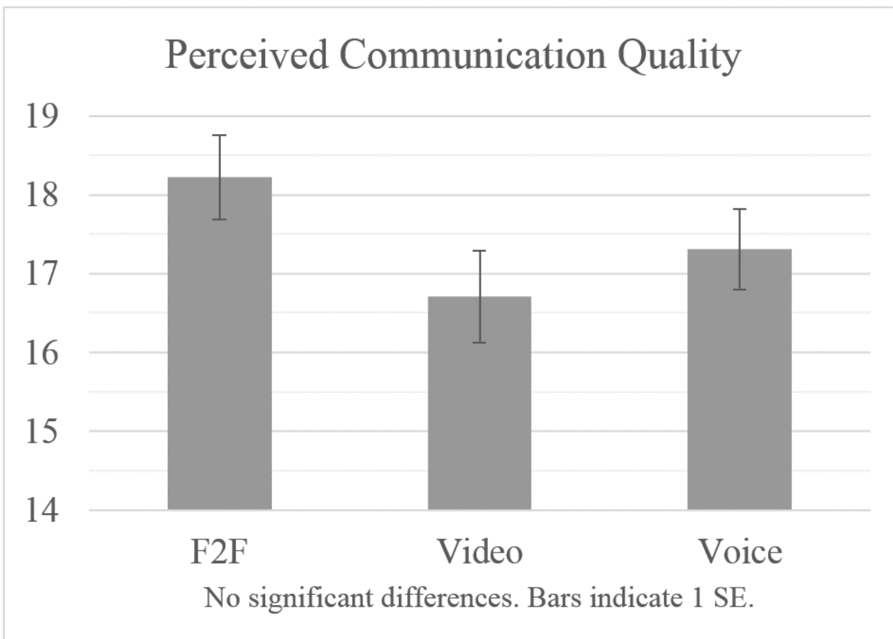



*Figure 12.* Results of Hypothesis 1a.

**Hypothesis 1b.** Virtuality will have a negative effect on participants' communication efficiency. To compare the three levels of virtuality groups on their communication efficiency, the efficiency equation was used for to each team's data (see Chapter 3). Next, a one-way ANOVA was conducted using virtuality as the IV and efficiency as the DV. There was no significant difference between the groups, $F(2, 91) = 0.548$, $p = .580$, suggesting that virtuality did not significantly affect the objective efficiency of team communication. Face-to-face groups (*M* = 3.76, *SD* = 1.74) rated similarly to both video groups (*M* = 3.23, *SD* = 2.04) and voice groups (*M* = 3.59, *SD* = 2.27).

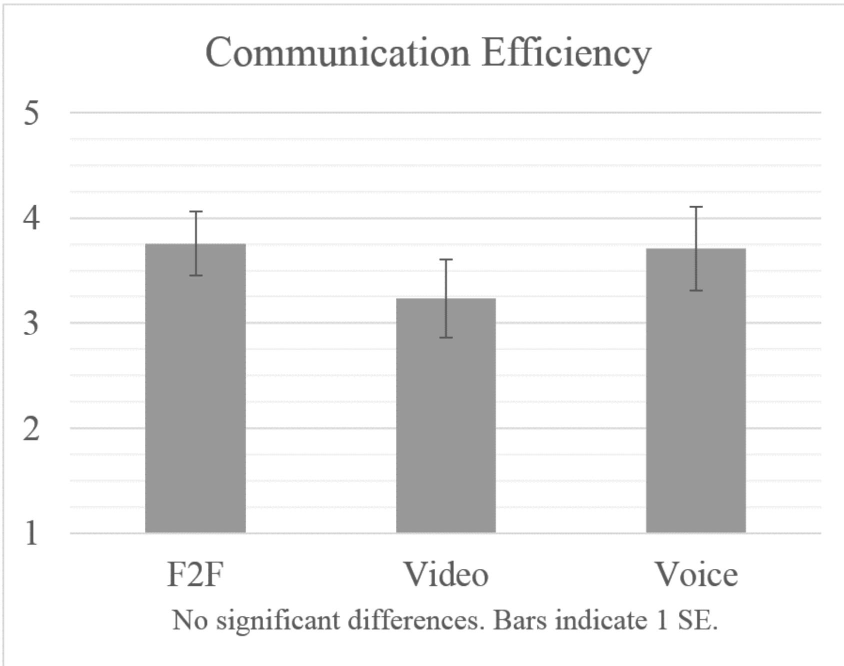



*Figure 13.* Results of Hypothesis 1b.

**Exploratory hypotheses.** The following exploratory hypotheses were not originally proposed when the study began. However, given the non-significance of Hypotheses 1a and 1b, a deeper look into the effects of virtuality on other aspects of team effectiveness are warranted.

**Exploratory hypothesis 1c.** Virtuality will negatively affect participants' number of modules completed, such that higher virtuality will relate with a lower number of modules completed. To evaluate whether team virtuality level affected their outcomes, a one-way ANOVA was conducted. While F2F teams (*M* = 8.12, *SD* = 4.13) completed slightly more modules than either video (*M* = 6.35, *SD* = 4.11) or voice teams (*M* = 6.62, *SD* = 3.88), this difference was not significant, $F(2, 95) = 1.816$, $p = .168$, suggesting that virtuality ultimately did not have a large effect on team effectiveness. There were no outliers, as assessed by boxplot, and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances. The following two hypotheses evaluate whether virtuality affected team trust and team communication.

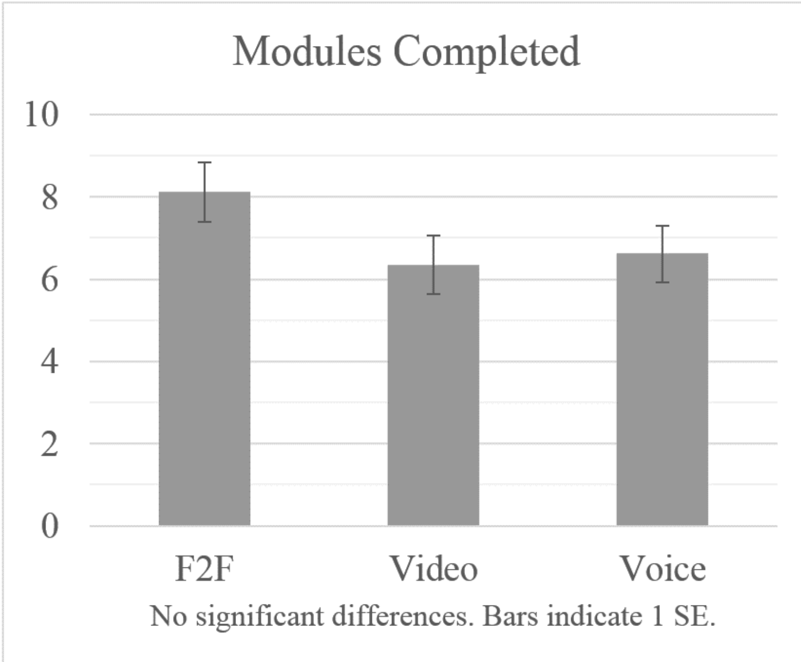



*Figure 14.* Results of Exploratory Hypothesis 1c.

**Exploratory hypothesis 1d.** Virtuality will negatively affect participants' cognitive trust ratings, such that higher virtuality will relate with worse cognitive trust. To evaluate whether team virtuality level affected their perceptions of cognitive trust, a one-way ANOVA was conducted. F2F teams ($M$ = 160.84, $SD$ = 33.90) and video teams ($M$ = 157.76, $SD$ = 31.31) had the highest cognitive trust ratings, and voice teams had the lowest ($M$ = 146.29, $SD$ = 36.55). This difference was significant, $F(2, 199) = 3.446$, $p < 0.05$, suggesting that virtuality has a considerable impact on team cognitive trust perceptions, despite its lack of objective effect on team outcomes. There were no outliers, as assessed by boxplot, and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances. In the context of the previous hypothesis, this finding is very compelling, and the relationship between the two is elaborated in Chapter 5.

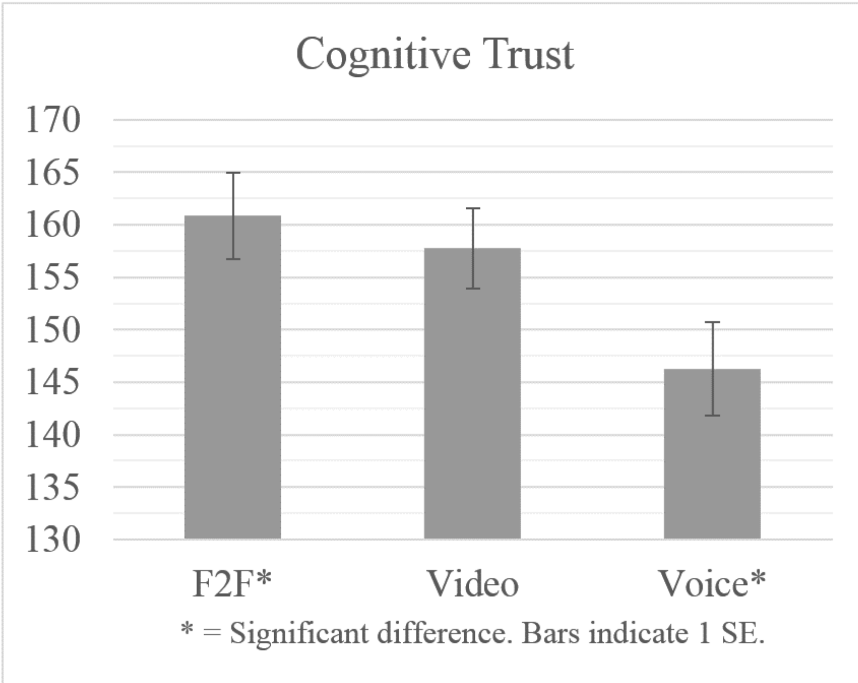



*Figure 15.* Results of Exploratory Hypothesis 1d.

**Exploratory hypothesis 1e.** Virtuality will positively affect participants' use of CLC, such that F2F teams will use the least, and voice teams will use the most. I hypothesize this on the basis that the lower richness of the Voice condition would induce participants to use more CLC to confirm messages sent or received. To evaluate whether team virtuality level affected how often they utilized CLC, a one-way ANOVA was conducted. F2F teams ($M$ = 14.21, $SD$ = 7.64) used the most CLC, followed by voice teams ($M$ = 11.91, $SD$ = 7.12) and then video teams ($M$ = 11.25, $SD$ = 5.79). However, the differences were not significant, $F(2, 95) = 1.651$, $p$ = .197, suggesting that virtuality ultimately did not affect team CLC usage. There were no significant outliers, as assessed by boxplot, and there was homogeneity of variances, as assessed by Levene's test of homogeneity of variances.

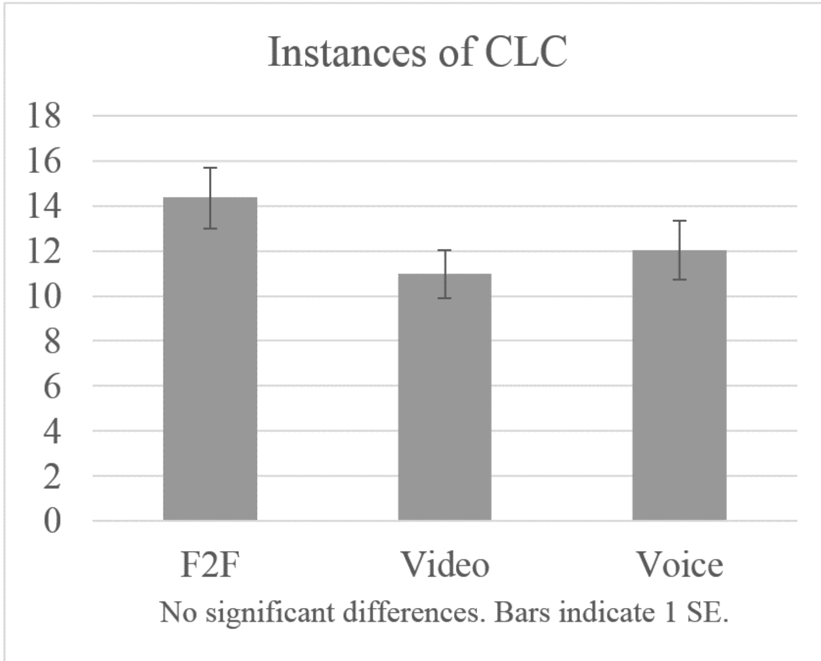



*Figure 16.* Results of Exploratory Hypothesis 1e.

**Hypothesis 2a**. Perceived communication quality (PCQ) will be positively related with participants' perceived team effectiveness (PTE) scores.

To evaluate whether participants' PCQ scores are related to their perceptions of team effectiveness, a linear regression was conducted using PTE as a dependent variable with PCQ as a predictor. The model significantly predicted PTE, $F(1, 200) = 142.614$, $p < 0.001$, $R^2 = .416$. The beta weight for PCQ was .645. Participants that perceived better communication quality also perceived better team effectiveness, likely due to the communication-heavy and largely interdependent nature of the task. Inspection of residual plots reveals no significant outliers or deviations from normality (see Appendix G for figures).

**Hypothesis 2b.** The use of closed-loop communication will be positively related with teams' number of modules completed. **Hypothesis 2c.** Communication efficiency will be positively related with a team's number of completed modules.

To test these two possible relationships, a linear regression was conducted using MC as a dependent variable, with total CLC (the sum of conservative and liberal CLC counts) and communication efficiency scores as predictors. The model significantly predicted modules completed, $F(2, 91) = 299.786$, $p < 0.001$, $R^2 = .868$. The beta weights for CLC and communication efficiency were .061 and .928, respectively, while their p values were .111 and .000, suggesting that CLC was not a useful predictor of effectiveness. The tremendous predictive ability of communication efficiency (and by extension, the outcome of this hypothesis) seems to be considerably artefactual, given that Modules Completed is a component of the equation used to calculate it (see Chapter 3). However, given that it also accounts for the words spoken and time taken by teams during the tasks, it is interesting that the strong relationship remains undiminished. Reviewing the normal probability plot revealed that there were approximately normal distributions among the predictors with no significant outliers (see Appendix G for figures).

**Hypothesis 3**. Propensity to trust scores (PTT) will be positively related with participants' cognitive trust scale scores (CT). To evaluate this prediction, a linear regression was conducted using CT_Total as a dependent variable with PTT as a predictor. The model significantly predicted CT_Total, $F(1, 200) = 37.017$, $p < 0.001$, $R^2 = .156$. The beta weight for PTT was .395. Participants that scored higher on the PTT measure also perceived their partners to be more reliable. Inspection of residual plots reveals no significant outliers or deviations from normality (see Appendix G for figures).

**Hypothesis 4a**: Perceived communication quality (PCQ) will be positively related with participants' cognitive trust scale scores (CT).

To evaluate this prediction, a linear regression was conducted using CT_Total as a dependent variable with PCQ as a predictor. The model significantly predicted CT_Total, $F(1, 200) = 60.68$, $p < 0.001$, $R^2 = .233$. The beta weight for PCQ was .482. Participants that scored higher on PCQ also perceived their partners to be more reliable. Inspection of residual plots reveals no significant outliers or deviations from normality (see Appendix G for figures).

**Hypothesis 4b.** The use of closed-loop communication (CLC) will be positively related with teams' cognitive trust scale scores (CT). **Hypothesis 4c.** Communication efficiency will be positively related with teams' cognitive trust scale scores.

To test these two possible relationships, a stepwise regression was conducted using CT_Total as a dependent variable, with total CLC (the sum of conservative and liberal CLC counts) and communication efficiency as predictors. This analysis would combine team-level data (CLC, communication efficiency scores) with individual-level data (CT scores), so to enable the analysis, each individual participant was analyzed using their team's CLC and communication efficiency scores. Table 6 contains an example of how the CLC and communication efficiency data was utilized to produce a larger sample size for the analysis. This method was chosen on the rationale that each participant's perceptions stemmed differently from the same teamwork outcomes, so there was no need to further adjust the data given that it already represents individuals' natural variance in how they perceive things in relation to team outcomes. If a robust enough relationship between predictors and DV exists, analyzing the data in this manner will produce usable findings so long as all the statistical assumptions for the test are met.

The stepwise regression model significantly predicted CT_Total, $F(1, 186) = 24.21$, $p < 0.001$, $R^2 = .115$, and CLC was not added to the stepwise model, indicating its lack of utility as a predictor. The beta weight for efficiency was .340 with $p < .001$. The utility of communication efficiency is interesting given that it was designed to objectively reflect the communication quality of teams, however, this effect should also be considered with a grain of salt given the outcome of H2c. Inspection of residual plots reveal no significant outliers or deviations from normality (see Appendix G for figures).

*Table 6. Sample data.*

| Participant Number | CT Score | CLC | Comm. Eff. |
|---|---|---|---|
| 1 | 108 | 5 | 2.37 |
| 2 | 214 | 5 | 2.37 |
| 3 | 161 | 7 | 4.76 |
| 4 | 150 | 7 | 4.76 |

**Hypothesis 5**. Cognitive trust scale scores (CT) will be positively related with participants' perceived team effectiveness scores (PTE).

To evaluate whether participants' CT scores were related to their PTE scores, a linear regression was conducted using PTE as a dependent variable and CT_Total as a predictor. The model significantly predicted PTE, $F(1, 200) = 36.61$, $p < 0.001$, $R^2 = .155$ The beta weight for CT_Total was .393. Inspection of residual plots reveals no significant outliers or deviations from normality (see Appendix G for figures).

**Hypothesis 6**. Perceived communication quality (PCQ) will mediate the relationship between team virtuality and cognitive trust scale scores (CT). To evaluate this effect, the mediation analysis method outlined by Hayes (2009, 2013) was followed using individual communication quality scale scores and cognitive trust scale scores. The categorical nature of virtuality was accounted for using the guidelines provided by Hayes and Montoya (2017).

Given the non-significance of Hypothesis 1, which found no significant relationship between virtuality and PCQ scores, the hypothesized mediation effect did not appear. An omnibus test of relative indirect effects of virtuality on CT_Total through PCQ found no significant mediation, given a confidence of interval of (-0.0392, 0.2018). An omnibus test of direct effects of virtuality on CT_Total found a significant effect, $p = .019$, but this effect came with a nearly nonexistent r squared of 0.03.

Despite the lack of a mediation effect, further review of the mediation output revealed significant statistical effects of a model in which the factors of virtuality and PCQ predicted CT_Total, $F(3, 198) = 23.53$, $p < .001$, $R^2 = .263$. To evaluate this better, a linear regression was conducted using virtuality and PCQ as predictors and CT_Total as the dependent variable. The regression model significantly predicted variance in CT_Total, $F(2, 199) = 33.28$, $p < 0.001$, $R^2 = .251$. Beta weights for both virtuality and PCQ were significant at $p < 0.05$, with values of -0.134 and 0.471, respectively. Virtuality was coded in such a way that F2F teams had a value of 1, video teams were 2, and voice teams were 3, so the negative beta weight of virtuality suggests that increasing the virtuality level (i.e. removing more communication dimensions from F2F) decreases PCQ. In short, while there is not a mediation between the three factors of virtuality, PCQ, and CT_Total, it instead appears that virtuality and PCQ jointly predict variance in CT_Total. Semi-partial correlations indicated that PCQ ($r = .469$) and virtuality ($r = -.134$) predicted mostly unique variance in CT_Total when compared to zero-order correlations (PCQ $r = .482$; virtuality $r = -.174$), supporting the idea that virtuality and PCQ predict unique variance in CT_Total. Inspection of residual plots reveal no significant outliers or deviations from normality (see Appendix G for figures).

**Hypothesis 7**. Perceived communication quality (PCQ) will mediate the relationship between team virtuality and team effectiveness scale scores (PTE). To assess this effect, I used the mediation analysis method outlined by (Hayes, 2009, 2013) using cognitive trust scale scores and team effectiveness scale scores. The categorical nature of virtuality was accounted for using the guidelines provided by Hayes and Montoya (2017).

Much like in Hypothesis 6, the non-significance of Hypothesis 1 means that Hypothesis 7's mediation effect for did not appear. An omnibus test of relative indirect effects of virtuality on PTE through PCQ found no significant mediation, with a confidence of interval of (-0.0093, 0.0527). Further, an omnibus test of direct effects of virtuality on PTE found no significant effect, $p = .132$.

While there was no mediation effect, further review of the mediation output revealed significant statistical effects of a model in which the factors of virtuality and PCQ predicted PTE, $F(3, 198) = 49.40$, $p < .001$, $R^2 = .428$. This is a similar to what was found in Hypothesis 6. To evaluate this result better, a stepwise linear regression was conducted using virtuality and PCQ as predictors and PTE as the dependent variable. The regression model significantly predicted variance in PTE, $F(1, 200) = 142.61$, $p < 0.001$, $R^2 = .416$. The beta weight of PCQ was significant at $p < 0.001$ with a value of 0.645. Virtuality was not added to the stepwise model. This suggests that PCQ is the strongest predictor of PTE, and that virtuality has a functionally negligible predictive effect on PTE. Ultimately, this hypothesis appears to be similar to the conclusion found in Hypothesis 6. While there is not a mediation between the three factors of virtuality, PCQ, and PTE, it instead appears that PCQ predicts considerable variance in PTE. Inspection of residual plots reveal no significant outliers or deviations from normality (see Appendix G for figures).

**Structural Equation Model**

A structural equation model was developed to test the relationships between the identified factors of virtuality, propensity to trust, cognitive trust, perceived communication quality, and perceived team effectiveness. Observed variables for PCQ and PTE did not include the team measures of CLC, communication efficiency, or modules completed; this was done to ensure that all measurements in the structural model would be at the individual level, and to avoid the issue of combining that data with team-level data. Thus, based on the relationships between the factors identified in this study, the full model consisted of the latent factors of PTT (20 items), CT (4 items), PCQ (5 items), and PTE (5 items).

**Confirmatory Factor Analysis**. First, a CFA was conducted to establish that the identified factors fit the data sample. Using SPSS AMOS 25, factors were laid out according to the hypothesized and tested relationships between factors (see Figure 11). Overall, the model fit the data acceptably, with a RMSEA of 0.072, $\chi^2$ (521, N = 202) = 1056.980, $p$ < .001. The CFA model is provided in Figure 17.

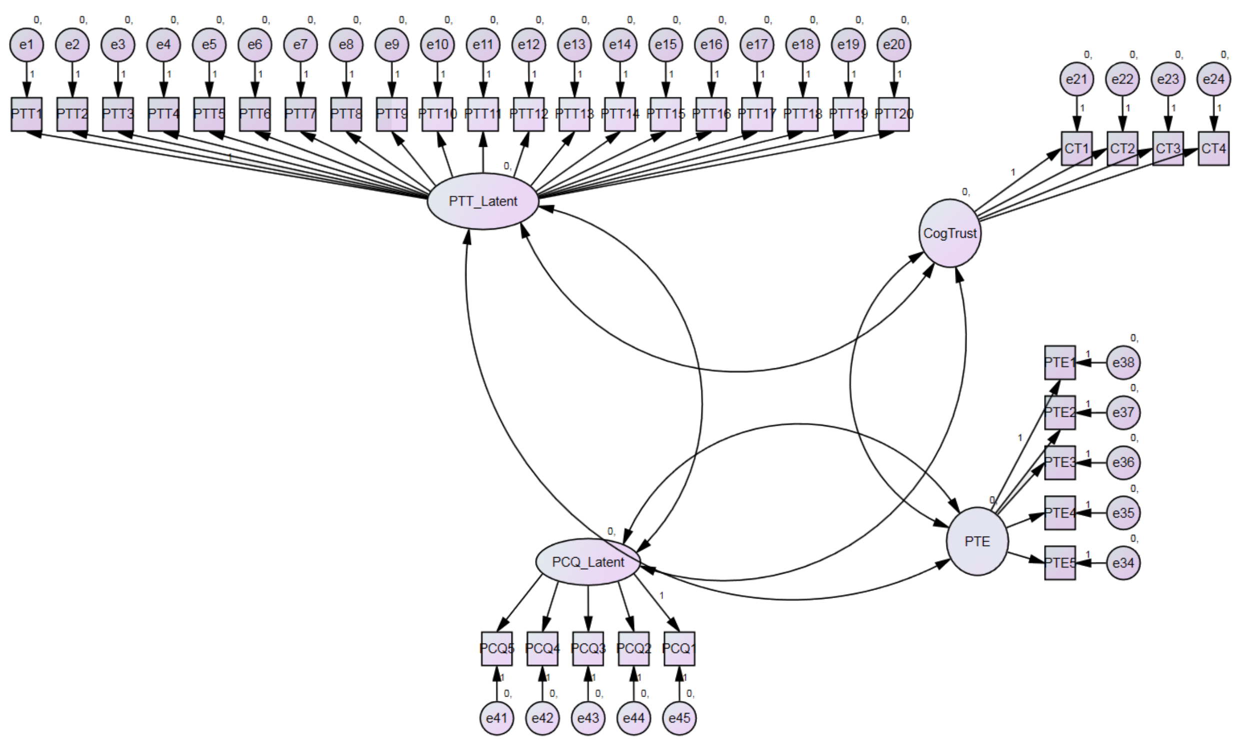



*Figure 17.* Model used to conduct confirmatory factor analysis.

**Testing the Structural Model**. After confirming that the selected arrangement of latent and manifest variables adequately fit the data, the structural model was tested, again using AMOS. In this instance, Virtuality was added to the model in a manner consistent with the hypothesized model in Figure 11. Paths between the factors were also drawn in a manner consistent with the hypothesized model. The resulting structural model is shown in Figure 18. This model was tested and resulted in an acceptable RMSEA of 0.068, $\chi^2$ (555, N = 202) = 1069.937, $p$ < .001. Several steps were taken in an attempt to increase the model's explanatory power.

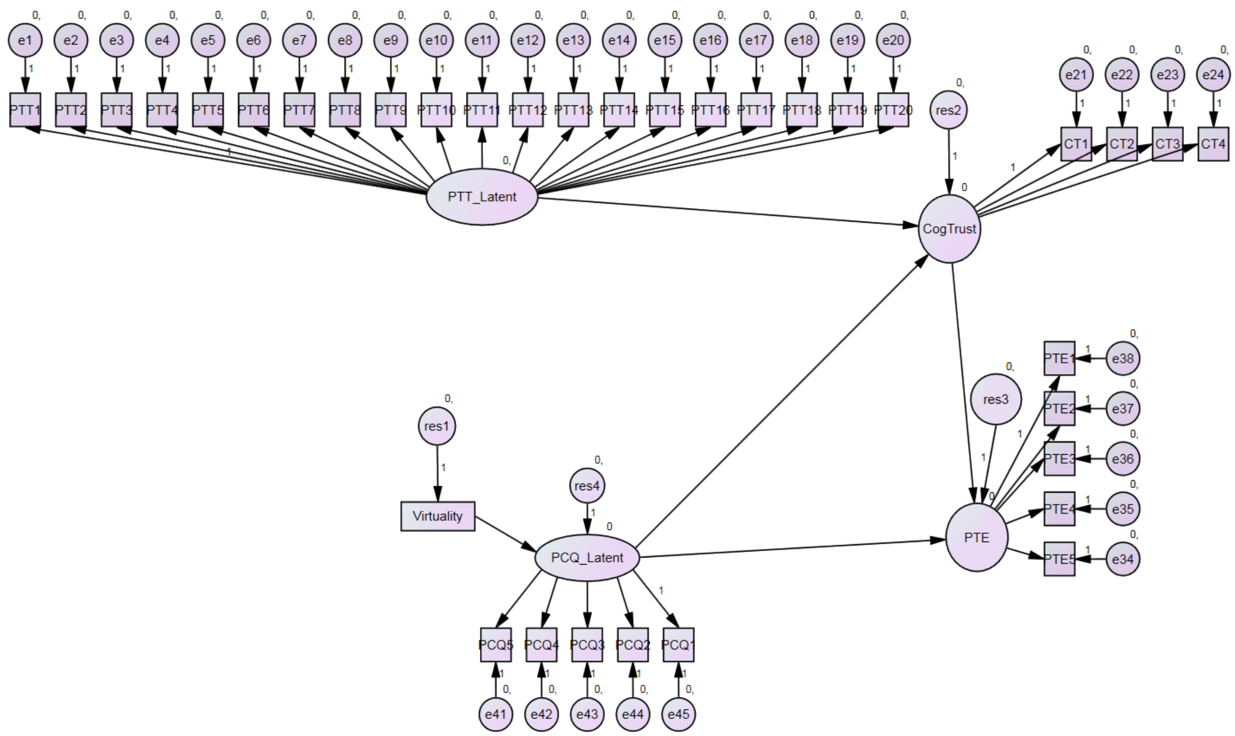



*Figure 18.* First model tested using SEM.

Modification indices indicated that linking several error terms within PTT, CT, and PTE could improve this model's fit. Successive iterations of the model were tested after linking error terms for the following items based on subsequent modification indices: items 3 and 4 on the PTT measure; items 18 and 19 on the PTT measure; CTs 1 and 2; items 1 and 4 on the PTE measure; and items 4 and 5 on the PTE measure. After adding those covariances, two factors were added to the model in an attempt to achieve a better fit: Modules Completed and Role (which had two levels: defuser and reader).

The final model fit the data well, RMSEA 0.058, $\chi^2$ (619, N = 202) = 1043.115, $p < .001$. Additional model fit criteria are provided in Table 7, while standardized regression weights and squared multiple correlations are provided in Table 8 and Table 9, respectively. The final model is provided in Figure 19. While its CFI (.872) fell below the .90 mark recommended by some researchers to indicate acceptable fit (Bentler, 1990; Hu & Bentler, 1999), others recommend avoiding CFI when the RMSEA of the independence model is less than 0.158 (Kenny, 2014). In our case, the null model has a RMSEA of 0.157. Finally, interpretation of Hoelter's critical N values in Table 7 suggests that they fall below the mark of at least 200, which would indicate adequate model fit, but they are above 75, the lowest threshold indicating acceptable model fit (Byrne, 2016; Hoelter, 1983; Kenny, 2014). However, some researchers advise against using Hoelter's CN as an indicator of model fit, recommending others such as RMSEA or CFI (Hu & Bentler, 1999; Kenny, 2014). For clarity of data, Table 7 regardless includes a variety of model fit measures.

Hypotheses 2a, 3, 4a, and 5 all predicted relationships between PTT, CT, PCQ, and PTE, and the analyses in preceding sections supported those individual connections. The structural model in Figure 19 lends support to the whole model originally hypothesized for this study and suggests that the other factors in the model can be used to predict approximately 60% of the variance in participants' perceptions of team effectiveness, approximately 50% of the variance in participants cognitive trust ratings, and nearly 40% of the variance in participants' module completion rates. Specific standardized regression weights for the model are provided in Table 8.

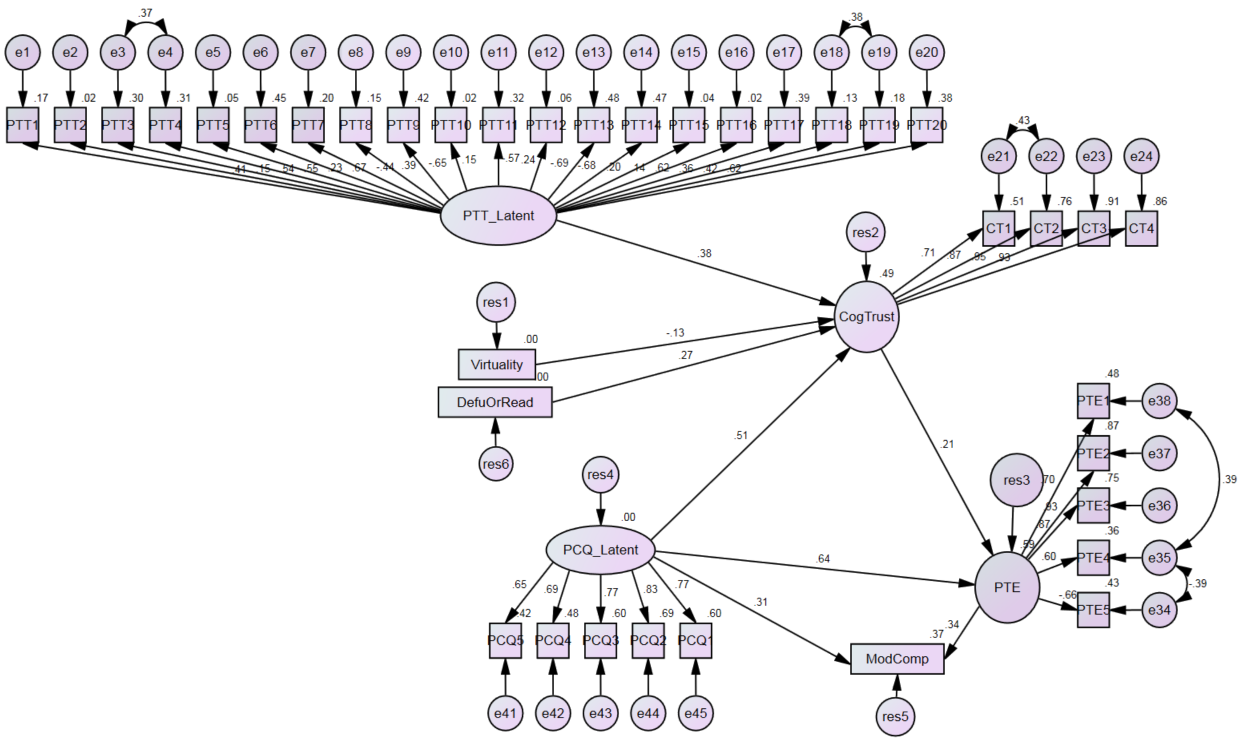



*Figure 19.* Final structural model of relationships, including standardized estimates.

*Table 7. Model fit summary (N = 202).*

| Model | CMIN | DF | RMSEA | NFI | RFI | TLI | CFI | AIC | Hoelter CN .05 | Hoelter CN .01 |
|---|---|---|---|---|---|---|---|---|---|---|
| Default | 1043.115 | 619 | .058 | .737 | .717 | .862 | .872 | 1285.115 | 131 | 136 |
| Saturated | .000 | 0 | | 1.000 | | | 1.000 | 1480.000 | | |
| Independence | 3971.788 | 666 | .157 | .000 | 0 | .000 | .000 | 4119.788 | 37 | 39 |

*Table 8. Standardized regression weights for final structural model.*

| Variable 1 | | Variable 2 | Standardized Weight | P value |
|---|---|---|---|---|
| PTT | → | CT | **.383** | **< .001*** |
| PCQ | → | CT | **.506** | **< .001*** |
| Virtuality | → | CT | **-.130** | **.020*** |
| Role | → | CT | **.267** | **< .001*** |
| CT | → | PTE | **..208** | **.002*** |
| PCQ | → | PTE | **.643** | **< .001*** |
| PTE | → | ModComp | **.344** | **< .001*** |
| PCQ | → | ModComp | **.309** | **.003** |

*Note.* Differences marked with * are significant at the 0.05 level

*Table 9. Squared multiple correlations for model factors.*

| Role | Virtuality | PCQ | CT | PTE | ModComp |
|---|---|---|---|---|---|
| .000 | .000 | .000 | .491 | .592 | .372 |

## Additional Analyses

**Task Role.** To evaluate the effects that participant roles played on their self-report measures, a series of independent-samples t-tests was conducted. The IV of interest was role (reader or defuser) and the DVs of interest were CT_Total, PTT, PCQ, and PTE scores. Of the four comparisons, the two roles only demonstrated a statistically significant difference in CT_Total, $t(200) = -4.321$, $p < .001$. For this variable, readers reportedly had more cognitive trust of defusers ($M$ = 164.97, $SD$ = 28.76) than the trust level that defusers displayed for their readers ($M$ = 144.90, $SD$ = 36.75). Table 10 contains the remaining statistics for these analyses.

*Table 10. Variable means and standard deviations across roles.*

| | | Reader | Defuser |
|---|---|---|---|
| PTT | Mean | 100.26 | 98.88 |
| | Std. Dev. | 12.83 | 13.42 |
| CT_Total | Mean | **164.97*** | **144.90*** |
| | Std. Dev. | **28.76** | **36.76** |
| PCQ | Mean | 17.88 | 16.96 |
| | Std. Dev. | 4.12 | 4.73 |
| PTE | Mean | 15.26 | 13.91 |
| | Std. Dev. | 6.48 | 6.92 |

*Note.* Differences marked with * are significant at the 0.05 level.

**Participant Gender.** To evaluate the effects that participant genders played on their self-report measures, a series of independent-samples t-tests was conducted. The IV of interest was reported gender (male or female) and the DVs of interest were CT_Total, PTT, PCQ, and PTE scores. There were no significant differences between males and females on any of the four comparisons, and Table 11 contains the remaining statistics for these analyses.

*Table 11. Variable means and standard deviations across genders.*

| | | Male | Female |
|---|---|---|---|
| PTT | Mean | 99.02 | 100.40 |
| | Std. Dev. | 12.16 | 14.47 |
| CT_Total | Mean | 153.60 | 156.94 |
| | Std. Dev. | 34.15 | 34.94 |
| PCQ | Mean | 17.38 | 17.48 |
| | Std. Dev. | 4.34 | 4.63 |
| PTE | Mean | 14.81 | 14.25 |
| | Std. Dev. | 6.65 | 6.86 |

Table 12 below outlines the study hypotheses and their outcomes. Following that, Figure 20 depicts a revision to the proposed model of the relationships between the study constructs. This new version of the model reflects the outcomes of the statistical analyses conducted to evaluate the relationships between each of the factors. Of note, CLC has been removed from the construct of communication quality as it was not statistically related to any other variable.

*Table 12. Hypotheses and outcomes.*

| | |
|---|---|
| H1a. Virtuality will have a negative effect on participants' perceived communication quality scores. | Not significant |
| H1b. Virtuality will have a negative effect on participants' communication efficiency. | Not significant |
| EH1c. Virtuality will negatively affect the participants' number of modules completed. | Not significant |
| EH1d. Virtuality will negatively affect participants' cognitive trust ratings. | **Significant** |
| EH1e. Virtuality will positively affect participants' use of CLC. | Not significant |
| H2a. Perceived communication quality will be positively related with participants' perceived team effectiveness scores. | **Significant** |
| H2b. The use of closed-loop communication will be positively related with the number of modules completed (MC) by teams. | Not significant |
| H2c. Communication efficiency will be positively related with the number of modules completed by teams. | **Significant** |

| | |
|---|---|
| H3. Propensity to trust will be positively related with participants' cognitive trust scale scores. | **Significant** |
| H4a. Perceived communication quality will be positively related with participants' cognitive trust scale scores. | **Significant** |
| H4b. The use of closed-loop communication will be positively related with teams' cognitive trust scale scores. | Not significant |
| H4c. Communication efficiency will be positively related with teams' cognitive trust scale scores. | **Significant** |
| H5. Cognitive trust scale scores will be positively related with participants' team effectiveness scale scores. | **Significant** |
| H6. Perceived communication quality will mediate the relationship between team virtuality and cognitive trust scale scores. | Not significant |
| H7. Perceived communication quality will mediate the relationship between team virtuality and team effectiveness scale scores. | Not significant |

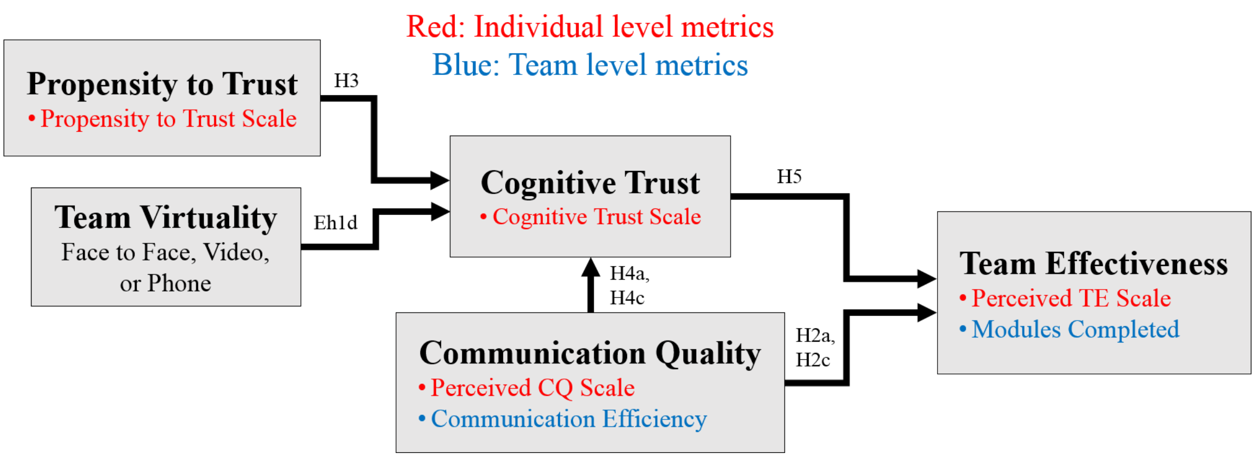



*Figure 20.* Revised model of virtual teamwork factors.

The following chapter provides a more general discussion of these findings, evaluates the types of validity relevant to the study, and addresses the study's limitations. After that, the chapter closes with concluding remarks.

# CHAPTER FIVE: DISCUSSION

In review, 7 out of the 15 proposed hypotheses were supported by the data. This study adds considerably to extant virtual teamwork research by providing lab-based insights into how and why teams perform the way that they do. On balance, rather than developing theories about the study constructs, this study was designed to test existing theory about virtual team trust and communication. The study contributes to modern research that evaluates different degrees of virtuality on teamwork and finds that virtuality did not significantly affect the effectiveness of teams (EH1c) or their perceptions of communication quality (H1a), but it *does* affect team perceptions of cognitive trust (EH1d). The combination of these three hypotheses presents perhaps the most compelling finding of the entire study. Together, they imply that F2F participants perceived their teammates as more reliable than voice-only participants, despite the lack of a difference between effectiveness and perceived communication quality between these groups. It is interesting that this pattern of results occurred, because prevailing theory implies that F2F teams would have performed significantly better and perceived significantly higher communication quality, given the increased media richness of F2F communication (Daft & Lengel, 1984).

The results of this study suggest that seeing a teammate's face inoculates one against the trust-deteriorating effects of virtuality, and this is made most apparent by inspecting the positions of video teams in the charts in Figure 21. Video teams performed equivalently to voice teams, and yet the ability to see each other's faces led video participants to perceive their teammates as more reliable. This finding is of broad value to virtual teams worldwide, especially in situations where they may not get much face time. The results imply that team perceptions of competence and reliability can be improved whether such face time is virtual or in-person, and managers of virtual teams should seek to apply these findings to their management methods given that virtual teams must rely on technology-mediated communication to build trust. Given the relationship between trusting dispositions and cognitive trust ratings (H3), such managers may also consider the effects of their workers' generalized trust levels to better understand how ready they are for virtual teamwork.

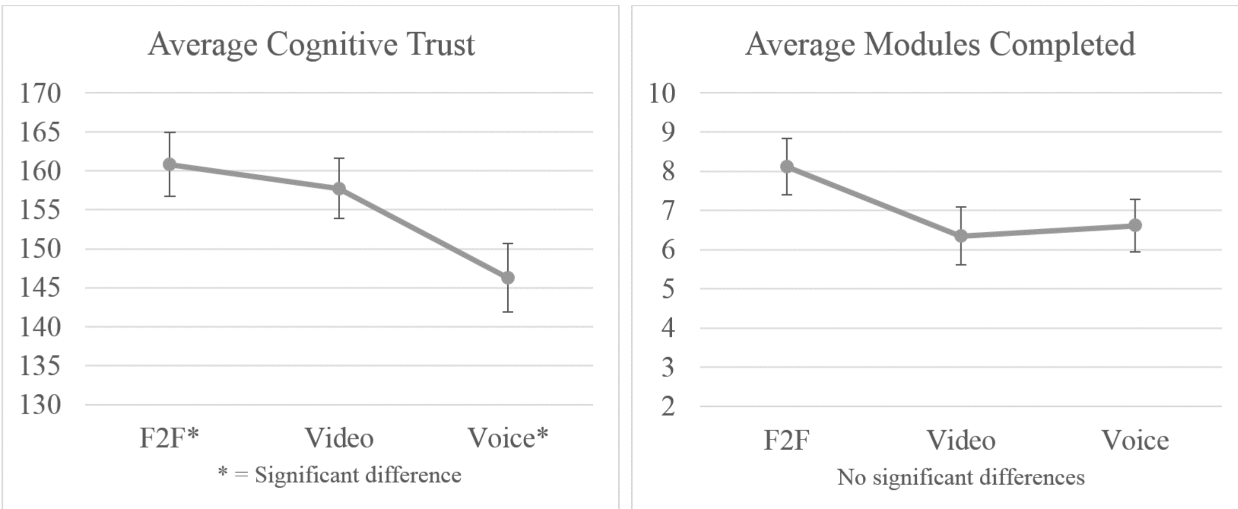



*Figure 21.* Comparisons of cognitive trust and module completion by virtuality level.

The observational measures of communication produced several interesting findings. H1b predicted that virtuality would negatively affect participants' communication efficiency given that unnecessary information can overload listeners with irrelevant information (Cruse, 2006), but this hypothesis was not supported by the data. This is partially due to the operational definition of communication efficiency used in the study. While the method used was improved over what was originally proposed for the study, it still produced a variable that demonstrated considerable overlap with Modules Completed (H2c), and thus lacked clear predictive ability. H4c fared somewhat better, but its actual significance is dubious considering the outcome of H2c. Additional work that builds on these findings should adapt the methods used to improve their effectiveness. For example, an operational definition of communication efficiency that involves nonverbal communication (e.g. affirmative nodding) would be founded by a wider base of literature that supports the efficiency-bolstering effects of nonverbal communication (Grant & Seitz, 2000; Schwartz et al., 2004; Wallace et al., 2009). Given the data collected for this study, this type of nonverbal data was not captured (see the following section on Limitations). Again, future work should look to improving these methods using techniques applied to other domains (c.f. Webster 2017).

The measurement of CLC, while more reliable, related poorly to the other constructs (EH1e, H2b, H4b). Indeed, it appears that team CLC usage does not really affect the study's main constructs of cognitive trust, perceived communication quality, perceived team effectiveness, or modules completed. This may have occurred because teams were evenly scattered on both ends of the CLC usage spectrum: there were both good and bad teams that either sought to confirm lots of information or that did not really use CLC during their performance, and thus using more of it had no bearing on how they performed. Teams tended to use CLC in two general situations:

1. When the reader provided an instruction to the defuser that the defuser wanted to confirm prior to completing the action (e.g. "You said cut the fourth wire?)
2. When the reader wanted to confirm information that the defuser provided previously (e.g. "The green light was flashing?")

The experimental task was such that these two situations would occur many times during the game, and teams of all performance levels approached them by confirming information using CLC – and while some used CLC more than others, it again had no bearing on other effectiveness factors or emergent states. Thus, it appears that CLC usage was an emergent property of the task and teams tended to include it in their communication procedure when encountering either of the two situations above. It would be interesting to assess this finding in a study involving teams that are briefed on CLC methods; presently, literature on CLC suggests that it improves various medical team outcomes by reducing communication errors (El-Shafy et al., 2017; Schuenemeyer et al., 2017), so it would be interesting to apply these findings to the telemedicine setting, which fuses the domains of medicine and virtual teamwork. More generalized research into CLC would contribute to existing research by providing additional insights into how CLC affects teamwork in contexts outside of aviation and healthcare, which are the primary domains of relevance for CLC.

H2a posited that PCQ scores would relate to PTE scores. The extent to which they did so was remarkable: PCQ scores predicted more than 40% of the variance in PTE scores. This is at least partly due to the high interdependence of the experimental task. In KTANE, participants rely greatly on each other in order to achieve team outcomes. Lapses in communication almost certainly lead to lapses in performance, and subsequently, to decreased perceptions of team effectiveness.

H3 predicted that PTT would affect CT on the grounds that PTT is a precursor for later perceptions of trust (Brown et al., 2004; Greenberg et al., 2007). This relationship was supported by the data, as participants with higher initial PTT reported higher cognitive trust of their partners. In other words, participants with more-trusting dispositions appeared more likely to give their teammates a pass when competence or reliability could have been in doubt.

H4a hypothesized a link between participant PCQ scores and CT ratings. The high interdependence of the task again appears to play a part in this finding. One participant cannot perform their role alone, as the defuser doesn’t know what to do and the reader doesn’t know what the tasks at hand are. Thus, team members that communicate better perceived each other as more competent at their roles. This finding pairs interestingly with the analysis that found a significant difference between readers' and defusers' CT perceptions of each other. Despite the fact that defusers consistently reported lower CT of their readers, all teams still displayed a considerable relationship between PCQ and CT.

The relationship between CT and PTE, demonstrated by H5, makes sense given that teams in this study worked in dyads. If one perceives that their teammate is competent and reliable, they might logically also perceive their team to be working effectively at their tasks, except in cases where one believes himself to be the weak link.

H6 and H7, the two predicted mediation effects, were not supported by the data. In both cases, this was because team virtuality did not significantly affect perceived communication quality. Whether this is due to the study's context or to an actual lack of mediation effects, it is not clear. In any case, enough data has been collected to allow for follow-up evaluations of interest. For example, Marlow et al. (2017) theorize that "virtuality moderates the relationship between closed-loop communication and effectiveness such that this relationship is stronger in more virtual teams than in less virtual teams." An exploratory analysis of this claim reveals that there is no moderation effect between those factors. More claims could be evaluated (and eventually published) in this way given that theoretical virtual teamwork literature far outweighs lab-based experimental work on virtual teams.

While the final model indicates a relationship in which PCQ predicts CT, it is quite likely that the two factors vary together instead of in a linear direction from PCQ to CT. Given the broad relationship between communication and trust across applied contexts and across literature, the two factors often develop in tandem (Mesmer-Magnus & Dechurch, 2009). Interestingly, one study implied that the relationship between trust and knowledge sharing was moderated by task interdependence, such that the relationship was stronger when interdependence was low (Staples & Webster, 2008). Further work in this domain will improve our understanding of how these factors relate to each other in different contexts.

Another factor that potentially influenced the trust patterns displayed by participants in this experiment is task criticality. Arguably, the way you trust a partner should be different if you are solving a crossword puzzle together versus defusing a virtual bomb together. In situations with higher criticality, we might place more value on judging someone using cognitive trust versus affective trust, so perhaps a less-critical task than bomb defusal might demonstrate a lower relationship between CT and the other factors.

In summary, the hypotheses that were supported were used to build the model in Figure 20, which better accounts for the relationships between the factors of interest in the study. The biggest change between the originally proposed model and this model is that virtuality no longer serves as an input to communication quality; it instead became an input to cognitive trust given the results of EH1d. On a smaller level, the model also dropped CLC from the communication quality factor given its lack of a relationship to the other factors. Communication efficiency remains in the model because of H2c and H4c, but this is tenuous for reasons outlined above and in the Construct Validity section below. With better methods, future work will shed more light on whether communication efficiency is indeed related to the other factors.

## Future Research

**Directions involving data generated by this study.** Additional data was collected beyond that proposed in the study: the majority of participants also completed questionnaires meant to assess their perceived psychological safety and their beliefs about power distance. Though they fell outside the scope of this dissertation, these measures can provide additional insight into the factors of interest for this study, resulting in more follow-up work. Next, all participants self-reported their genders, so additional analyses could evaluate how team gender composition affects outcomes, and how virtuality relates to those factors (c.f. Baker et al., 2017). Last, all participants provided open-ended text responses to the question "Why do you think your team performed the way that it did?" Parsing these free responses can provide insight into how participants perceived their teammates. For example, cursory inspection of the dataset reveals that some participants assigned blame to their teammates, so this data could be combined with the CT data to find some cutoff point on the measure below which participants start to express negative emotions towards their partners.

Task engagement could potentially have affected participant involvement with the task and their performance in the task. All else being equal, teams that were less engaged with the task and with each other may have perceived lower communication quality or had a worse cognitive trust of each other. Video recordings would have provided insight into task engagement, but only audio was recorded. Follow up work on this study could potentially analyze participant communication using LIWC: the categories of positive emotion, present focus, and achievement could provide insight into how engaged teams are based on how much language they use within those three categories.

**Directions involving other contexts.** Follow up research can seek to evaluate the conclusions drawn by the data. For example, a smaller-scale lab study could evaluate whether the effects in Figure 21 hold true in other contexts, while a larger-scale real-world study could evaluate the relationship between PCQ, CT, and PTE across levels in an organizational hierarchy. Additionally, research in this domain can build outward with related constructs such as power distance (Hofstede, 1984) to evaluate its relationships with various communication constructs. Extant research has identified that power distance influences some communication factors such as tendency to use indirect communication and propensity to interrupt (Merkin, Taras, & Steel, 2014), and additional research can build our understanding of its effects on other aspects of virtual teamwork.

The communication efficiency metric used in this study is a clear target for improvement. Follow up work that evaluates communication from a human factors perspective could benefit from applying some of the principles of Information Theory such as word entropy and information content (Shannon, 2001). Manually counting the bits of information spoken during team communication can be laborious for large data sets, so perhaps researchers can apply linguistics approaches to code the informational content of words using methods such as those used by Bentz and colleagues (2017).

**Limitations**

Several limitations were observed over the course of the study. First, it became apparent during data collection that one of the strengths of the study came from its diverse sample of participants: the study sample was approximately 50% white, compared to America at large, which is approximately 77% white (US Census Bureau, 2016). However, given the range of participant backgrounds and the communication-heavy nature of the task, it would have been prudent to collect data on whether English was a participant’s second language, as well as participants’ level of fluency in the language. These are two uncaptured sources of variance that could have potentially predicted some aspects of team effectiveness.

Second, in the same vein of “uncaptured variance”, some participants used non-verbal communication such as hand gestures during the study. Observation suggests that this communication did not play a large role in any team’s effectiveness, but recording such nonverbal communication would have provided additional insight into the advantages of F2F work versus virtual work.

Third, the selected virtuality levels only covered synchronous communication methods, whereas higher virtuality levels consist of communication methods with increasing asynchrony such as instant messaging or e-mails. The nature of the experimental task was such that these asynchronous teams would have performed disastrously, as the task warrants immediate and high-quality feedback. This exposes a limitation of those communication methods more than it indicts this study's methods, but it is apparent that future research should also evaluate tasks that can be completed using communication methods of varying degrees of synchrony to evaluate more of the virtuality spectrum within one study.

Fourth, the task was difficult for participants. The game bombs used in the study were selected with the goal of ensuring that the average performance solved roughly half of all modules, allowing for a considerable amount of variance above and below that mark. Out of a total of 16 modules, the average team completed about seven, just under half. This did a good job of avoiding ceiling or floor effects… but it also ensured that few teams defused many bombs. Indeed, only about a third of teams completely defused at least one of the four bombs, meaning most teams blew up all of their bombs. This likely deflated participants' perceptions of their effectiveness throughout the task. However, the robustness of the study's findings is owed largely to the wide variance captured by the current study methods (i.e. assessing module completion) and mapping that to variations in their responses to the study surveys.

Fifth, the use of a single coder when coding instances of CLC could potentially be biased. If the coder has an innate understanding of CLC that differs from others, that could be reflected in their interpretation of situations as being either positive or negative examples of CLC.

Ultimately, the choice to use a single coder was made to avoid the need to calculate inter-rater reliability statistics and to avoid possible discrepancies in coding instances of CLC, factors outlined by a previous study that utilized audio transcription and coding protocols for human factors research (Lazzara, 2013).

Sixth, shared mental models (SMMs) play a considerable role in how teams perform (Mathieu et al., 2000). This study lacked a clear method for evaluating participants' SMMs, which could have provided additional interesting insights into the relationships between communication and trust in virtual teams. In some cases, participants pushed large amounts of information to their partners, ostensibly in an attempt to synchronize their teams' shared understanding of the task, but without a way to actually measure their SMMs (such as concept mapping or using questionnaires), it is difficult to tell the extent to which information pushing helped or harmed their understanding of the task at hand. In this way, measuring their SMMs might have offered a deeper understanding of why teams' communication resulted in their respective outcomes.

## Validity

**Internal validity.** This study was designed in response to gaps in experimental research linking communication and trust factors to team effectiveness factors; such gaps are consequences of the large amount of workplace-based research into these constructs. As such, a goal of this study was to construct a high-quality lab study, necessarily resulting in a higher level of internal validity than external validity. All participants experienced the same bombs and the same situations, and a variety of metrics were used to capture factors that explained considerable variance in team outcomes. However, not analyzed in this study were some factors that could have predicted additional variance in those outcomes. Some examples are participant accents and participant reading comprehension skills. On a positive note, the recording of team communication allows for follow-up research to evaluate some of these potential sources of variance.

**External validity.** Several factors within the study either contributed to or served to mitigate external validity. First, I will address factors that mitigate the external validity. The lab-based nature of the study means that applying the results to real-world situations is slightly difficult. The college-aged population also somewhat diminishes the external validity, as does the nature of the video game, which does not necessarily represent the types of team tasks carried out in most workplaces.

In contrast, the multicultural participant sample (see the study demographics section in the previous chapter) provides a better simulation of a diverse workplace and improves the external validity of the results as they represent a variety of participant backgrounds. In addition, the protocol used for analyzing communication can be applied to a multitude of situations and work teams in order to better understand team effectiveness. Indeed, Marlow et al. (2017) argue that there is a scarcity of research that analyzes communication in-depth for its effects on team performance, and this was a primary goal of this project. Finally, the ad hoc nature of teams in this study reflects the use of ad hoc teams for virtual teamwork (e.g. Crisp & Jarvenpaa, 2013). Given the mix of factors that bolstered and mitigated the external validity of the study, it is reasonable to conclude that the external validity of the study was moderate, but not strong.

**Construct validity.** Measures used in this study were selected based on their ability to effectively assess the latent variables of interest: trust, communication, and team effectiveness. It is important to remember that the self-report scales were designed to assess *perceptions* of communication quality, *perceptions* of team effectiveness, etc. To that end, the self-report metrics excel at their purpose, reflecting good construct validity. The CLC coding method also has good construct validity, given its clear basis in established literature and the development of a codebook to guide its assessment. However, the variable of communication efficiency had poorer construct validity—this is partly due to the lack of robust methods for measuring communication efficiency. Approaches such as those used by Webster (2017) may prove useful; in that study, the author evaluated handoff efficiency by parsing the amount of unique information passed during each handoff.

Overall, the selected variables of cognitive trust, communication quality, propensity to trust, etc. all have broad support in recent seminal literature on virtual teamwork, and they each posed clear value to analyses—though the implementation of communication efficiency demonstrated less utility.

**Statistical validity.** The conclusions drawn from the statistical tests used have considerable validity. The large sample size utilized exceeds the minimum number specified by the power analysis; G*Power estimated that 92 teams were required to observe a good effect size given the experiment's configuration of factors, and the final data set consisted of 101 teams. In addition, for each statistical test, assumptions like normality were evaluated to ensure that conclusions drawn were significantly unlikely to be due to random variance. Finally, the self-report metrics used all demonstrated good internal reliability, with Cronbach's alpha values ranging between approximately .70 and .89 (see Appendix F), lending more support to the validity of the conclusions drawn from the described statistical tests.

The statistical validity of the codebook is good given that CLC was rated based on established and consistent criteria across each of the teams. Notably, the use of a single rater presents one advantage and one disadvantage regarding validity. Using a single rater means that there are no situations in which interrater reliability was even a slight concern. However, it instead means that any potential biases were not evened out by having another rater. As a whole, those two points virtually balance each other out, as the potential for bias is reasonably mitigated by the clear operationalization of CLC.

One exception to the validity of the study's statistics should be noted: findings related to the objective communication efficiency measure (which uses the equation provided in Chapter 3) should be considered with a grain of salt. The equation's use of Modules Completed means that communication efficiency, as currently measured, is extremely highly correlated with Modules Completed. By extension, this means that communication efficiency is related to other factors in similar ways to Modules Completed. Follow up work should seek to develop this equation further to mitigate its tight relationship to outcomes.

**Conclusion**

As technological development continues to advance, virtual teamwork will become even more ubiquitous, making the results of this study even more pertinent. Virtuality will remain a focus of study for at least the foreseeable future, and as methods of measuring different teamwork constructs improve, our understanding of virtual teamwork will improve with them. While this study had a few limitations, it contributes to the corpus of virtual teamwork literature by evaluating a model of teamwork that contains inputs, mediators, and outputs. The greatest strength of the study stems from its comparatively massive sample size of 206 participants, and its most compelling findings imply that virtuality doesn't necessarily make teams work better or worse, and that intelligent use of video technology can make teams trust each other more with little to no effectiveness decrement compared to face-to-face work. Further, the extensive communication analyses used in the study set the groundwork for future research to continue building on the methods used.

In closing, while it’s virtually impossible to predict what future technologies will shape the workforce, effective research and solid methods can bring us face-to-face with our potential.

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# APPENDIX A: DEMOGRAPHICS

Please enter your Participant ID number.

What is your age?

What is your gender?

- Male
- Female
- Other (please specify)

What is your ethnicity?

- American Indian/Alaskan Native
- Asian/Pacific Islander
- Black/African American
- Biracial/Multiracial/Mixed
- Hispanic/Latino
- White (not of Hispanic origin)
- Prefer not to answer

How would you rate your general level of video game experience?

| None at all | A little | A moderate amount | A somewhat large amount | An extensive amount |
|---|---|---|---|---|

About how many years have you played video games? If greater than 15, move the slider to 15.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Years of experience

# APPENDIX B: GENERALIZED TRUST SCALE

For this section, please select the option which most closely reflects your level of agreement with each statement.

| | Strongly Disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| I tend to be accepting of others | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| My relationships with others are characterized by trust and acceptance | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Basically I am a trusting person | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| It is better to trust people until they prove otherwise than to be suspicious of others until they prove otherwise | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I accept others at "face value" | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Most people are trustworthy | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| It is better to be suspicious of people you have just met, until you know them better | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I make friends easily | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Only a fool would trust most people | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I find it better to accept others for what they say and what they appear to be | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | Strongly Disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| I would admit to being more than a little paranoid about people I meet | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I have few difficulties trusting people | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Basically, I tend to be distrustful of others | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Experience has taught me to be doubtful of others until I know they can be trusted | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I have a lot of faith in the people I know | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Even during the "bad times," I tend to think that things will work out in the end | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I tend to take others at their word | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| When it comes to people I know, I am believing and accepting | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I feel I can depend on most people I know | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I almost always believe what people tell me | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

# APPENDIX C: COGNITIVE BASED TRUST SCALE

Select the option which most closely reflects your level of agreement with each statement.

*Please respond honestly -- your answers are not shared with the other participant, and will help us better understand how your team performed.*

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| I was assured that the other participant would make intelligent decisions | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I had faith that the other participant could do the task at hand | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I was confident in the other participant's ability to complete a task | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I was afraid that the other participant would make a mistake | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I felt compelled to keep tabs on the other participant to be sure things got done | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I felt certain that the other participant would perform well | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I was paranoid that the other participant would fail | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I felt worried that the other participant would do something wrong | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

# APPENDIX D: COMMUNICATION QUALITY SCALE

To what extent was the communication between you and your teammate...
**CLEAR?**

| Not at all | Slightly | Somewhat | Moderately | Very much |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

---

To what extent was the communication between you and your teammate...
**EFFECTIVE?**

| Not at all | Slightly | Somewhat | Moderately | Very much |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

---

To what extent was the communication between you and your teammate...
**COMPLETE?**

| Not at all | Slightly | Somewhat | Moderately | Very much |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

---

To what extent was the communication between you and your teammate...
**FLUENT?**

| Not at all | Slightly | Somewhat | Moderately | Very much |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

---

To what extent was the communication between you and your teammate...
**ON TIME?**

| Not at all | Slightly | Somewhat | Moderately | Very much |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

# APPENDIX E: TEAM EFFECTIVENESS SCALE

**Take a moment to think about your team's performance.**

Please select the option which most closely reflects your level of agreement with each statement.

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| This team has a low error rate | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| This team does high quality work | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| This team consistently provides high-quality output | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| This team is consistently error-free | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| This team needs to improve its quality of work | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

# APPENDIX F: RELIABILITY STATISTICS

**PCQ**

*Reliability Statistics*

| Cronbach's Alpha | N of Items |
|---|---|
| .858 | 5 |

**PTE**

*Reliability Statistics*

| Cronbach's Alpha | N of Items |
|---|---|
| .891 | 5 |

**PTT**

*Reliability Statistics*

| Cronbach's Alpha | N of Items |
|---|---|
| .836 | 20 |

**CT1**

*Reliability Statistics*

| Cronbach's Alpha | N of Items |
|---|---|
| .697 | 8 |

**CT2**

*Reliability Statistics*

| Cronbach's Alpha | N of Items |
|---|---|
| .754 | 8 |

**CT3**

*Reliability Statistics*

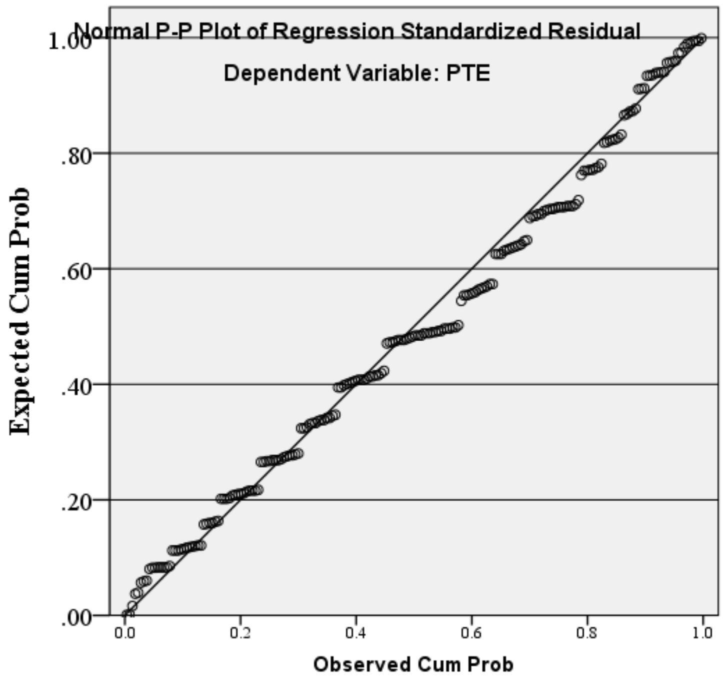
| Cronbach's Alpha | N of Items |
|---|---|
| .745 | 8 |

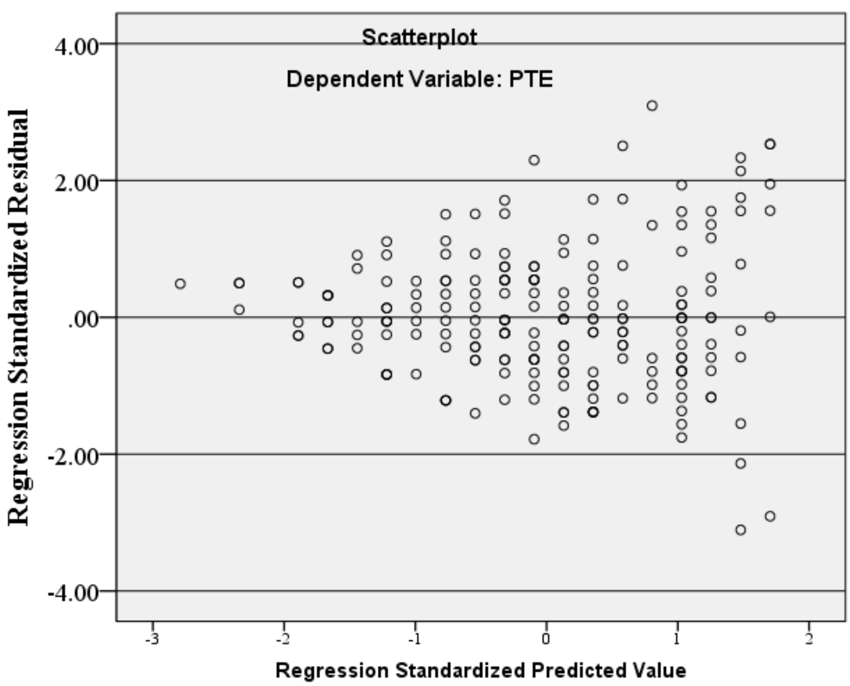
**CT4**

*Reliability Statistics*

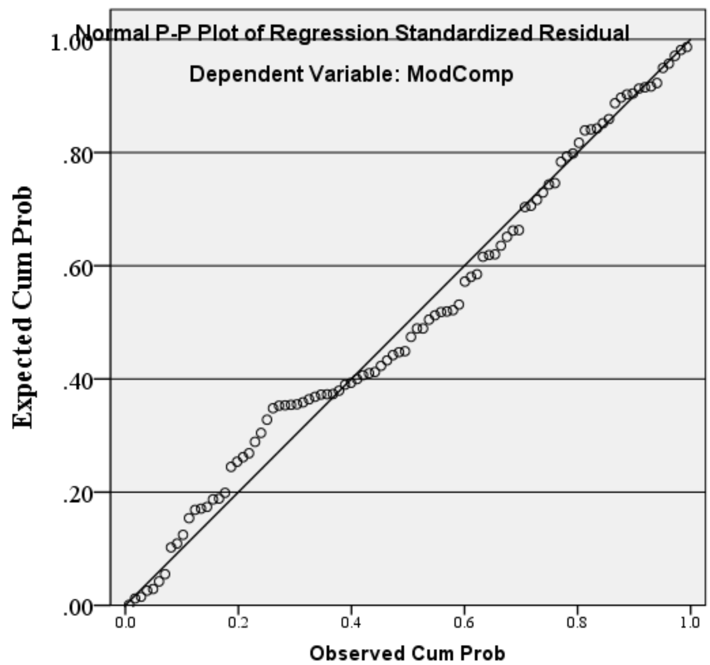
| Cronbach's Alpha | N of Items |
|---|---|
| .755 | 8 |

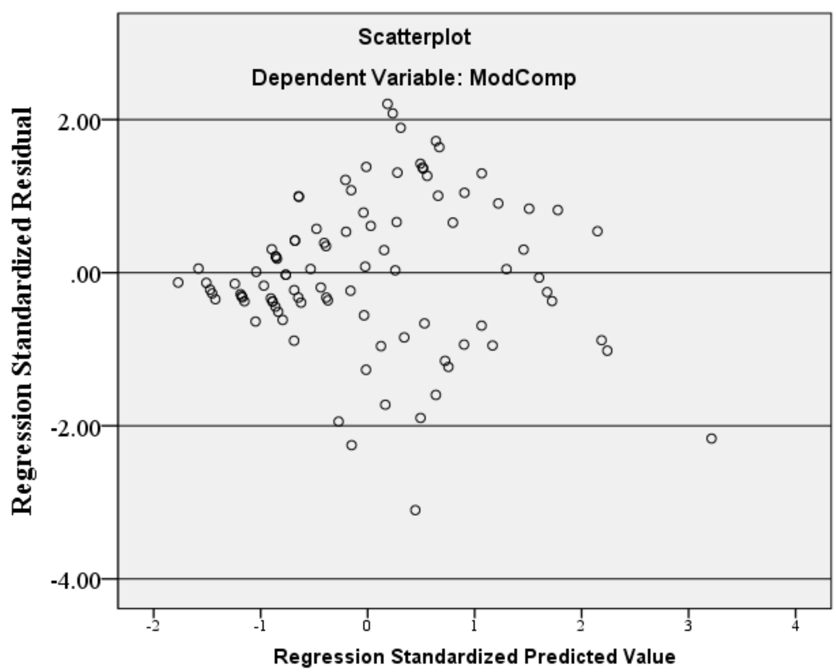
# APPENDIX G: NORMAL P-P PLOTS AND RESIDUAL SCATTER PLOTS



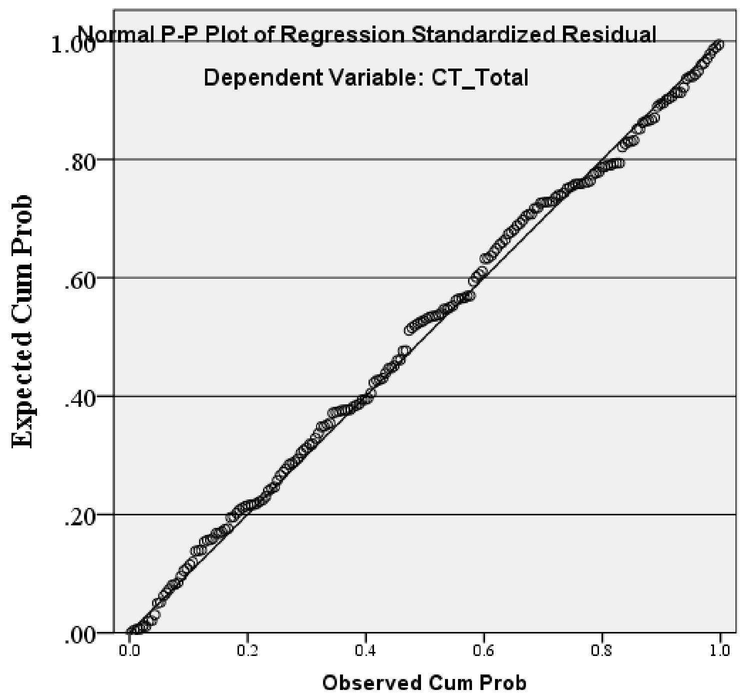



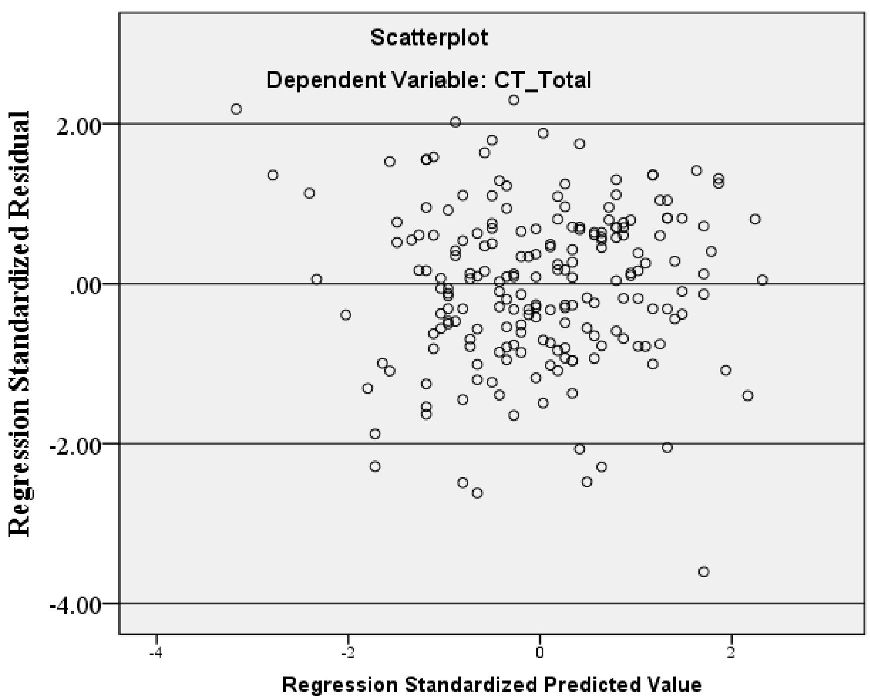

Hypothesis 2a.



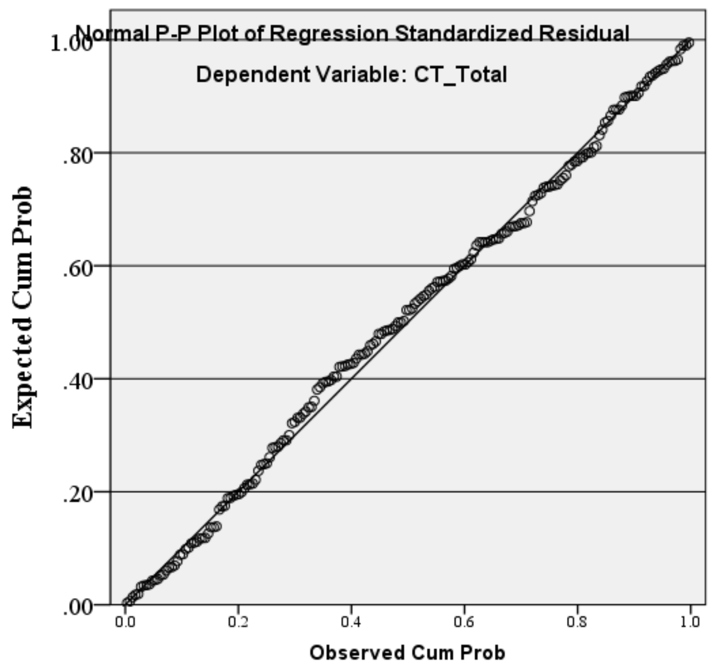



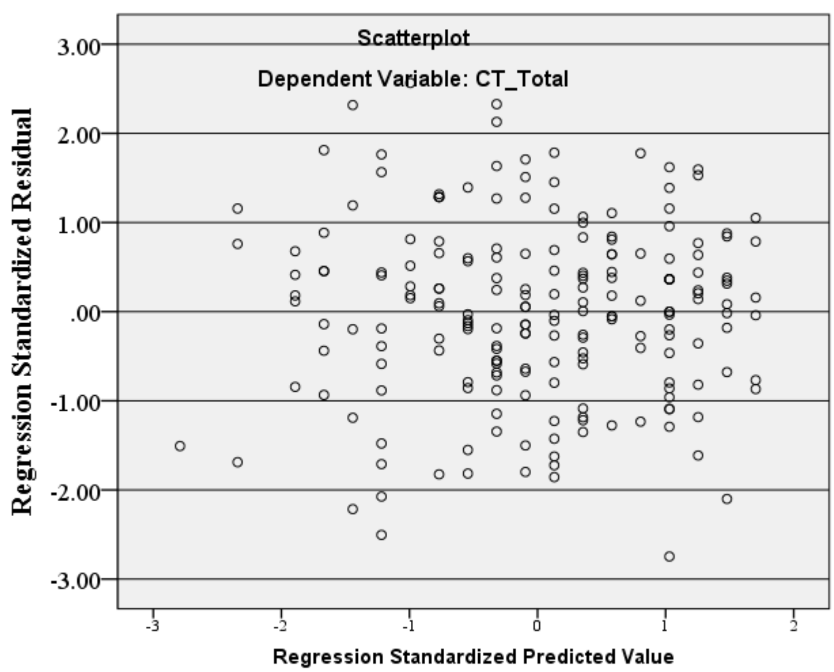

Hypotheses 2b and 2c.



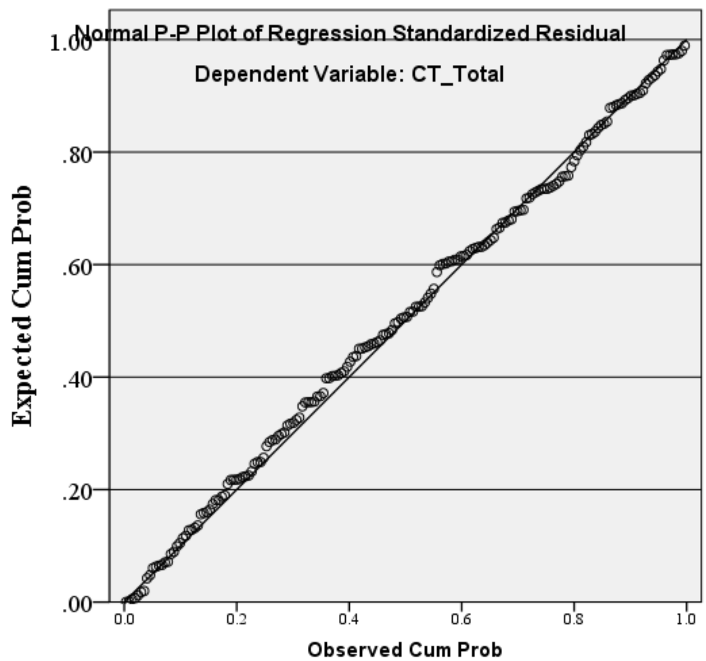



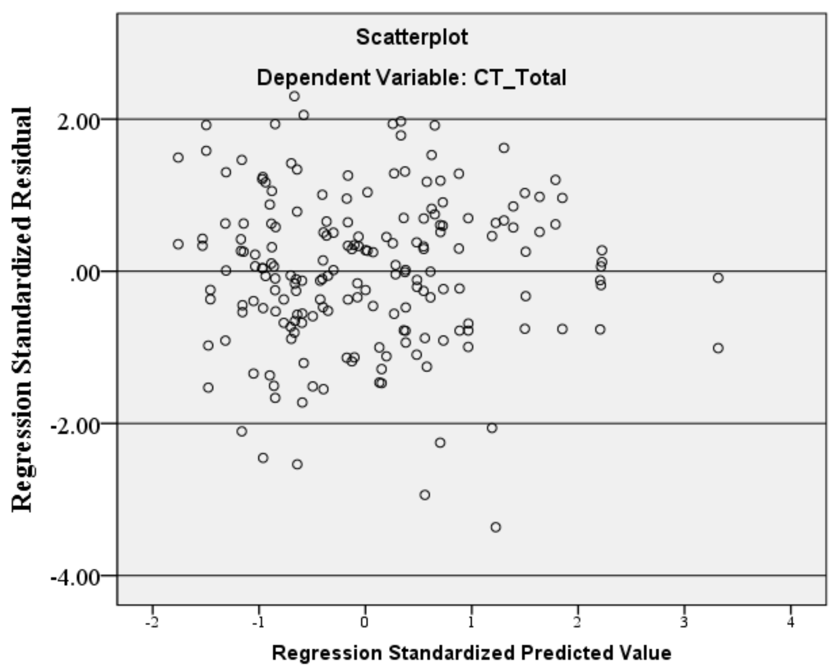

Hypothesis 3.



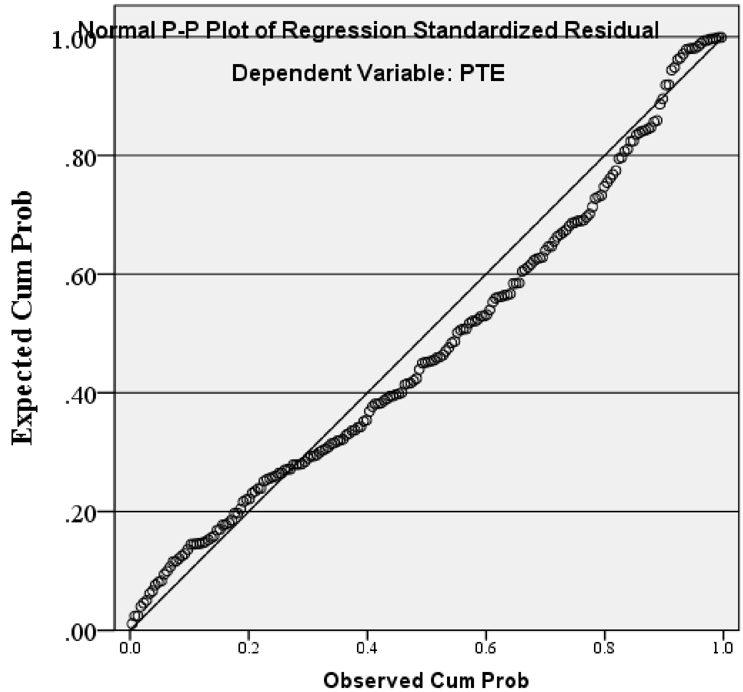



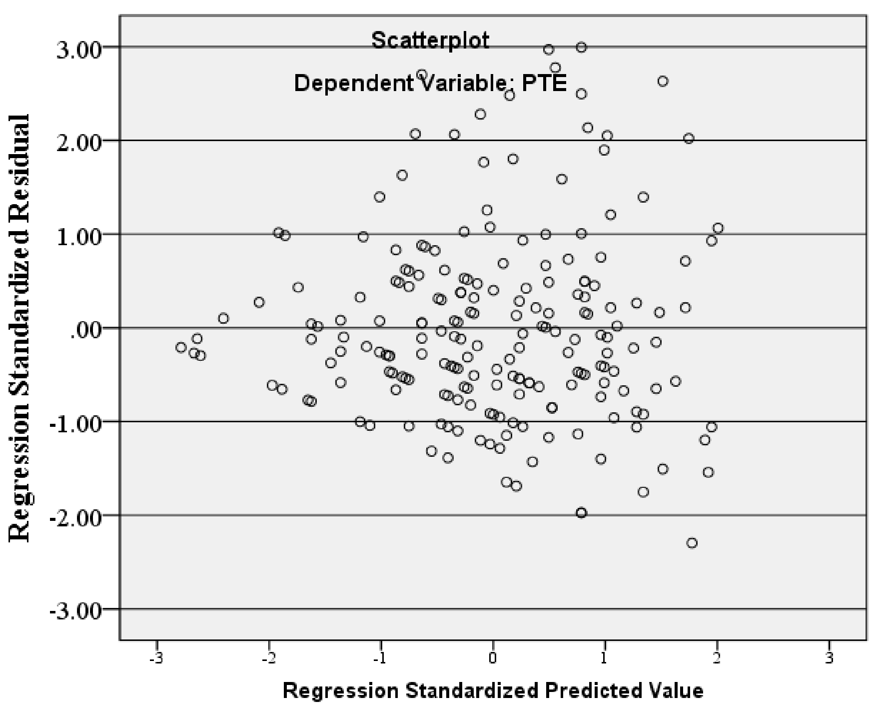

Hypothesis 4a.



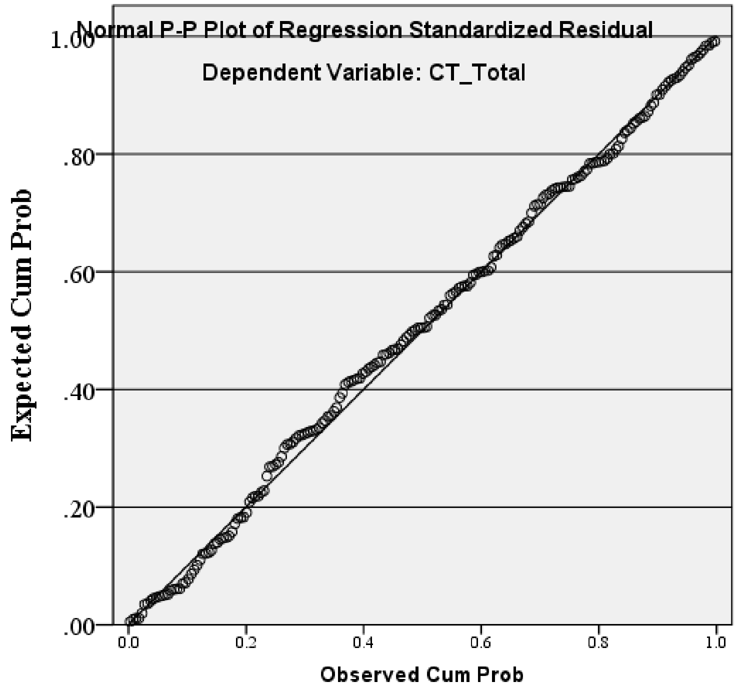



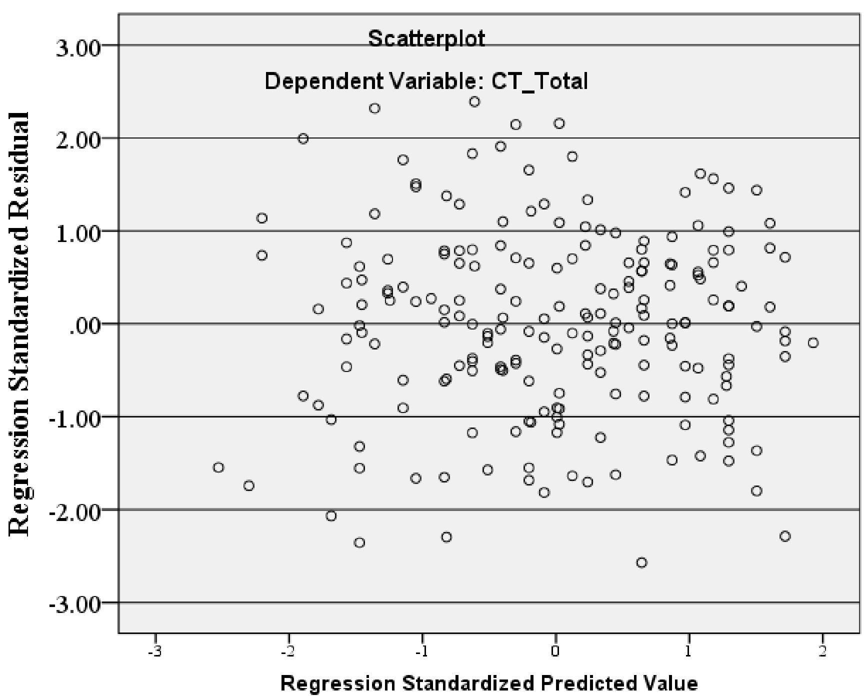

Hypotheses 4b and 4c.



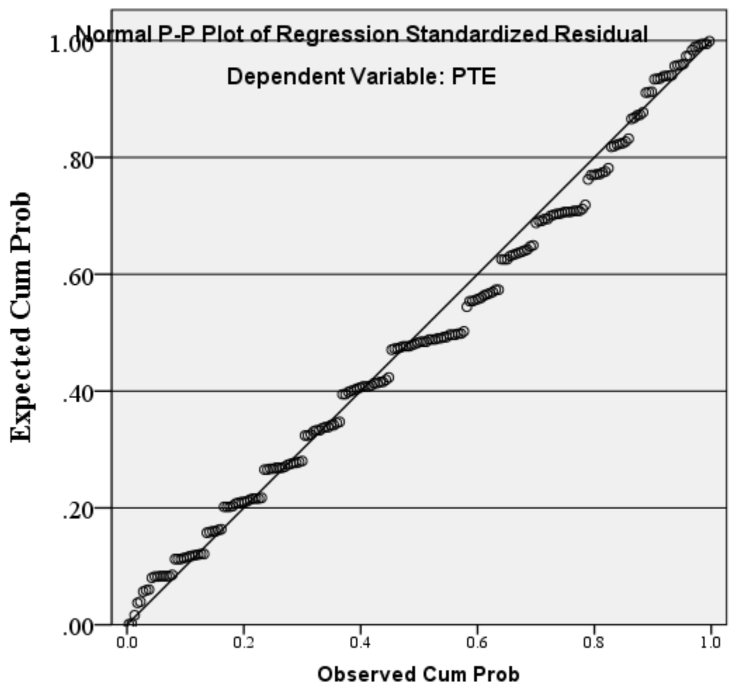



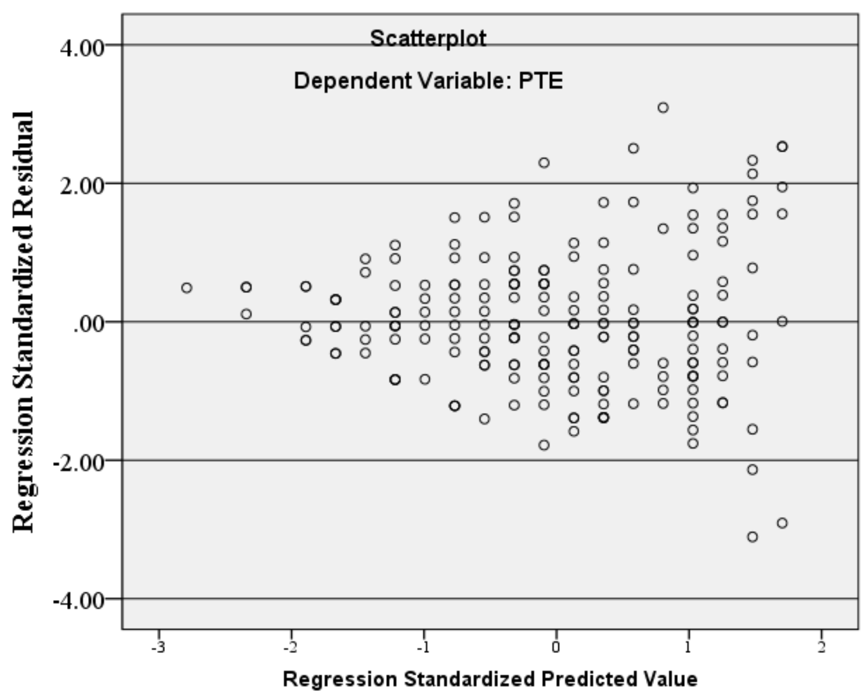

Hypothesis 5.




Hypothesis 6.




Hypothesis 7.

## APPENDIX H: BOMB DEFUSAL MANUAL

Several of the modules in the game were not used in this study as they were judged to be too difficult for participants during pilot testing. As such, the full bomb defusal manual was abridged to the pages provided below. Participants received the first three pages during their training and the remaining pages during the task. For pages 4 through 23, participants were only allowed to look at the pages while the bomb timer was active and the task was in progress.

KEEP TALKING and NOBODY EXPLODES

# BOMB DEFUSAL MANUAL

**Version 1**

Verification Code: 241

Revision 3

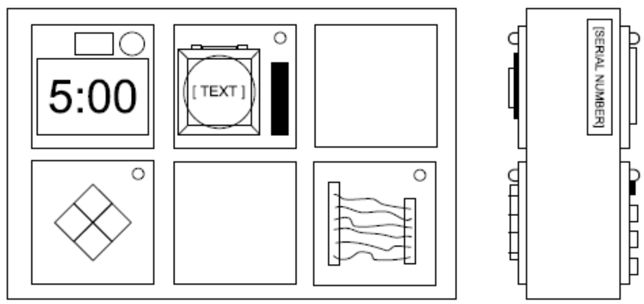
*Welcome to the dangerous and challenging world of bomb defusing.*

*Study this manual carefully; you are the expert. In these pages you will find everything you need to know to defuse even the most insidious of bombs. And remember — One small oversight and it could all be over!*

# Defusing Bombs

A bomb will explode when its countdown timer reaches 0:00 or when too many strikes have been recorded. The only way to defuse a bomb is to disarm all of its modules before its countdown timer expires.

Example Bomb




Front Side

## Modules

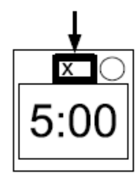
Each bomb will include up to 11 modules that must be disarmed. Each module is discrete and can be disarmed in any order.

Instructions for disarming modules can be found in Section 1. "Needy" modules present a special case and are described in Section 2.

## Strikes

When the Defuser makes a mistake the bomb will record a strike which will be displayed on the indicator above the countdown timer. Bombs with a strike indicator will explode upon the third strike. The timer will begin to count down faster after a strike has been recorded.

Strike Indicator

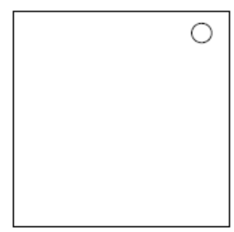



If no strike indicator is present above the countdown timer, the bomb will explode upon the first strike, leaving no room for error.

## Gathering Information

Some disarming instructions will require specific information about the bomb, such as the serial number. This type of information can typically be found on the top, bottom, or sides of the bomb casing. See Appendix A, B, and C for identification instructions that will be useful in disarming certain modules.

# Section 1: Modules

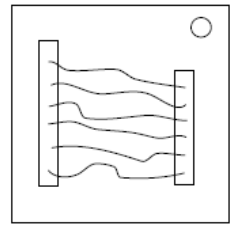


Modules can be identified by an LED in the top right corner.
When this LED is lit green the module has been disarmed.

All modules must be disarmed to defuse the bomb.

# On the Subject of Wires

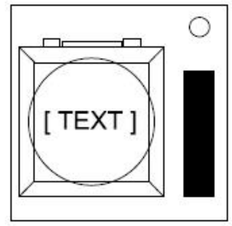
*Wires are the lifeblood of electronics! Wait, no, electricity is the lifeblood. Wires are more like the arteries. The veins? No matter...*



- A wire module can have 3-6 wires on it.
- Only the one correct wire needs to be cut to disarm the module.
- Wire ordering begins with the first on the top.

| |
|---|
| **3 wires:**<br>If there are no red wires, cut the second wire.<br>Otherwise, if the last wire is white, cut the last wire.<br>Otherwise, if there is more than one blue wire, cut the last blue wire.<br>Otherwise, cut the last wire. |
| **4 wires:**<br>If there is more than one red wire and the last digit of the serial number is odd, cut the last red wire.<br>Otherwise, if the last wire is yellow and there are no red wires, cut the first wire.<br>Otherwise, if there is exactly one blue wire, cut the first wire.<br>Otherwise, if there is more than one yellow wire, cut the last wire.<br>Otherwise, cut the second wire. |
| **5 wires:**<br>If the last wire is black and the last digit of the serial number is odd, cut the fourth wire.<br>Otherwise, if there is exactly one red wire and there is more than one yellow wire, cut the first wire.<br>Otherwise, if there are no black wires, cut the second wire.<br>Otherwise, cut the first wire. |
| **6 wires:**<br>If there are no yellow wires and the last digit of the serial number is odd, cut the third wire.<br>Otherwise, if there is exactly one yellow wire and there is more than one white wire, cut the fourth wire.<br>Otherwise, if there are no red wires, cut the last wire.<br>Otherwise, cut the fourth wire. |

## On the Subject of The Button




*You might think that a button telling you to press it is pretty straightforward. That's the kind of thinking that gets people exploded.*

*See Appendix A for indicator identification reference.*
*See Appendix B for battery identification reference.*

Follow these rules in the order they are listed. Perform the first action that applies:

1. If the button is blue and the button says "Abort", hold the button and refer to "Releasing a Held Button".
2. If there is more than 1 battery on the bomb and the button says "Detonate", press and immediately release the button.
3. If the button is white and there is a lit indicator with label CAR, hold the button and refer to "Releasing a Held Button".
4. If there are more than 2 batteries on the bomb and there is a lit indicator with label FRK, press and immediately release the button.
5. If the button is yellow, hold the button and refer to "Releasing a Held Button".
6. If the button is red and the button says "Hold", press and immediately release the button.
7. If none of the above apply, hold the button and refer to "Releasing a Held Button".

### Releasing a Held Button

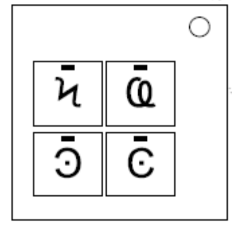
If you start holding the button down, a colored strip will light up on the right side of the module. Based on its color you must release the button at a specific point in time:

- Blue strip: release when the countdown timer has a 4 in any position.
- White strip: release when the countdown timer has a 1 in any position.
- Yellow strip: release when the countdown timer has a 5 in any position.
- Any other color strip: release when the countdown timer has a 1 in any position.

## On the Subject of Keypads

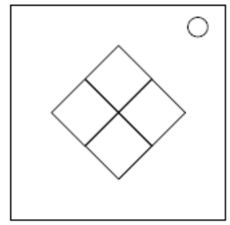
*I'm not sure what these symbols are, but I suspect they have something to do with occult.*

- Only one column below has all four of the symbols from the keypad.
- Press the four buttons in the order their symbols appear from top to bottom within that column.



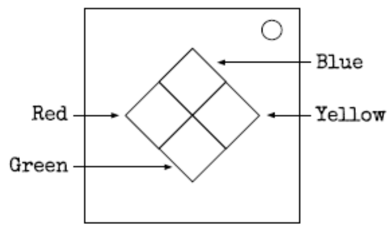
| | | | | | |
|---|---|---|---|---|---|
| Ϙ | Ӭ | © | б | Ψ | б |
| Ѧ | Ϙ | Ѽ | ¶ | ټ | Ӭ |
| ƛ | Ͽ | Ҩ | Ѣ | Ѣ | ҂ |
| Ϟ | Ҩ | Җ | Ѭ | Ͼ | æ |
| Ѭ | ☆ | Ԇ | Җ | ¶ | Ψ |
| ϗ | ϗ | ƛ | ¿ | Ѯ | Ҋ |
| Ͽ | ¿ | ☆ | ټ | ★ | Ω |

# On the Subject of Simon Says



*This is like one of those toys you played with as a kid where you have to match the pattern that appears, except this one is a knockoff that was probably purchased at a dollar store.*

1. One of the four colored buttons will flash.
2. Using the correct table below, press the button with the corresponding color.
3. The original button will flash, followed by another. Repeat this sequence in order using the color mapping.
4. The sequence will lengthen by one each time you correctly enter a sequence until the module is disarmed.



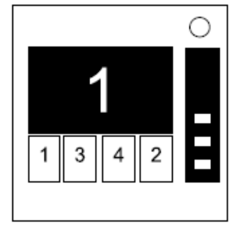

If the serial number contains a vowel:

| | | Red Flash | Blue Flash | Green Flash | Yellow Flash |
|---|---|---|---|---|---|
| Button to press: | No Strikes | Blue | Red | Yellow | Green |
| | 1 Strike | Yellow | Green | Blue | Red |
| | 2 Strikes | Green | Red | Yellow | Blue |

If the serial number does <u>not</u> contain a vowel:

| | | Red Flash | Blue Flash | Green Flash | Yellow Flash |
|---|---|---|---|---|---|
| Button to press: | No Strikes | Blue | Yellow | Green | Red |
| | 1 Strike | Red | Blue | Yellow | Green |
| | 2 Strikes | Yellow | Green | Blue | Red |

# On the Subject of Memory




*Memory is a fragile thing but so is everything else when a bomb goes off, so pay attention!*

- Press the correct button to progress the module to the next stage. Complete all stages to disarm the module.
- Pressing an incorrect button will reset the module back to stage 1.
- Button positions are ordered from left to right.

**Stage 1:**

If the display is 1, press the button in the second position.
If the display is 2, press the button in the second position.
If the display is 3, press the button in the third position.
If the display is 4, press the button in the fourth position.

**Stage 2:**

If the display is 1, press the button labeled "4".
If the display is 2, press the button in the same position as you pressed in stage 1.
If the display is 3, press the button in the first position.
If the display is 4, press the button in the same position as you pressed in stage 1.

**Stage 3:**

If the display is 1, press the button with the same label you pressed in stage 2.
If the display is 2, press the button with the same label you pressed in stage 1.
If the display is 3, press the button in the third position.
If the display is 4, press the button labeled "4".

**Stage 4:**

If the display is 1, press the button in the same position as you pressed in stage 1.
If the display is 2, press the button in the first position.
If the display is 3, press the button in the same position as you pressed in stage 2.
If the display is 4, press the button in the same position as you pressed in stage 2.

**Stage 5:**

If the display is 1, press the button with the same label you pressed in stage 1.
If the display is 2, press the button with the same label you pressed in stage 2.
If the display is 3, press the button with the same label you pressed in stage 4.
If the display is 4, press the button with the same label you pressed in stage 3.

# Appendix A: Indicator Identification Reference

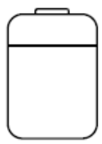
Labelled indicator lights can be found on the sides of the bomb casing.


## Common Indicators

- SND
- CLR
- CAR
- IND
- FRQ
- SIG
- NSA
- MSA
- TRN
- BOB
- FRK

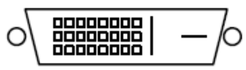
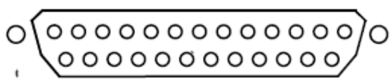
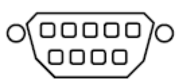
## Appendix B: Battery Identification Reference

Common battery types can be found within enclosures on the sides of the bomb casing.

| Battery | Type |
|---|---|
|  | AA |
|  | D |

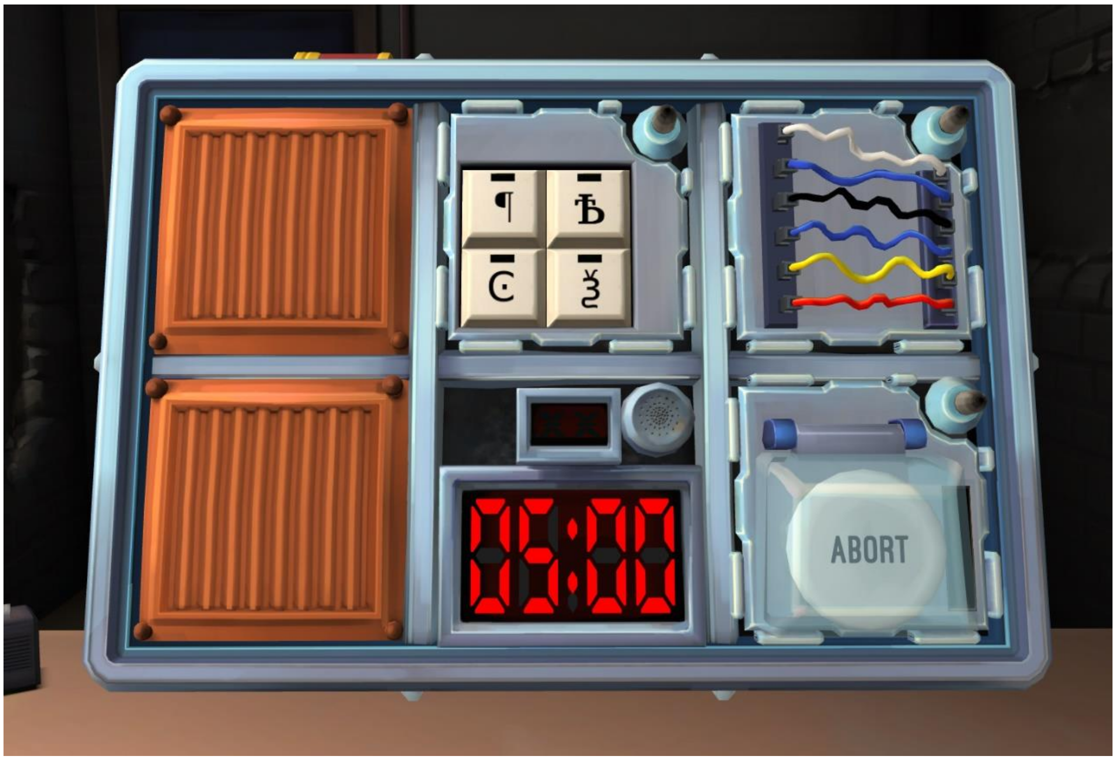
# Appendix C: Port Identification Reference

Digital and analog ports can be found on sides of the bomb casing.

| Port | Name |
|---|---|
|  | DVI-D |
|  | Parallel |
|  | PS/2 |
|  | RJ-45 |
|  | Serial |
|  | Stereo RCA |

## APPENDIX I: GAME BOMBS ENCOUNTERED BY PARTICIPANTS

Each bomb had a five-minute timer and each team encountered the same series of four bombs. Bombs increased in difficulty approximately linearly.




Bomb 1.


Bomb 2.


Bomb 3.


Bomb 4.

# APPENDIX J: IRB APPROVAL OF HUMAN SUBJECTS PROTOCOL

## Embry-Riddle Aeronautical University
## Application for IRB Approval
## Expedited Determination

**Principle Investigator:** Anthony Baker

**Other Investigators:** Joseph Keebler, Jacob Guliuzo, Tyler Wolowicz, Olivia Villamagna, Daniel Marte, Christopher Rarick, Nicholas Unger

**Role:** Student **Campus:** Daytona Beach **College:** Arts & Sciences

**Project Title:** Communication Trust in Virtual Teams - Revision 2

**Submission Date:** 11/01/2017

**Review Board Use Only**

**Initial Reviewer:** Teri Gabriel **Date:** 11/01/2017 **Approval #:** 18-051
**Exempt:** No

IRB Member Reviewer #1 Signature: Dr. Timothy B. Holt Digitally signed by Dr. Timothy B. Holt DN: cn=Dr. Timothy B. Holt, o=Dean, College of Aviation, ou=ERAU, Prescott campus, email=holtt@erau.edu, c=US Date: 2017.11.16 11:09:31 -07'00' Date: 11/16/2017

IRB Member Reviewer #2 Signature: Robin A Roberts Digitally signed by Robin A Roberts DN: cn=Robin A Roberts, o=Worldwide On-line Campus, ou=Organizational Leadership, email=roberr36@erau.edu, c=US Date: 2017.11.16 18:13:04 -05'00' Date: 11/16/2017

Dr. Michael Wiggins IRB Chair Signature: Michael E. Wiggins, Ed.D. Digitally signed by Michael E. Wiggins, Ed.D. DN: cn=Michael E. Wiggins, Ed.D., o=Embry-Riddle Aeronautical University, ou=Aeronautical Science Department, email=wigginsm@erau.edu, c=US Date: 2017.11.20 09:53:29 -05'00' **Date**: 11/20/2017

**Expires**: 11/19/18

**Brief Description**:

This project is to study the communication, trust, and teamwork differences between in-person teams, virtual teams speaking through a video call, and virtual teams speaking through a voice call. The purpose of this study is to investigate the constructs of trust, propensity to trust, and communication in order to evaluate how virtuality affects the team effectiveness of a virtual team.

This research falls under the expedited category as per 45 CFR 46.110 (b) because one or both of the following apply:

(1) ☑ some or all of the research appearing on the list below are found by the reviewer(s) to involve no more than minimal risk,

(2) ☑ minor changes in previously approved research during the period (of one year or less) for which approval is authorized.

Research activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the following categories. The activities listed should not be deemed to be of minimal risk simply because they are included on this list. Inclusion on this list merely means that the activity is eligible for review through the expedited review procedure when the specific circumstances of the proposed research involve no more than minimal risk to human subjects. (Bankert & Amdur 2006)

1. ☐ Prospective collection of biological specimens for research purposes by noninvasive means.

2. ☑ Collection of data from voice, video, digital, or image recordings made for research purposes.

3. ☐ Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.) [This means research that presents *more than minimal risk to human subjects.*]

Bankert, E. A., Amdur, R. J., (2006) Institutional Review Board Management and Function, Second Edition, pp. 517-518.

# APPENDIX K: INFORMED CONSENT DOCUMENTS

**Informed Consent Document**
**Title of Project:** Teamwork in Bomb Defusal

**Principal Investigator:** Joseph Keebler
Embry-Riddle Aeronautical University
600 S Clyde Morris Blvd
Daytona Beach, FL 32114

**Purpose of Research**
The purpose of the experiment is to investigate how teams work together during simulated bomb defusal tasks.

**Specific Procedures to be used**
After several demographic measures, you will be given a tutorial that will teach you how to work together to defuse a virtual bomb. Following that, you and your partner will be tasked with defusing three bombs.

**Duration of Participation**
The study will take about one hour to complete.

**Conditions of Participation**
You must be 18 years of age or older in order to participate in this study. Further, you must have normal or corrected vision with no color vision impairments. If you do not meet these conditions, or if you have a color vision impairment, please inform the researcher at this time.

**Benefits to the Individual**
Participating in this research may help contribute to your understanding of your performance in small teams. In addition, you will gain knowledge about the research process. Ultimately, participation will help researchers to better understand the process of teamwork in difficult tasks like bomb defusal.

**Risks to the Individual**
The risks of participating in this study are the same as the risks of using a computer and playing a computer video game; slight motion sickness can occur, and the use of computer hardware can exacerbate existing repetitive-strain injuries. A researcher will be observing you for the extent of the study, either in person or through a video monitor. Should you become uncomfortable for any reason, let the researcher know, and you may either take a brief break or rescind your participation at any time without consequence.

**Confidentiality**
Confidentiality will be maintained to protect your rights. Audio recording will be taken and survey data will be collected. Data records are only tied to you by an individually-assigned participant ID number. Names or other personally identifiable information are not collected. Completed paper forms will be scanned. After this, the paper forms will be shredded. The digital paper forms, the recording files, and the electronic survey results will be kept within a secure shared folder only accessible to the researchers. Three years after the study's conclusion, electronic files, including audio recordings, will be deleted.

**Voluntary Nature of Participation**
Participants do not have to participate in this research project and may terminate their participation at any time without penalty. Participants can skip any questions they do not feel comfortable answering and can stop at any time. If you choose to "opt out", your physical and electronic study data will be deleted immediately.

**Compensation**
Participants will be compensated $10 in cash for completing the study. Participants who complete only part of the study will be compensated an amount proportionate to how much of the study was completed. As the HF department has many studies running, we will work with participants who refuse informed consent to find other research studies they may be interested in.

Thank you for your participation. For answers to pertinent questions about the research or about your rights as a participant, or in the event of a research-related injury, please do not hesitate to contact Anthony Baker at BakerA19@my.erau.edu

For any concerns or questions as a participant in this research, contact Teri Gabriel, IRB Assistant Director, at 386-226-7179 or via email teri.gabriel@erau.edu.

The following message will be delivered verbally to the participant. Participant consent will be recorded via signature and this form will be kept by the researchers for record-keeping purposes.

---

I consent to participating in the research project entitled: **Teamwork in Bomb Defusal**

The principal investigator of the study is: **Anthony Baker.**

The individual above, or their research assistants, have explained the purpose of the study, the procedures to be followed, and the expected duration of my participation. I have read the page labeled "Informed Consent Document" and agree to the conditions of the study. Possible benefits of the study have been described, as have alternate procedures, if such procedures are applicable and available.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that I am free to withdraw consent at any time and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. An electronic copy has been given to me.

Signature of Participant ________________________________ Date ____________

Printed Name of Participant ________________________________

OCTANE