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COLLABORATIVE PROBLEM SOLVING: THE ROLE OF TEAM KNOWLEDGE
BUILDING PROCESSES AND EXTERNAL REPRESENTATIONS

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the College of Sciences
at the University of Central Florida
Orlando, Florida

Spring Term
2010

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ABSTRACT

This dissertation evaluates the relationship between five team knowledge building processes (i.e., information exchange, knowledge sharing, option generation, evaluation of alternatives, and regulation), the external representations constructed by a team during a performance episode, and performance outcomes in a problem solving task. In a broad range of domains such as the military, and healthcare, team-based work structures used to solve complex problems; however, the bulk of research on teamwork to date has dealt with behavioral coordination in routine tasks. This leaves a gap in the theory available for developing interventions to support collaborative problem solving, or knowledge-based performance, in teams. Sixty nine three person teams participated in a strategic planning simulation using a collaborative map. Content analysis was applied to team communications and the external representations team members created using the collaborative tool. Regression and multi-way frequency analyses were used to test hypotheses about the relationship between the amount and sequence of team process behaviors respectively and team performance outcomes. Additionally, the moderating effects of external representation quality were evaluated. All five team knowledge building processes were significantly related to outcomes, but only one (i.e., knowledge sharing) in the simple, positive, and linear way hypothesized. Information exchange was negatively related to outcomes after controlling for the amount of acknowledgements team members made. Option generation and evaluation interacted to predict outcomes such that higher levels of evaluation were more beneficial to teams with higher levels of option generation. Regulation processes exhibited a negative curvilinear relationship with outcomes such that high and low performing teams engaged in less regulation than did

moderately performing teams. External representation quality moderated a composite team knowledge building process variable such that better external representations were more beneficial for teams with poorer quality processes than for teams with high quality process. Additionally, there were significant differences in the sequence of team knowledge building processes between high and low performing teams as well as between groups based on high and low levels of external representation quality. The team knowledge building process framework is useful for understanding complex collaborative problem solving. However, these processes predict performance outcomes in complex and inter-related ways. Further implications for theories of team performance and applications for training, designing performance support tools, and team performance measurement are discussed.

This dissertation is dedicated to my mother Carol, father Bert, and sister Melanie. I could not have done this without them.

ACKNOWLEDGMENTS

It is difficult to fully acknowledge all of the people who played a role in this dissertation and the years of preparation leading up to it. This entire process has been a team effort. My fellow MURI-SUMMIT graduate students—Davin, Heather, Ari, and Chris—helped manage the technology and organizational challenges involved in pulling off a large team study. My research assistants—Olivia, Kirsten, and Julia—helped to collect the data and more than stepped up to the challenge of a large detail-oriented (and at times excruciatingly tedious) communication coding process. I was lucky enough to find numerous undergraduate volunteers who transcribed communications. I've been fortunate enough to have worked with an exceptional group of fellow students over the past five years. These people have shaped how I think and include, but are not limited to: Kat Wilson, Heather Priest, Kevin Stagl, Debbie DiazGranados, Sallie Weaver, Liz Lazzara, Becki Lyons, Wendy Bedwell, Jessie Wildman, Davin Pavlas, and Heather Lum. Of course, my committee members—Steve Fiore, Florian Jentsch, Shawn Burke, and Ben Morgan—provided guidance and insight on some of the tough problems encountered along the journey of this dissertation and more broadly over my entire graduate career. Finally, Ed Salas has provided me with guidance and passion for applied science as well as a unique way of thinking about things that was entirely foreign to me at the outset of my graduate career. I owe everyone listed here and more a great debt.

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CHAPTER ONE: INTRODUCTION

Statement of the Problem

Across a number of industries and application domains, there is a growing trend towards more interdependence and complexity in tasks deemed critical for organizational effectiveness. The network centric warfare paradigm in the military entails adopting organizational structures that push the responsibility for complex decision making and planning to lower levels of command (Alberts, 2007). This approach is intended to place the power to solve problems and make decisions with the people who have the best understanding of what is happening locally in a given situation (Dekker & Suparamaniam, 2007). In healthcare, interprofessional care teams must combine expertise in different clinical areas to diagnose patient conditions and generate plans of care (Hammick, Freeth, Koppel, Reeves, & Barr, 2007). Different clinical specialties and roles have diverse knowledge and skill sets that must be combined in order to reach the desired outcomes of safety and efficiency of care. In industry, strategic planning teams must work to understand the changes in the external economic environment and devise means of adapting organizational structures and capacities for maximum effectiveness (Hambrick, 1987). These teams have to make sense of vast amounts of uncertain information and deal with adversarial conditions (i.e., market competitors) in order to maintain and grow their business.

All of these situations can be classified as collaborative problem solving because effective performance requires individuals to combine unique areas of expertise in order to address novel situations. As this type of performance is increasingly frequent in

modern organizations, it represents an opportunity for applied science to guide

organizational practice. However, there is presently a lack of theory capable of driving

systematic and scientifically-rooted interventions to improve this type of performance.

While the scientific community has made great strides in understanding, training, and

supporting teamwork in a variety of contexts (see Salas, Burke, & Goodwin, 2009;

Kozlowski & Ilgen, 2006), the majority of this theoretical and empirical work has

focused on what Rasmussen (1983) describes as rule-based performance, that is, the

execution of known task procedures in relatively familiar contexts (Rosen, Fiore, Salas,

Letsky, & Warner, 2008). Knowledge-based performance is another type of performance

described by Rasmussen. This type of performance requires adaptation to novel contexts

where there are no pre-existing task procedures in place. Knowledge-based performance

has received much less attention from team researchers, and is the topic addressed in this

study.

General Approach

The Macrocognition in Teams Model (Fiore, Smith-Jentsch, Salas, Letsky, &

Warner, in press) has been proposed to explain knowledge-based performance in teams

and is the perspective adopted to guide this study. More specifically, this study examines

the relationship between two predictors of problem solving outcomes identified in the

Macrocognition in Teams Model: team processes, and external representations. These

two phenomena have been investigated frequently by team researchers (more so for

process than for externalization), but rarely investigated together.

Investigators from a variety of disciplines have generated a relatively large literature base dealing with the nature and impact of team processes in determining the effectiveness of teams. Within this diverse literature, two general perspectives have emerged: functional and interactional perspectives. A *functional perspective* views team process as a resource that can be applied to different tasks (or functions). Effectiveness is determined by the degree to which teams focus their process (a limited resource) on critical task-relevant functions. An *interactional perspective* proposes that the effectiveness of team processes is a function of the sequence of different process behaviors. From this perspective, the way in which a team temporally sequences its communications and behaviors determines the effectiveness of its outcomes. The current study examines collaborative problem solving processes and performance from both of these perspectives.

In addition to team processes, external representations play a major role in problem solving outcomes. In collaborative team problem solving, building, modifying and sharing an understanding of a novel situation can be mediated through physical artifacts. Two general perspectives on the function of external representations in individual problem solving can be translated to the team level: externalization as *offloading* and externalization as *scaffolding*. From the offloading perspective, external representations can serve to <u>replace</u> cognitive processing (i.e., cognitive work is performed externally so it frees up internal cognitive processing resources). On the team level, this can mean that important aspects of team task performance once mediated through processes such as verbal communication can be offloaded into the environment, thereby reducing the need for teamwork interactions. From the scaffolding perspective,

external representations can serve to <u>facilitate or enhance</u> internal cognitive processing (i.e., processing is not replaced, but its effectiveness is increased). On the team level, the scaffolding function of external representations implies that the effectiveness of team processes can be altered (ideally enhanced) via external representations used by the team. The role of both of these functions of external representations in collaborative problem solving will be evaluated in the current study.

Purpose of the Present Study

The present study tests core relationships in the Macrocognition in Teams Model from functional and interactional perspectives. From the functional perspective, two high level relationships are tested: 1) the direct effects of team knowledge building processes on Team Problem Solving Outcomes, and 2) the moderation of this direct effect by the external representations teams create during task performance. From the interactional perspective, two types of relationships are explored: 1) the degree to which Team Problem Solving Outcomes can be predicted by how teams interleave process and externalization (i.e., differences in the sequencing of when content is discussed and when external representations are created to represent it), and 2) differences in the sequence of team knowledge building process behaviors for effective and ineffective teams creating high and low quality external representations. Specific hypotheses will be tested using data collected in a laboratory study using three person teams engaged in collaborative problem solving in a planning task.

CHAPTER TWO: LITERATURE REVIEW

The hypotheses proposed and evaluated in this dissertation involve two core phenomena of collaborative problem solving: team processes, and external representations. That is, the interactions among team members engaged in collaborative problem solving and the external representations of information and knowledge they create interact to predict the effectiveness of outcomes. As proposed and described below, the nature of this interaction is hypothesized to be dependent upon the amount, content, and sequencing of team process behaviors and characteristics of the external representations constructed by teams. While a substantial amount of research has investigated the role of team process and externalization independently in team problem solving, far less work has examined these factors concurrently. Therefore, in the following sections, the team cognition and related team process literature and the scientific literature on external representations are reviewed separately. Subsequently, the Macrocognition in Teams perspective is presented. This model integrates team process and externalization and serves as the basis for the hypotheses proposed and evaluated in this dissertation. This section ends with a summary of hypotheses.

Team Cognition and Team Process

In this section, two related, complementary, and at times overlapping research traditions are reviewed: the team cognition literature and the broader interdisciplinary team research literature on problem solving and decision making. However, before these topics are reviewed, an over arching framework of team effectiveness is presented to

provide the basic terminology for discussing issues of team performance across different research traditions.

Overview of Team Effectiveness

The effectiveness of teams has been investigated from many perspectives and by many disciplines (e.g., Poole & Hollingshead, 2005). The majority of this theoretical and empirical work uses at least some part of an Input → Mediator → Output → Input (IMOI) framework to conceptualize the classes of constructs important to team effectiveness (Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Salas, Dickinson, Converse, & Tannenbaum, 1992; Hackman, 1987). An overview of this framework is provided in Figure 1 and briefly detailed below.

Inputs to this team effectiveness cycle include a variety of variables such as team composition (e.g., team member intelligence, diversity, expertise, familiarity, structure, size; Bell, 2007; Horwitz & Horwitz, 2007) team design issues such as structure and task variables (Stewart, 2006), and organizational level variables such as culture and climate (Anderson & West, 1998; Salas et al., 1992). In team cognition research, the sharedness or distribution of team member mental models is one of the primary inputs of interest (Smith-Jentsch, 2009; Mohammed & Dumville, 2001; Cooke, Salas, Cannon-Bowers, & Stout, 2000); however, mental models have also been conceptualized as outputs of team interaction (McComb, 2007). While team inputs are no doubt a critical component of team effectiveness, they are not the focus of this dissertation.

Mediators of team effectiveness are variables that transform team inputs into outputs. They include two broad categories of variables: processes and emergent states.

Processes are defined as team "members' interdependent acts that convert inputs to outcomes through cognitive, verbal, and behavioral activities directed toward organizing taskwork to achieve collective goals" (Marks, Mathieu, & Zaccaro, 2001, p. 357), and emergent states are defined as "properties of the team that are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes" (Marks et al., 2001, p. 357).

A great diversity of team processes have been proposed and empirically validated in the literature (Rousseau, Aubé, & Savoie, 2006; Kozlowski & Ilgen, 2006). These include communication (Bowers, Jentsch, Salas, & Braun, 1998), coordination (Entin & Serfaty, 1999), leadership (Burke, Stagl, Klein, Goodwin, Salas, & Halpin, 2006), mutual performance monitoring and back up behavior (Porter, Hollenbeck, Ilgen, Ellis, West, & Moon, 2003), conflict management (Montoya-Weiss, Massey, & Song, 2001), and many others. In fact, so many team processes have been identified that the sheer number has become problematic for researchers. To help remedy the proliferation of different process constructs, Marks and colleagues (2001) have proposed a three factor framework for categorizing teamwork process. From this perspective, teamwork processes are either transition (i.e., occurring between performance episodes and focusing on mission analysis, goal specification, and strategy formulation), action (i.e., activities focusing directly on goal achievement such as coordination and various forms of monitoring), or interpersonal (i.e., focusing on the interpersonal relationships in the team such as conflict management, motivation building, and affect management). A recent meta-analysis of the team performance literature has provided support for this three factor structure of teamwork processes (LePine, Piccolo, Jackson, Mathieu, & Saul, 2008).

Emergent states are a more complex phenomenon describing the cognitive, affective and motivational states of the team as a whole, and not their behavioral interaction (i.e., team process). Emergent states include affective variables such as trust (Jones & George, 1998), and collective efficacy (Tasa, Taggar, & Seijts, 2007) as well as transient types of knowledge such as team situation awareness (Stout, Cannon-Bowers, & Salas, 1996). In the team cognition literature, team level emergent states are generally taken to be holistic constructs; that is, they capture a property of the team as a whole, and not as an aggregation of the properties of individual members (Cooke et al., 2004; Cooke et al., 2003). Additionally, emergent states are more dynamic in nature than inputs as they develop and change as the team engages in performance. For example, team situation awareness is described as the moment to moment changes in the collective understanding of the team's environment, task, and member states (Artman, 2000)

Outputs→Inputs. The O in IMOI represents the performance outputs of the team such as task outcome effectiveness, member satisfaction, and group viability. The final I in the IMOI framework stands for Input and is intended to highlight the recursive nature of team performance. That is, team inputs are changed during the course of a performance episode. These altered inputs then feed into future team performance episodes. While each component of the IMOI framework contributes uniquely to team effectiveness (e.g., LePine et al., 2008; Peeters, Van Tuijl, Rutte, & Reymen, 2006; Stewart, 2006; Oliver, Harman, Hoover, Hayes, & Pandhi, 2000), the present study focuses on the role of team processes during collaborative problem solving. Consequently, the following literature review does not include team inputs or emergent states. Omission of these variables is not a statement of their lack of importance.

Additionally, external representations have been found to play a major role in problem solving effectiveness in individuals and teams (Kirsch, 2009; Zhang, 1998). However, the notion of external representations is not represented clearly in the IMOI Models in team research. The Macrocognition in Teams Model discussed in a later section synthesizes these traditions of research in team effectiveness and external representations and serves as the basis for the hypotheses proposed and evaluated in the present study. In the following section, empirical and theoretical work on team process is further reviewed and subsequently integrated with the external representation literature.
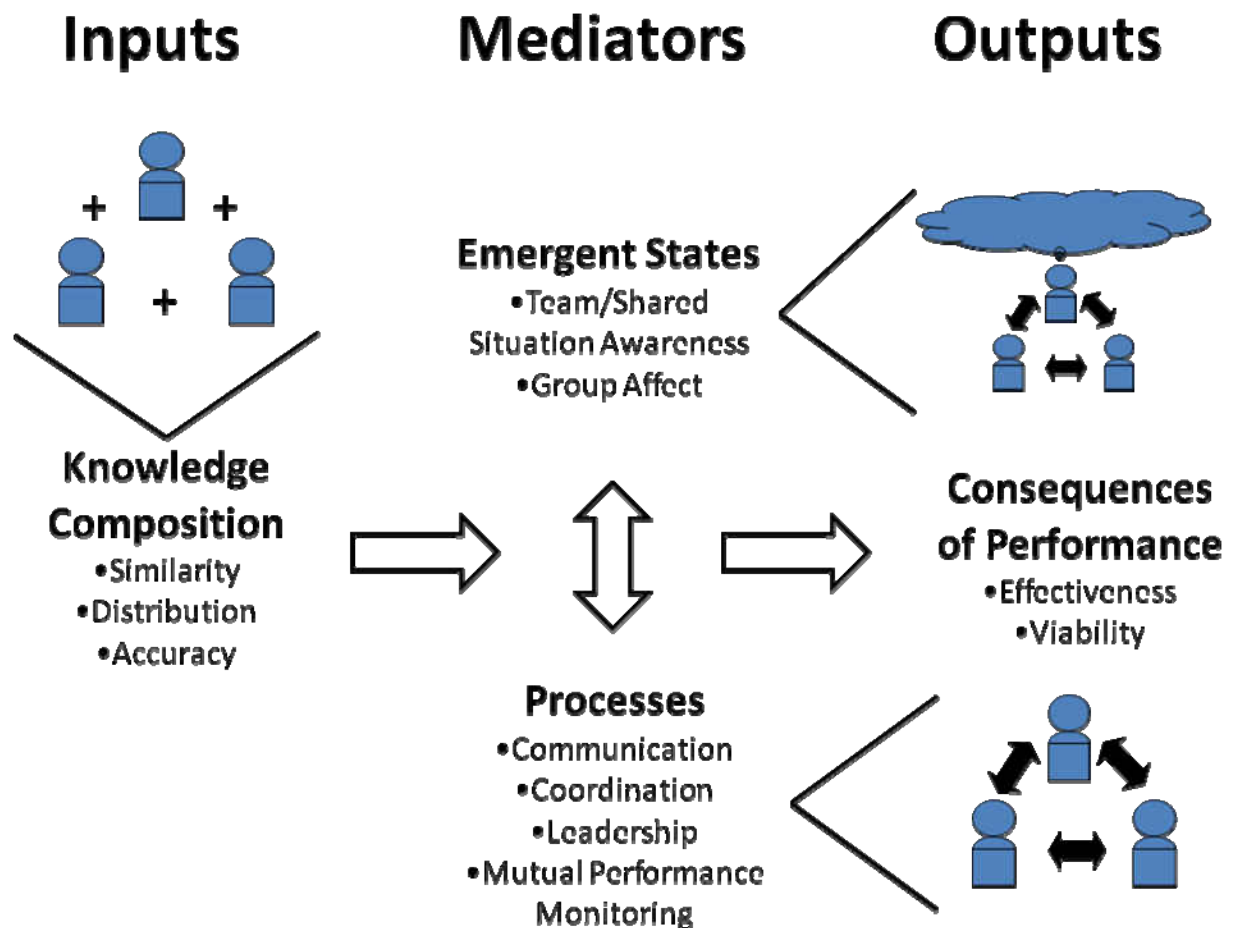
Figure 1. IMOI Framework for Team Effectiveness with Example Constructs

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Team Cognition

Team cognition is a general perspective (and not a specific theory) that views teams as information processing units (Hinsz, Tindalre, & Volrath, 1997). It seeks to understand the interaction between intra-individual (i.e., internal cognitive) and inter-individual (i.e., external social) level processes (Fiore & Schooler, 2004). Similar to the broader team performance literature, team cognition researchers generally use an input, mediator, output framework (Ilgen et al., 2005) such that the knowledge composition of team members (e.g., shared mental models, Cannon-Bowers, Salas, & Converse, 1993; transactive memory, Wegner, 1986) is transformed by team processes (e.g., communication, coordination; Cooke et al., 2004) into emergent states (e.g., dynamic team situation awareness; Cooke, Gorman, Duran, & Taylor, 2007; Salas, Prince, Baker, & Shrestha, 1995; Artman, 2000) which in conjunction with processes determine important team outcomes (e.g., effectiveness, viability). For the present purposes, it is most important to note that communication is the primary means by which teams process information (Cooke et al., 2004), and that this team level cognitive processing is inherently a 'low capacity' channel (or a limited resource) in that the team generally discusses specific content in a serial manner. These general ideas will be explained further below. While input and emergent state views of team cognition are important components of team level cognitive processing, they are not the focus of the present study. Therefore, the following review focuses primarily on issues of team processes.

Characterizing Team-level Cognitive Processing

Some researchers have come to view communication as synonymous with team cognition (Cooke, Gorman, & Kiekel, 2008). More specifically, there is team cognition

that can be best characterized as occurring *within* individual team members (i.e., a collective form of team cognition comprised of an aggregation of the internal cognition of the individual team members) and there is team cognition that occurs *between* team members as they share and transform information through process behaviors such as communication and coordination (i.e., a holistic level team cognition; Cooke et al., 2004; Cooke et al., 2003). This perspective is consistent with a long tradition investigating cognition in social contexts as summarized by Levine and Choi (2004):

> "in many situations it is neither possible nor conceptually useful to separate social interaction and cognition. In such cases, rather than being the cause or consequence of cognition, interaction *constitutes* cognition" (p. 158).

This begs the question of how to characterize effective and ineffective team level cognitive processing. Is more better? Do teams that communicate more reach better performance outcomes? Does what is communicated matter more than how it is communicated, or when? These are the types of issues team cognition researchers have addressed. Researchers have focused on understanding the nature of team cognition by examining the properties of team communication that lead to effective team outcomes. From this research, at least four main factors have emerged with regards to communication and the quality of team level cognitive processing: amount, form, content, and sequencing (or flow). While these dimensions are often crossed in theories and empirical studies (e.g., the amount of a specific type of content, the sequence of different communication content units) they can be conceptualized as independent dimensions. Table 1 provides an overview of these dimensions of team cognitive processing and each is reviewed below.

Table 1. Summary of dimensions of team process associated with team effectiveness.

Process Dimension	Description	Examples	Citations
Amount	The volume of communicative acts	Amount of information sharing	Foushee & Manos, 1981; Mosier & Chidester, 1991
Content	The 'what' that is communicated	Latent-semantic analysis; Content analysis	Foltz, 2005; Orlitzky & Hirokawa, 2001
Sequence/Flow	The temporal dynamics of content or member contributions	Closed-loop communication sequences; ideal cycles of communication	Bowers et al., 1998; Tschan, 2001; Tschan, 1995
Form	The quality of the communication delivery regardless of content	Use of proper phraseology; clear, concise, and complete communication	Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008

Team Communication Amount

The amount of communicative acts is a fundamental way of describing team level cognition. The initial assumption adopted by researchers was that teams with higher levels of communication were processing more information and should therefore reach better outcomes (i.e., more communication was equated to more and better team cognition). However, studies have shown equivocal results concerning the degree to which 'more is better' for team communication. For example, in the aviation domain, several studies have shown that larger volumes of communicative acts are associated with better team performance outcomes (e.g., Foushee & Manos, 1981; Mosier & Chidester, 1991) but this finding has not been replicated elsewhere (Bowers, Jentsch, Salas, & Braun, 1998). In addition, Levine and Choi (2004) found that teams who performed poorly during a performance episode subsequently engaged in more communication than

higher performance teams. In efforts to reconcile these findings, MacMillan, Entin, and Serfaty (2004) proposed the concept of team communication overhead; that is, teams require (to varying degrees) communication to coordinate their actions but this communication is costly in terms of the workload it generates for team members. Essentially, the concept of team communication overhead and the accompanying model and experiments reported by MacMillan and colleagues propose that "communication requires both time and cognitive resources, and, to the extent that communication can be made less necessary or more efficient, team performance can benefit as a result" (Macmillan et al., 2004, p. 61).

The idea that team communication is both necessary to team performance as well as a source of workload is an extension of Entin and Serfaty's (1999) work on adaptive team training and the anticipation ratio as an index predictive of team performance outcomes. The anticipation ratio is the number of information transfers to an individual divided by the number of information requests made by that individual. Anticipation ratios above one indicate that team members' informational needs are being anticipated whereas ratios below one indicate that information needs are being communicated explicitly. Teams with members who proactively pass information before being requested have better performance outcomes because they are more efficient at processing information at the team level. This represents a lower 'communication overhead' (i.e., they require fewer utterances to process the same amount of information). This efficiency facilitates timely coordination of actions. While the type of performance investigated using the anticipation ratio is primarily behavioral coordination, there is evidence indicating that reducing the amount of communication necessary for task performance

(i.e., decreasing the team communication overhead) can result in better outcomes for more cognitive tasks such as problem solving as well (e.g., Zhang, 1998; discussed in more detail in later sections). Essentially, the notion of team communication overhead qualifies the overly simplistic assumption that more communication is always better.

Team Communication Form

Form in team communication refers to the characteristics of how information is transmitted in the team as opposed to what is transmitted (i.e., content) or when (i.e., sequence and flow). This concept is analogous to a 'communication channel quality' in that the issue of concern is the degree to which messages (regardless of content) are transmitted in an effective manner. In the team guided self-correction model of teamwork (Smith-Jentsch, Zeisg, Acton, & McPherson, 1998) there is a dimension that captures most of the communication form issues. The *communication delivery* dimension includes team process behaviors of "using proper terminology, avoiding excess chatter, speaking clearly (audibly), and delivering complete standard reports containing data in the appropriate order" (Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008, p. 309). These characteristics of communication facilitate team-level cognitive processing because they reduce the effort involved in communication in various ways. For example, reducing excess chatter increases the signal to noise ratio; that is, team members spend less effort discriminating relevant from irrelevant information. Additionally, using proper or standard terminology as well as speaking audibly helps to ensure that the messages are understood.

Team Communication Content

Content in team communication focuses on what was said. A common theme in
this regard is that communication will be related to higher levels of team performance
outcomes to the degree that the content of the communication is consistent with the task
requirements (Hackman & Morris, 1975; McGrath, 1984; Salazar, Hirokawa, Propp,
Julian, & Leatham, 1994). The content of team discussion has proven to be predictive of
performance outcomes in many contexts (e.g., Harris & Sherblom, 2005; see also the
section on the Functional Theory of Group Decision Making below). Two general
approaches to the analysis of content in team communication have been applied: the
general methodology of manual content analysis (Krippendorff, 2004), and the automated
method of Latent Semantic Analysis (LSA; Landauer, Laham, & Foltz, 1998). In some
applications (i.e., automated tagging; Foltz, & Martin, 2009), LSA is used in a similar
manner as manual content analysis; however, LSA can also be used to compare
similarities in discourse without generating tags or categories of communication.

Content analysis traditionally involves the manual coding of transcripts in order to
categorize some unit of communication. Various coding schemes rooted in different
theoretical perspectives of team effectiveness have been developed (e.g., Tschan, 1995;
Bowers et al., 1998; Bales, 1950; Fisher, 1970). These coding systems attempt to reduce
the complexity of team communication by representing the discourse with a simpler set
of categories (Poole & Folger, 1981). For example, Harris and Sherblom (2005) discuss
the need of teams to focus the content of their communication on task ordering (i.e.,
creating an understanding of the team's processes and goals) and process orientation (i.e.,
developing a standard method of team interaction to reach those goals). Of course, much

of the detail is lost when condensing the richness and complexity of discourse to a limited number of categories, but this abstraction is part of generating measures of team processes grounded in theoretical constructs.

Latent Semantic Analysis is a machine learning technique that statistically infers expected relations between contextual usages of words in a discourse (Foltz, 2005). For example, machine learning algorithms have been applied to sets of team discourses with an associated distribution of performance scores. After this learning phase, the LSA algorithms were able to predict team performance outcomes with a reasonable degree of accuracy (correlation of $r = .63$ between performance scores predicted by LSA algorithms and actual team performance scores; Gorman, Foltz, Kiekel, Martin & Cooke, 2003; Martin & Foltz, 2004). While these LSA techniques are fairly good at discriminating high performing and low performing teams based on communication content, this technique involves a very low level, bottom up, and somewhat atheoretical approach to understanding team communication. A more detailed discussion of the specific content linked to effectiveness in decision making and problem solving teams is provided in following sections.

In sum, the content of a team's communication is predictive of performance outcomes. Specifically, teams reach better outcomes by focusing more of their processes on important task functions.

Team Communication Sequencing and Flow

Beyond amount, content, and form, the flow or sequencing of communication in teams has been examined by team cognition researchers. This includes both the sequence

of different content units (e.g., the closed-loop communication; Bowers et al., 1998) as well as the simple flow of communication between team members without considering content (Cooke, Gorman, & Rowe, 2009), that is, the sequence of team member contributions to the team's communication or when who is talking to whom.

In terms of sequence of team member contributions, Cooke and colleagues (Cooke et al., 2009; Cooke,Gorman, Pederson, Winner, Duran, Taylor, Amazeen, & Andrews, 2007; Gorman, Cooke, & Winner, 2006) have conducted a series of experiments in an Unmanned Aerial Vehicle (UAV) synthetic task focusing on the sequence of communication between different members of the teams. While the content of communication was not explicitly defined, the roles on the team were highly specialized (i.e., a pilot, navigator, and photographer), and an ideal sequence of communication based on task requirements was developed (e.g., at a certain point in the mission, the navigator needs to provide information to the pilot or the photographer needs to provide feedback to the entire team). Teams conforming to this optimal model reached better performance outcomes. Furthermore, the stability of turn taking (i.e., pattern of member contributions to communication) was significantly predictive of team performance outcomes, especially in the skill acquisition phase of team development (Kiekel, Cooke, Foltz, Gorman, & Martin, 2002). Additionally, network analysis has been applied to identify patterns of "who talked to whom" linked with better performance outcomes as well. Metrics such as the sequential edge count as well as nature of networks emerging from this data (i.e., long-chained networks and star shaped networks) were associated with higher performing teams (Carley, Moon, Schneider, & Shigiltchoff, 2005; Moon, Carley, Schneider, & Shigiltchoff, 2005).

In addition to approaches that do not directly deal with content, the temporal patterns of content units in team communication have been investigated. For example, the sequence of closed-loop communication (i.e., sender initiates a message, recipient acknowledges and verifies correct understanding, sender acknowledges recipient's understanding of message) is an example of the sequence of content units predicting team performance outcomes (Bowers et al., 1998). In a series of studies Tschan (1995; 2002) tested the hypothesis that teams with communication patterns conforming to ideal cycles of communication would outperform those teams whose communication does not adhere to this structure. Communicative cycles are logically related clusters of communication or segments of the team discussion (Futoran, Kelly, & McGrath, 1989). Ideal cycles of communication were defined in terms of action regulation theory (e.g., Frese & Zapf, 1994) in that they started with orientation or planning statements and ended with evaluation statements. In three studies (Tschan, 1995; 2002) high performing teams had more ideal cycles than did low performing teams. The number of ideal cycles predicted unique variance in team performance above and beyond more basic measures of communication amount (Tschan, 2002).

Each of these four dimensions of team communication investigated in team cognition research has emerged in other research traditions as well. In the following section, contributions from group communication theorists and others researching team decision making and problem solving are reviewed.

Team Process in Decision Making and Problem Solving

Supplementing the team cognition literature, researchers from a variety of traditions have investigated the processes by which teams go about making decisions and solving problems. This section provides a review of some of the key theories in this area. Specifically, from the group communication theory literature, the functional perspective on team decision making as well as phasic and multi-sequence models of team decision making are reviewed. Additionally, multi-disciplinary work on information sharing and sampling in group decision making is discussed. Throughout these varied perspectives, the theme of team communication as a limited processing resource (discussed in the team cognition literature) remains consistent. Aspects of the four dimensions of team communication described above emerge as well.

Functional Theory of Group Decision-Making Effectiveness

Consistent with the team cognition approach, the general functional perspective on teams assumes that team members are oriented towards a common set of goals, and that performance processes within a team exhibit variance and can be evaluated (Hollingshead, Wittenbaum, Paulus, Hirokawa, Ancona, Peterson, Jehn, & Yoon., 2005). Efforts at applying this general perspective to team decision making have led to the Functional Theory of Group Decision Making Effectiveness (Hirokawa, 1988; 1987; 1985; 1980; Hirokawa & Pace, 1983; Hirokawa & Rost, 1992). This theory proposes that decision making effectiveness is determined by the amount and quality of team process (i.e., communication) that focuses on fulfilling critical task requirements. That is, in order to solve a problem or make a decision, a team must complete some set of functions or

sub-tasks. In this way, effective teams have been said to engage in vigilant interaction (Hirokawa & Rost, 1992); that is, they focus the team's processing resources on task critical functions in a coherent manner. Specifically, Hirokawa's functional theory proposes five critical team functions in its most recent form (Orlitzky & Hirokawa, 2001): problem analysis (i.e., develop an accurate understanding of the problem, its likely causes, and consequences of not solving the problem), establishment of evaluation criteria (i.e., define what an acceptable solution looks like), generation of alternative solutions (i.e., create a set of practical and acceptable solution alternatives), evaluation of positive consequences of solutions (i.e., evaluate the merits of solution alternatives), and evaluation of negative consequences of solutions (i.e., evaluate the disadvantages of solution alternatives).

Orlitzky and Hirokawa (2001) conducted a meta-analysis of the existing literature testing the functional theory of group decision making effectiveness. Their findings support the premise that the five functions outlined in the theory play an important role in team outcomes; however, not all functions contribute equally. Estimated true-score correlations between outcomes and negative evaluation of solution consequences (estimated $\rho = .89$), and problem analysis (estimated $\rho = .55$) were the highest of the five, followed by establishment of evaluation criteria (estimated $\rho = .27$) and positive evaluation of solution consequences (estimated $\rho = .20$), and finally generation of alternative solutions (estimated $\rho = .12$). These findings suggests that, consistent with the single-option generation and evaluation models of individual decision making (e.g., Klein, 1998), teams do not do better by generating an exhaustive or even large set of options, but by rigorously evaluating a limited set of options they generate. The function

of generating solution options was far less predictive of team effectiveness than functions involving evaluation of the problem and solution options.

While the five functions discussed above can be arranged into a logical order to some degree (e.g., it would make sense to analyze the problem before generating options), this is not an assumption of the theory. Teams shift the focus of team level cognitive processing to these various functions in different orders. It is the amount and quality of communication focused on different functions that matters, not the sequence of this processing. This contrasts with the work of Tschan on ideal cycles of communication discussed above as well as phasic and multi-sequence models of group decision making discussed below. The following section discusses issues of sequencing.

Phasic and Multi-sequence Models

Many models of group decision making and problem solving represent these processes as movement through a linear set of logical phases. For example, the decision emergence perspective holds that groups pass through four phases of activity (Ellis & Fisher, 1994): orientation (i.e., building a stable social climate, coming to a shared understanding of the problem and likely solutions), conflict (i.e, expressing favorable opinions about preferred options and unfavorable opinions about competing options), emergence (i.e., members supporting the losing option begin to back off their initial position), and reinforcement (i.e., consensus forms around the option ultimately chosen by the group). Many variations of these models exist for both groups and individuals (e.g., the Observe, Orient, Decide, and Act—OODA–loop).

However, group communication theorists have questioned the notion that there is a unitary, logical, and normative model for group decision making and problem solving. In a series of studies, Poole and colleagues (Poole, 1981; 1983a; 1983b; Poole & Roth, 1989a; Poole & Roth, 1989b; Poole & Holmes, 1995) demonstrated that groups progress through a variety of trajectories or paths that are not always best characterized by a logical normative model. Instead, group decision making and problem solving can be characterized using multi-sequence models. Factors such as the nature of the task and the interpersonal relationships between members will influence the nature of group interaction and the trajectory through problem solving stages that teams take as they develop a solution (Poole, 1981). The multiple sequence approach holds that groups manage interaction in different threads over time. Poole and Roth (1989) identified three types of group interaction threads: task process activities, relational character, and topical focus.

This line of research has led to the general conclusion that teams do not always follow a logical or normative model in decision making or problem solving activities (e.g., some teams focus early and almost exclusively on solution generating activities without engaging in an analysis of the situation). However, logical normative models do serve as a good approximation of the problem solving process adopted by most teams and, additionally, teams whose trajectories most closely resemble a logical normative model tend to reach the best performance outcomes (e.g., Poole & Holmes, 1995). That is, a logical sequence model of group decision making does not describe the path all teams take to reaching a decision, but it is a better characterization of high performing teams than of low performing teams. These findings are consistent with those of Tschan

(1995); however, Poole and colleagues investigated the flow of the group discussion as a whole whereas Tschan focused on smaller units of the group's communication.

Information Sharing and Sampling

In many organizations, teams are formed to solve problems and make decisions in part because no one individual possess the full range of information or expertise needed to reach effective outcomes. However, a large number of studies using a hidden profile problem solving scheme (i.e., the sets of information given to individuals in a group varies; uniquely held individual information favors one solution; combining individual information will favor a different and correct solution; Stasser, 1992) indicate that this sharing of unique information is not achieved easily by groups. To describe why this is the case, Stasser and Titus (1985) proposed the biased sampling model of group discussion wherein the content of the group discussion is biased by 1) a focus on shared information over individually held information (i.e., a piece of information is more likely to be discussed if it is already shared rather than uniquely held by a team member), and 2) the current preferences of group members (i.e., a piece of information is more likely to be discussed by the group if it is aligned with rather than opposed to the preferences or positions of the group members). The problem of distributed information in group problem solving becomes more complex when the interconnections between information in the group are considered. For example, Fraidin (2004) showed that group performance in hidden profile problem solving decreased when groups had to manage uniquely held information whose meaning was dependent upon uniquely held information of other team members relative to groups whose members' information meaning was not dependent

upon uniquely held information of other members. In these situations, team members may not understand the value of the information they have until it is combined with information held by other team members. This bias in information sampling in group discussion results in groups accepting solutions to problems based on an insufficient exploration of the problem search space (Fiore, 1996). Consequently, information sharing in teams has emerged as an important function of communication. In a recent meta-analysis of the information sharing literature, Mesmer-Magmus and DeChurch (2009) found a strong estimated true score correlation between information sharing and team performance outcomes (estimated $\rho = .42$). This effect was stronger in complex tasks and attenuated in simple ones.

Summary of Team Cognition and Team Process Literatures

In sum, communication can be viewed as the mechanism by which teams process information. In this way, it is a resource that can be devoted to different functions or tasks in a way analogous to attention on the individual level. Additionally, it is not just the content of the process but the form and sequence of how the process is enacted that can be predictive of team performance outcomes. Two overarching perspectives on team cognition and more broadly on the role of team processes in decision making and problem solving can be identified: 1) a *functional perspective* based in the idea that team process leads to effective outcomes to the extent that it fulfills important tasks and, 2) an *interactional perspective* which links temporal characteristics of team process to outcomes.

The functional perspective as exemplified by the Functional Theory of Group

Decision Making Effectiveness (Hirokawa, 1980) and more generally the functional

perspective on groups (Hollingshead et al. 2005) views group processes as a resource that

the team can apply (or not) to accomplishing important tasks. The more group process the

team focuses on these important tasks (or functions) the better the team's outcomes will

be. Additionally, a recent meta-analytic path model provides some evidence that there is

an underlying latent factor accounting for all group process variables (LePine et al.,

2008). From investigations of group problem solving, several functions have emerged as

critical to effectiveness including information sharing (Mesmer-Magnus & DeChurch,

2009) as well as those proposed by the Functional Theory of Group Decision-Making

Effectiveness such as the evaluation of proposed solutions (Orlitsky & Hirokawa, 2001).

The functional view is consistent with much of the team cognition literature investigating

the content of communication.

The interactional perspective on team processes incorporates aspects of temporal

arrangement or sequencing of team communication behaviors. It is not just what is said

(i.e., the amount of team cognition focused on task functions) but who is saying what

when. Examples of the interactional perspective include Poole and colleagues work on

multi-sequence models of team decision making, Tschan's work on ideal cycles of team

communication, and Cooke and colleagues work on information push and pull in UAV

teams. The interactional perspective is consistent with team cognition research

investigating the flow or sequence of communication.

The interactional and functional perspectives are not mutually exclusive, and

researchers have found both are critical to describing team effectiveness in problem

solving. For example, Barron (2000) described three main mechanisms of achieving coordination in team problem solving: a mutuality of exchanges (i.e., the sequencing of exchanges, an interactional feature of team process), achievement of joint attentional focus (i.e., communicating about similar content, a functional feature of team process), and alignment of team member's goals for problem solving (i.e., a defining characteristic of a team). In following sections, hypotheses will be developed within the Macrocognition in Teams framework from both the functional and interactional perspectives. First, the second major component of the Macrcognition in Teams framework investigated in this proposed study—external representations—will be developed in the following section.

External Representations

It is a well established fact that the representation of a problem plays a major role in the solution of that problem. The strongest position on this relationship can be stated as "solving a problem simply means representing it so as to make the solution transparent" (Simon, 1999, p. 132). From framing choices in terms of losses or gains (Levin, Schneider, & Gaeth, 1998; Tversky & Khanemen, 1981), to providing information in frequency versus probability formats (Gigerenzer & Hoffrage, 1995), to providing information in different forms of visualizations (Chen & Yu, 2000; Zhang, 1996), the external representations used in the process of solving a problem or making a decision influence outcomes (Kirsch, 2009). There are several research traditions actively pursuing a detailed understanding of how external structure influences internal cognitive processing and vice versa. Examples of these traditions include distributed cognition

(Hutchins, 1995), situated cognition (Robbins & Aydede, 2008; Clancey, 1997), and extended and embodied cognition (Clark, 2008). While there are important distinctions between these approaches, in general they share the following view:

> "… the classical cognitive science approach can be applied with little modification to a unit of analysis that is larger than one person… to characterize the behavioral properties of the unit of analysis in terms of the structure and the processing of representations that are internal to the system" (Hutchins, 1995, p. 266).

That is, cognition is intertwined with the physical and social environment such that considering only one of these things in isolation from the others yields a skewed and incomplete understanding of the phenomenon of interest. While the phrase 'unit of analysis larger than one person' in the preceding quote makes the team cognition and external representation literature naturally compatible, the focus of work carried out in each of these research areas has not capitalized on work carried out in the other to a large extent. Consequently, with several exceptions this section reviews literature concerning external representations in individual performance. Specifically, this section addresses three core issues: definitions of external representations, functions of external representations, and the limited literature available on external representations in teams.

Defining External Representations

Kirsh (1995) describes the process of experts building external representations as physically and informationally 'jigging' the environment. This metaphor from carpentry cogently depicts the nature of how creating external structure can change the internal processes necessary for task performance. The carpenter who creates a jig is no longer bound to the more internally processing intensive 'measure twice and cut once' rule; all

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knowledge of correct dimensions has been offloaded to the jig. In this way, externalized

representations serve a variety of functions (Zhang & Norman, 1994): memory aiding,

providing information that can be directly perceived and used, anchoring internal

cognition, and changing the nature of tasks. These same types of functions play out on

the team-level as well. Before these various functions are discussed in detail, it is

necessary to explore a precise definition of an external representation. In general, an

external representation is defined as "…knowledge and structure in the environment, as

physical symbols, objects, or dimensions… and as external rules, constraints, or relations

embedded in physical configurations" (Zhang, 1997, p. 180). External representations are

also referred to as cognitive artifacts, physical objects "made by humans for the purpose

of aiding, enhancing, or improving cognition" (Hutchins, 1999, p. 129). This second

definition articulates a purpose and origin to the nature of external representations; that is,

they are created by people in order to help them think about a task. Rowlands (2009)

provides an extensive review of the representation literature and provides six criteria used

to define representations. These criteria are not universally accepted, but represent

different themes in the research literature. Table 2 provides definitions of the six different

criteria.

Table 2. Summary of different criteria used to define representations

Constraint / Criterion	Definition
Combinatorial	A representation must not occur in isolation; it has to be part of a larger representational system.
Informational	A representation must carry information about something extrinsic to itself.
Teleological	A representation must have a proper function of tracking the 'state of affairs' that produced it or allowing an agent (a representational consumer) some benefit in tracking this state of affairs.
Decouplability	A representation must be separable from that which it represents.
Misrepresentation	A representation must allow for inconsistent or inaccurate mappings between the situation or object it represents and the manifestation of the representation.
Causality	A representation must play some role in guiding the behavior of the person using that representation.

Unfortunately, there remains a gap between these conceptual definitions and an understanding of how different external representations will influence different types of performance. For example, using Rowlands' criteria of representation, both the Roman and Arabic numeral systems qualify as external representations and can not be distinguished from one another using these criteria; however, there are large differences in the degree to which these representational systems serve as good externalizations (i.e., facilitate performance) for different cognitive processes such as mathematical computation (Zhang & Norman, 1995). The Arabic numeral system functions as a much better aid to cognition for mathematical computation than the Roman numeral system (e.g., is it easier to add XLVI and LIV or 46 and 54?).

This finding of formally equivalent representations (i.e., different representations of the same thing) being functionally different (i.e., facilitating or hindering task performance) has not been fully explained; however, theoretical frameworks have been

proposed to address this issue. Most notably, Zhang and Norman's (1994; also, Zhang & Norman, 1995; Zhang, 1996; 1997) representational analysis methodology was developed to help describe why different problem representations can drastically increase or decrease the difficulty (and subsequently, the performance outcomes) of tasks that are essentially the same. Representational analysis is based in three main concepts: hierarchical representations, isomorphic representations, and distributed representations. Many tasks have representations with a hierarchical structure; that is, representations within a task can be divided into component levels (e.g., goals and sub-goals, procedures and sub-procedures, rules and component rules). At each of these levels, representations within the task have an abstract structure that can be represented in multiple ways. That is, different representations can be created for the same content (e.g., set of procedures or operators within a task). When two representations are created which are equivalent in content or meaning, they are called isomorphic representations. Using different isomorphic representations, the abstract structure of a task can be distributed across individuals and the environment in different ways. For example, the abstract structure of a task can be the same, but distributed differently across various members (i.e., different members know different rules or have different information sets) or across members and the environment (i.e., rules can be internal to a team member or externally represented to just one member or the entire team).

The representational analysis framework provides a language for discussing representations. Specifically it contributes the concepts of abstract and isomorphic representations. In the context of team problem solving, this suggests that various task functions (i.e., the abstract representation of the team's task) can be accomplished via

team processes or external representations or a combination of both. That is, the team can create isomorphic representations of the team functions (e.g., information exchange) via verbal team communication or through the creation of shared external representations. However, this framework does not provide specific predictions about what types of representations will be most effective in a given situation. Hypotheses of this sort will be developed from the Macrocognition in Teams framework in later sections.

<center>*The Functions of Externalization*</center>

Kirsh and Maglio (1994) draw a distinction between epistemic and pragmatic actions in task performance. *Pragmatic* actions are behaviors intended to bring an individual physically closer to his or her goal. They are the basic actions required to complete a task. In contrast, *epistemic* actions are those behaviors whose primary function is to improve cognition by means of reducing the memory load, number of steps, or probability of error in internal cognitive processing. These actions are not a part of implementing a plan or reaction, but are intended to simplify the problem space, to make the problem solving environment more 'cognitively congenial' (Kirsh, 1996). Epistemic actions do not bring an individual physically closer to a goal; instead, they uncover information or translate it into a form that requires less internal processing. Kirsh and Maglio present data suggesting that Tetris players rotate puzzle pieces on the screen instead of in their heads because the perceptual and motor loop involved in on-screen rotation is faster than internal mental rotation of puzzle pieces. This on-screen rotation of puzzle pieces is an example of epistemic action; it is intended to uncover the best position

for the piece to be placed. Moving the puzzle piece to the selected position is an example of pragmatic action.

In order to further specify how external representations influence performance and learning, Salomon (1993) makes a distinction between tools (or external representations) that 1) *off-load* processing demands or cognitive burden, and those that 2) *scaffold, guide, or support* cognition. These two functions are fundamentally different in that one involves replacing internal cognitive work and the other involves supporting it. Both of these functions are described below.

Externalization as Off-loading

The example of Tetris players' rotating pieces on the screen is an example of offloading the resource intensive task of mental rotation to the external environment. Tetris players rotate pieces on the screen because doing this eliminates the need to do these computationally intensive rotations in their minds. The Soft Constraints Hypothesis (SCH; Gray & Fu, 2004; Gray, Sims, Fu & Schoelles, 2006) is an exemplar theory based entirely in the externalization as off-loading perspective designed to further understand this type of behavior. Essentially, the SCH states that the mixture of cognitive (i.e., internal processing) and perceptual motor (i.e., use of externalization) strategies a person adopts in a given task is based on temporal cost-benefit tradeoffs. That is, people use externalization as a task performance strategy to the degree that it is faster than internal processing. To continue with a simple example used previously, if the response times of controls in a Tetris game were manipulated so that the on screen rotation was slower than mental rotation, the expert Tetris player would no longer rotate pieces on screen.

From this perspective, the brain does not have an innate preference for where information comes from (internal or external). The fastest task strategy wins out even over concerns of information quality. People sacrifice 'perfect knowledge in-the-world for imperfect knowledge in-the-head' when it is faster (Gray & Fu, 2004). That is, people will rely on faulty memory over accurate information in the environment when the time costs of accessing that information in the environment are even just marginally greater than accessing information in memory.

Externalization as Scaffolding

In addition to offloading cognitive processing, the idea that externalizations serve to support (rather than replace) internal processing has emerged. Understanding the difference between these two functions is especially important for educational researchers who note that merely off-loading processing is ineffective from a learning point of view (i.e., if people offload processing, they may not learn important aspects of a task; Salomon, 1993). Instead, tools and representations should be designed that increase the learner's (or task performer's) ability to engage in processes effectively. Inspired by evolutionary theory, the cognitive niche construction perspective on use of external representations is based in a scaffolding approach. This is a broad perspective discussed in a variety of contexts from language development (Pinker, 1995) to the emergence of cultures (Laland, Kendall, & Brown, 2007; Laland, Odling-Smee, & Feldman, 2000) and is rooted in the idea that organisms and environments co-evolve. That is, a person makes changes to their task environment in order to make task performance more efficient (i.e., epistemic actions), and these changes alter the person's understanding of the task or

processes of performance. This new understanding of the task may prompt further epistemic actions modifying the environment to better support the refined understanding of task performance. This iterative process of mutual causality between the task environment and an individual's performance has been conceptualized as developing a cognitive niche, which is defined as "…an animal-built physical structure that transforms one or more problem spaces in ways that (when successful) aid thinking and reasoning about some target domain or domains" (Clark, 2006, p. 370). Cognitive niche construction is not just memory aiding or increasing the speed of access, it involves changing the conceptual understanding of a problem. In this vein, Bardone and Magnani (2007) propose that building shared representations in teams is a memetic process wherein individuals externalize fleeting thoughts which are subsequently picked up by others to alter their decision making process. This type of thinking is bolstered by the work of Schwartz (1995) who found that teams generating abstract representations of a problem were more effective in problem solving tasks. These abstract representations were not directly necessary for solving the problem (i.e., they were not pragmatic actions).

The functions of off-loading and scaffolding can be intertwined, especially in complex tasks. Given a limited processing resource (working memory capacity on the individual level, communication on the team level) offloading some task functions to the environment can free up more of the limited resource to be applied to the remaining task functions. For example, an individual can use a calculator (i.e., offload basic math computations) to more effectively make decisions about investment options. Here, the higher order decision making processes are scaffolded by offloading more basic tasks.

Additionally, a team can offload information sharing using collaborative tools (i.e., push information to team members without verbal communication) in order to support the generation of solution options. Here, less team process is devoted to information sharing (i.e., it is offloaded) and consequently other processes are facilitated. In following sections, hypotheses within the Macrocognition in Teams perspective will be developed for both externalization as offloading and scaffolding.

External Representations in Teams

The vast majority of systematic and methodologically rigorous work investigating the role of external representations has been conducted on the individual level. There are several research communities (e.g., Computer Supported Collaborative Work, Stahl, 2006; Computer Supported Argumentation Visualization, Kirschner, Buckingham, & Carr, 2003) researching externalization in team problem solving, but the amount and quality of empirical research is limited (van den Braak, van Oostendorp, Prakken, & Vreeswijk, 2006) However, there are some notable exceptions concerning the external representation of elements of the task as well as externalization of team processes to aid self-regulation on the team level.

With regard to external representations of tasks, Zhang (1998) proposed and evaluated a model of distributed representations in team problem solving rooted in the representational analysis approach described above. At the core of the model is the idea of an abstract task space representing the structure of the task. This abstract structure can be represented in various isomorphic ways with elements represented internally and externally on the individual level. Additionally, the abstract task space can be distributed

across the individual members of the team. Using a variant of the Towers of Hanoi problem, Zhang conducted an experiment where he distributed the rules of this simple task (three rules in all) across two team members in three conditions such that either 1) both team members knew all three rules, 2) one team member knew all three rules and the second knew only one, or 3) both team members knew two rules, one shared and one unique. In this way the abstract structure of the task (i.e., the three rules) is represented in different isomorphic ways and distributed across team members. Team members with higher levels of shared representation performed better. Zhang proposed two high level hypotheses to explain his results. First, the *communication hypothesis* states that "the less communication required among individuals, the better the performance of the distributed system in terms of solution times" (Zhang, 1998, p. 807). Second, the *representation sharing hypothesis* states that "the more representation shared among individuals, the better the performance of the distributed system in terms of solution steps" (Zhang, 1998, p. 807).

These hypotheses are consistent with the team cognition literature. First, the communication hypothesis closely parallels the concept of team communication overhead previously discussed (MacMillan et al, 2004) as well as findings from research on information sampling in team discussions. Additionally, it suggests that a method of reducing communication overhead could involve using different isomorphic representations of the same abstract task space. Second, the representation sharing hypothesis is similar in concept to Shared Mental Model (SMM) Theory (Cannon-Bowers et al., 1993); however, SMM Theory is based on the distribution of internal

knowledge structures and the Zhang's representation sharing hypothesis can be extended to include external representations shared by the team.

Several studies have looked at the use of external representations for supporting reflection or self-regulation in teams as well. Shirouzu, Miyake, and Masukawa (2002) provide a detailed description of how teams engaged in problem solving use physical traces of their process to evaluate the correctness of their solution. Additionally, Jermann and Dillenbourg (2008) describe team mirrors (i.e., a graphical representation of the team's actions and communications) and how, when team process is mirrored relative to some set criteria, communication within the team is altered. While limited in number, these studies suggest that external representations can influence a broad variety of team processes.

Summary of External Representation Literature

There are two broad and inter-related categories of functions external representations can play in cognitive work in individuals and teams. First, they can serve to *off-load* cognitive processing. That is, on the individual level externalizations can be used to do what was originally done internally. On the team level, this can be viewed as freeing up the low capacity channel of team communication. Team cognitive work mediated through communication can be offloaded into the environment through external representations and made accessible to all, allowing the team to apply its processes to different functions. Second, externalizations can *scaffold* internal processing. That is, an external representation can provide information that facilitates understanding of a domain or cognitive processing rather than replacing it. On the team level this means that the

external representations a team constructs can improve the effectiveness of their

processes. For example, team self-regulation can be improved by providing team

members with a visual representation of the team's communication exchanges (Jermann

& Dillenbourg, 2008).

There are two primary implications of the preceding discussion in the present

context. First, quality external representations can serve to 'free up' the low-capacity

channel of team process and communication. Cognitive work in the team can be

offloaded into the environment and made accessible to all, allowing the team to apply its

processes to different functions. Second, the quality of the external representations

generated by a team changes the effectiveness of different team processes. For example,

if the team externalizes much of the uniquely held information of its members, then the

relationship between the amount of team effort devoted to sharing information via verbal

communication and outcomes will be attenuated. In this case, if unique information is

shared through external representations, team process focusing solely on information

exchange become redundant and less predictive of effective outcomes. These

implications will be discussed in relation to specific hypotheses provided in the

Macrocognition in Teams section below.

Macrocognition in Teams

The preceding sections provided an overview of team process and externalization

literatures, two areas of research that rarely interact. The Macrocognition in Teams

perspective seeks to unify the contributions of team cognition and other team process

traditions with work on externalized cognition. Figure 2 depicts a framework of

Macrcocognition in Teams proposed by Fiore and colleagues (in press). This model is

firmly rooted in the science of teams as described earlier and takes a multi-level input,

process, output form. The internalized knowledge of team members serves as the main

input. This knowledge is involved in both team and individual level knowledge building

processes which subsequently influence the effectiveness of the team problem solving

activities, the outcomes. However, a unique feature of the Macrocognition in Teams

Model is the addition of externalized team knowledge which emerges from team

processes and moderates the linkage between team knowledge building processes and

team problem solving outcomes. As the present focus is on team process and

externalization, these components of the framework (blocked in red in Figure 2) will be

developed in the following sections.
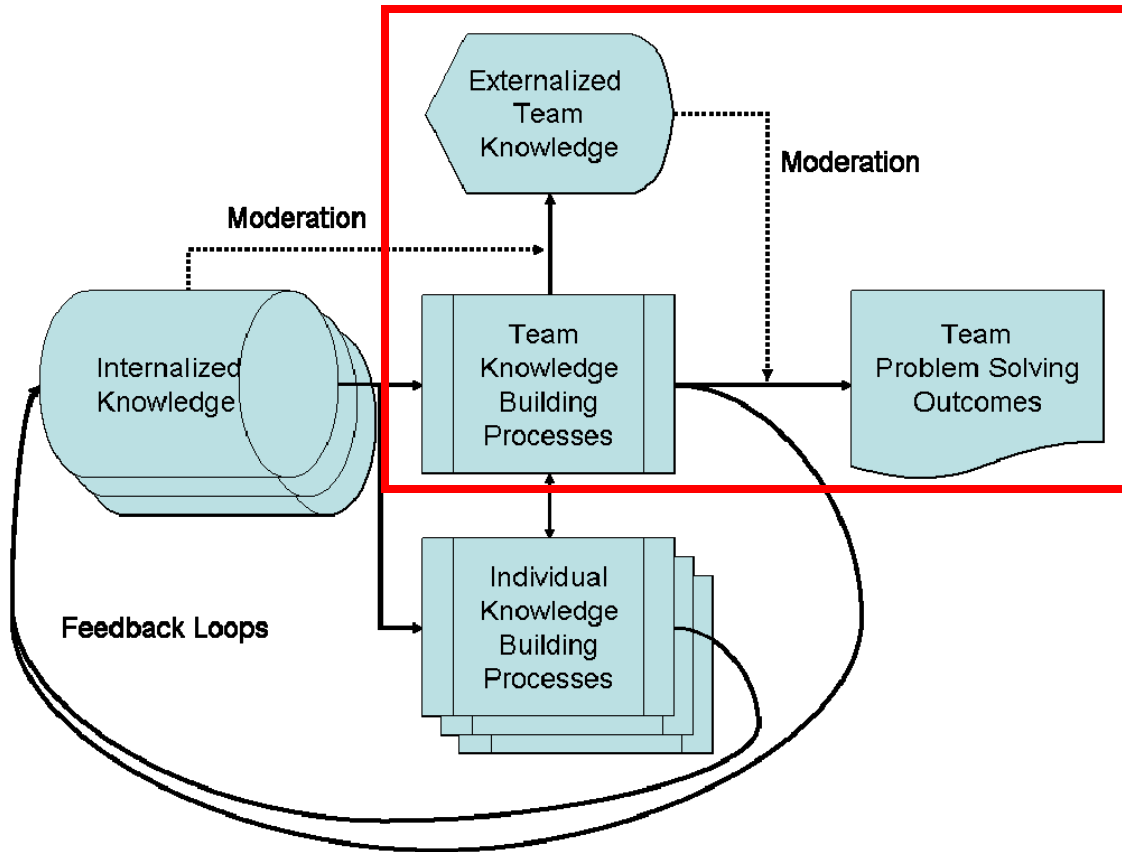
Figure 2. Framework of Macrocognition in Teams.

Team Knowledge Building Processes

Table 3 provides definitions of the five processes comprising team knowledge building. These are team information exchange, team knowledge sharing, team solution option generation, team evaluation and negotiation of alternatives, and team process and plan regulation. These processes are based on an extensive literature review of the team problem solving, knowledge building, and group communication literatures (e.g., Stahl, 2006; Salas & Fiore, 2004; Poole & Roth, 1989) and describe the functions that a team must fulfill in order to solve a unique problem. While these processes can be viewed as a

unitary sequence model (i.e., a step by step procedure), it is recognized that teams may not proceed in a stepwise fashion through these processes but cycle through different activities in different orders. As depicted in Figure 2, it is hypothesized that the five team knowledge building processes have a direct causal effect on team problem solving outcomes. Consistent with functional perspectives of team decision making and problem solving, teams will reach effective outcomes to the degree to which they focus their processes on these five team knowledge building functions.

Table 3. Definitions of Team Knowledge Building Processes

Team Knowledge Building Process	Definition
Team Information Exchange (TIE)	Sharing relevant information with team members
Team Knowledge Sharing (TKS)	Communicating explanations and interpretations of information
Team Solution Option Generation (TSOG)	Offering potential solutions to a problem
Team Evaluation and Negotiation of Alternatives (TENA)	Clarifying and discussing positive and negative consequences of potential solution options
Team Process and Plan Regulation (TPPR)	Critiquing the team's process

Externalized Team Knowledge

In the Macrocognition in Teams framework, externalized knowledge is defined as "facts, relationships, and concepts that have been explicitly agreed upon, or not openly challenged or disagreed upon, by factions of the team" (Fiore et al., in press, p. 16). This definition is broader than the definition of external representation discussed previously. External representation refers to information and knowledge in the environment, where the definition of externalized team knowledge in the Macrocognition in Teams Model

includes both external physical representations as well as content of communication.

Language is a fundamental type of externalization (Pinker, 1995), but verbal

communication and external physical representations differ in significant ways such as

temporal stability (i.e., verbal communication is more ephemeral in nature than textual,

iconic or graphical information that persists over time). This study investigates aspects of

externalized team knowledge in the environment. The content of each of the five team

knowledge building processes can be externalized (i.e., information, knowledge or

relationships, potential courses of actions, consequences of actions, and team regulation).

Differences in the content of external representations as well as their quality will have

different implications for effectiveness.

Summary of Hypotheses

The hypotheses tested in the study proposed here are organized around the two

different perspectives of team process: the functional and interactional views. These

perspectives are not mutually exclusive. They provide different conceptual foundations

for understanding team effectiveness in problem solving tasks. The majority of team

research on problem solving tasks has been rooted in the functional perspective;

therefore, a stronger basis exists for making predictions from a functional perspective.

The hypotheses proposed and evaluated from the interactional perspective are more

exploratory in nature.

The functional perspective on teams suggests that higher levels (i.e., more) of team process focused on important tasks are associated with more effective outcomes. The Macrocognition in Teams framework proposes five team knowledge building processes as described in Table 3. Therefore, the degree to which teams focus their processes on each of the five team knowledge building functions will be associated with effective outcomes. These relationships are depicted in Figure 3 and serves as the first set of hypotheses examined in this study. Specifically:

> *Hypothesis 1:* Each of the team knowledge building processes account for significant and unique variance in Team Problem Solving Outcomes, such that:

> > *Hypothesis 1a:* Teams with more TIE will have better outcomes after accounting for the effects of the remaining four team knowledge building processes.

> > *Hypothesis 1b:* Teams with more TKS will have better outcomes after accounting for the effects of the remaining four team knowledge building processes.

> > *Hypothesis 1c:* Teams with more TSOG will have better outcomes after accounting for the effects of the remaining four team knowledge building processes.

> > *Hypothesis 1d:* Teams with more TENA will have better outcomes after accounting for the effects of the remaining four team knowledge building processes.

> > *Hypothesis 1e:* Teams with more TPPR will have better outcomes after accounting for the effects of the remaining four team knowledge building processes.
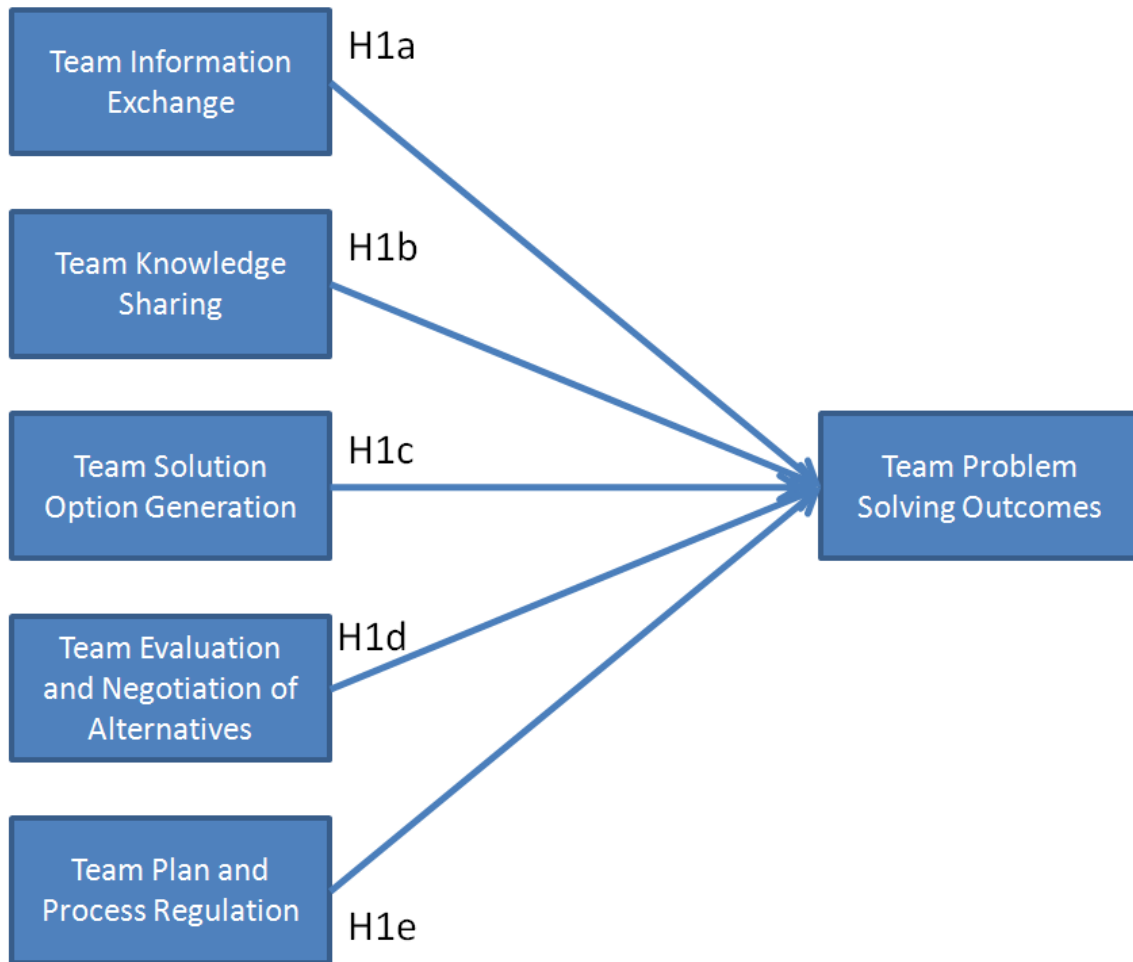
Figure 3. Illustration of Hypotheses 1a-e

As illustrated in Figure 4, the Macrocognition in Teams Model proposes an overall moderating effect of quality of externalized team knowledge on the relationship between team knowledge building processes and problem solving outcomes. Hypotheses H2a-d and H3a-b propose a more detailed set of predictions based upon interactions between the content of the team process and external representation. H2 deals with cases where the content of the process and external representation are of the same type (i.e., fulfilling the same team knowledge building process function) and H3 deals with cases where the content is different. Conditions where the content of the process and

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externalization are the same will be referred to as *content matching* and conditions where the content is different will be referred to as *content disparate*. Due to the tools available to team members in this study, external representations will be created for information almost exclusively. Consequently, the hypotheses advanced below deal with external representations of the TIE team knowledge building process.

First, in content disparate conditions both the scaffolding and offloading perspectives predict the same relationship between external representations, team knowledge building processes, and problem solving outcomes. Higher quality external representations should increase the effectiveness of a team process in these circumstances. From the offloading perspective, teams with a high quality external representation of information will not need to devote limited team cognitive processing resources (i.e., communication) to the function of team information exchange. Consequently, they will have more resources to devote to the remaining four team knowledge building processes. This is consistent with the team communication overhead perspective discussed earlier. From the scaffolding perspective, a high quality external representation of information should increase the effectiveness of other team knowledge building processes. Consequently, the following hypotheses are proposed:

> *Hypothesis 2:* External Representation Quality will have a positive moderating effect on the relationship between team knowledge building processes and Team Problem Solving Outcomes when the content type of the externalization and process are different, such that:

>> *Hypothesis 2a:* For teams with higher levels of External Representation Quality of TIE, the relationship between TKS and Team Problem Solving Outcomes will be strengthened.

>> *Hypothesis 2b:* For teams with higher levels of External Representation Quality of TIE, the relationship between TSOG and Team Problem Solving Outcomes will be strengthened.

Hypothesis 2c: For teams with higher levels of External Representation Quality of TIE, the relationship between TENA and Team Problem Solving Outcomes will be strengthened.

Hypothesis 2d: For teams with higher levels of External Representation Quality of TIE, the relationship between TPPR and Team Problem Solving Outcomes will be strengthened.
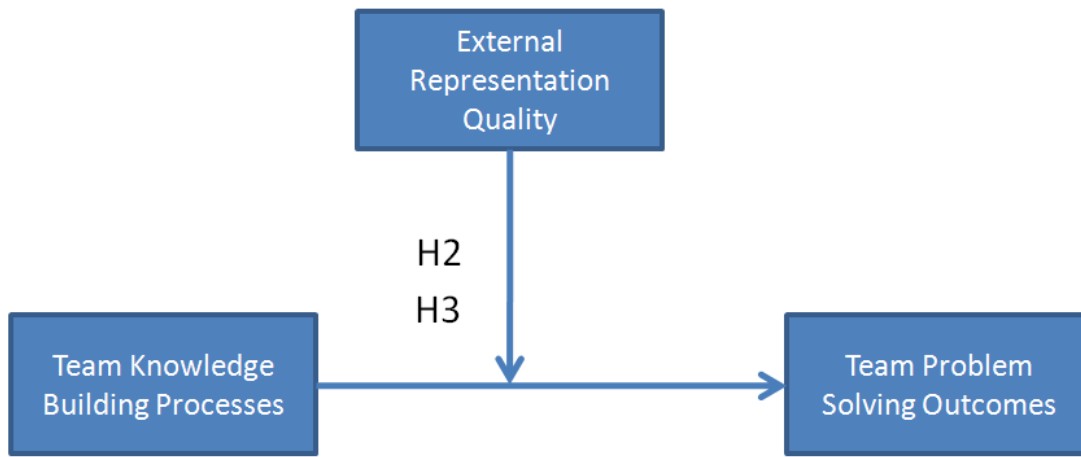
Figure 4. Overall moderating effect of external representation quality on team problem solving outcomes.

Second, in content matching circumstances the predictions of the offloading and scaffolding perspectives of external representations become more complex. As detailed in Table 4, scaffolding and offloading perspectives on external representation function diverge in their predictions for content matching cases. From the offloading perspective, teams with high quality external representations of information who also engage in high levels of the team information exchange process are in a sense duplicating efforts. Consequently, the relationship between that process and team problem solving outcomes should be weakened. However, from the scaffolding perspective, a high quality external representation of the content of a given team knowledge building process should make

the relationship between process and outcome stronger. It should improve the

effectiveness of the process and not replace it. Therefore, two competitive hypotheses are

proposed for evaluation in this study.

Table 4. Overview of hypotheses for process and externalziation interaction

		Team Knowledge Building Process				
		TIE	TKS	TOG	TENA	TPPR
External Representation Content and Quality	TIE	**-O / +S**	+	+	+	+
	TKS	+	**-O / +S**	+	+	+
	TOG	+	+	**-O / +S**	+	+
	TENA	+	+	+	**-O / +S**	+
	TPPR	+	+	+	+	**-O / +S**

Note: '+' indicates a moderating effect such that higher levels of external representation quality increases strength of the relationship between the team knowledge building process and team problem solving outcomes and '-' indicates the opposite relationship. For cells shaded in grey (i.e., content matching cases), there are competitive hypotheses between offloading (O) and scaffolding (S) functions of externalization. Relationships blocked in red will be tested in this dissertation.

As illustrated in Figure 5a, the offloading perspective on external representations

predicts a negative moderating relationship between team knowledge building process

and external representations for content matching cases. Therefore, the following

hypothesis is offered.

> *Hypothesis 3a:* External Representation Quality of TIE will have a negative
> moderating effect on the relationship between TIE and Team Problem Solving
> Outcomes such that this relationship will be attenuated for teams with high levels
> of External Representation Quality.

As illustrated in Figure 5b, the scaffolding perspective of external representations

predicts a positive moderating relationship between team knowledge building process and

external representations for content matching cases. Therefore, the following hypothesis

is offered. As this hypothesis predicts the opposite relationship as H3a, H3a-b are considered competitive hypotheses.

> *Hypothesis 3b:* External Representation Quality of TIE will have a positive moderating effect on the relationship between TIE and Team Problem Solving Outcomes such that this relationship will be attenuated for teams with high levels of External Representation Quality.
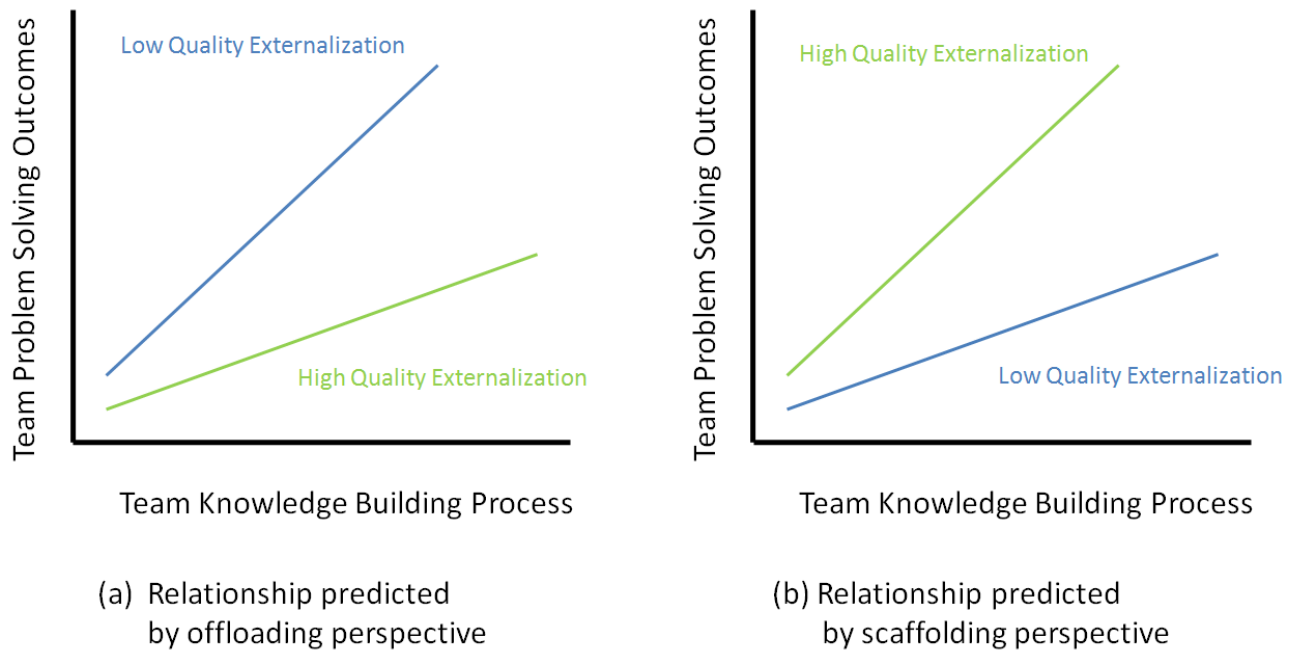
Figure 5. Illustration of moderating relationships

Interactional Perspective Hypotheses

Hypotheses advanced in the previous sections are all based on the functional view of team process. That is, the more the team focuses its processes on the five team knowledge building functions, the better the problem solving outcomes will be. A more nuanced view of the temporal dynamics of how teams interleave process and externalization may be needed to guide the design of training and technology

interventions (e.g., Bowers, Jentsch, Salas, & Braun, 1998). These types of issues fall within the interactional perspective of team process and team cognition and involve generating an understanding of the sequence or timing of different team process behaviors or communications. However, there is far less theoretical or empirical grounding for developing specific predictions about what types of sequential patterns will be predictive of good performance outcomes. Therefore, several exploratory hypotheses are advanced to better understand the temporal relationship between externalization and team processes.

First, it is hypothesized that there are differences in the sequential patterns of team knowledge building processes and externalization between high and low performing teams. While the exact nature of these patterns is an empirical question, several prototypical strategies or trends can be identified based upon the degree and timing of the team processing (e.g., discussion) and externalization of content. For example, a team that only creates external representations of content (e.g., information, relationships, interpretations, possible courses of action) that was previously the object of team knowledge building processes can be thought of as engaging in a *breadcrumb trail* externalization strategy. The team marks the trajectory or course its process has taken through a problem space. This can be useful for the purposes of memory aiding and scaffolding team regulatory processes (Shirouzu, Miyake, & Masukawa, 2002). Additionally, a team that externalizes large amounts of information or knowledge (i.e., interpretations and meaning) before this content is the object of team knowledge building processes can be viewed as engaging in a *front-loading* externalization strategy. The degree to which either of these strategies, a mix between the two, or a strategy where

externalized content does not become the object of team knowledge building processes (i.e., externalization preemptively removes the need for discussion) are most predictive of effective outcomes is to be determined in this study.

> *Hypothesis 4: The degree to which teams adopt a frontloading, breadcrumb trail, or mix of strategies will predict significant amounts of variance in Team Problem Solving Outcomes.*

Additionally, it is hypothesized that different patterns of interaction will characterize high and low performing teams and that these patterns will differ based on the external representations constructed. That is, teams can reach good outcomes without externalization, but these teams will have different sequential patterns of interaction then those teams who create high quality external representations. Teams structure their environment with external representations. Within these differently structured environments, effectiveness may be determined by different patterns of interaction. That is, the sequence of team knowledge building process behaviors will be different for effective and ineffective teams and there will be further differences between effective and ineffective teams that generate low and high quality external representations. Consequently, the following hypotheses are advanced and illustrated in Figure 6.

> *Hypothesis 5:* Different sequences of team knowledge building process behaviors will be associated with effective and ineffective outcomes for teams that build high and low quality external representations.
>
> > *Hypothesis 5a:* There will be significant differences in the sequence of team knowledge building process behaviors for effective and ineffective teams that build high quality external representations of information.
> >
> > *Hypothesis 5b:* There will be significant differences in the sequence of team knowledge building process behaviors for effective and ineffective teams that build low quality external representations of information.

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Hypothesis 5c: There will be significant differences in the sequence of team knowledge building process behaviors for effective teams building high and low quality external representations.

Hypothesis 5d: There will be significant differences in the sequence of team knowledge building process behaviors for ineffective teams building high and low quality external representations.

Team Problem Solving Outcomes

High Effectiveness   Low Effectiveness

H5a

High Quality

Sequence of Team Knowledge Building Process Behaviors

H5c   H5d

Low Quality

H5b

External Representations
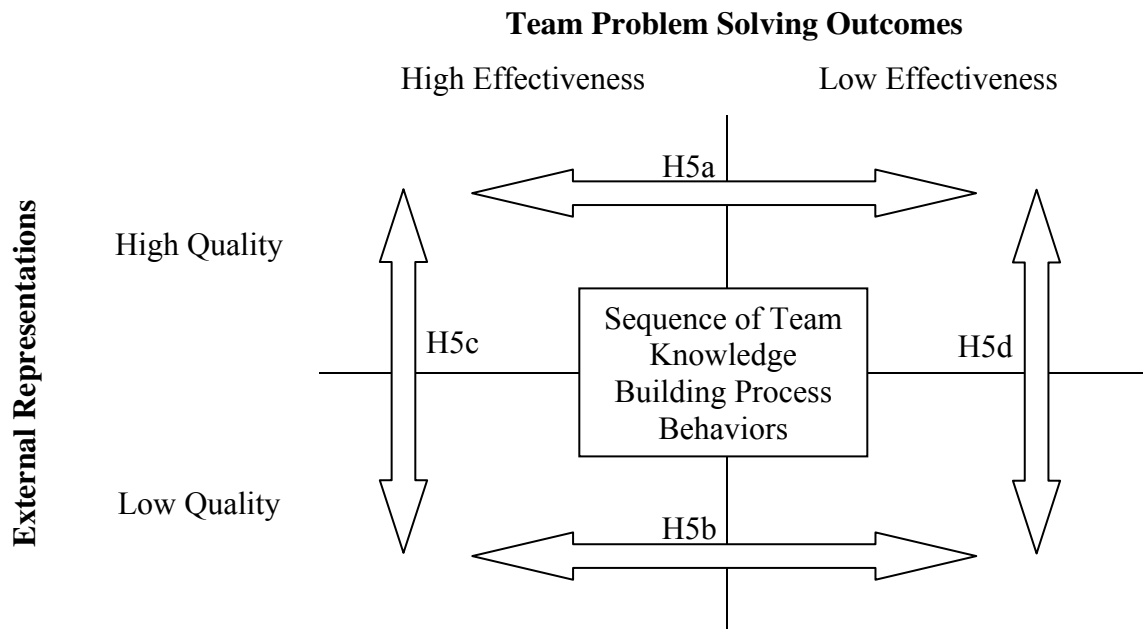
Figure 6. Illustration of the four comparisons of sequential patterns of interaction

The five hypotheses proposed above are summarized in Table 5. They are rooted in the predictions of the Macrocgnition in Teams Model, the functional and interactional perspectives on team process, and the offloading and scaffolding perspectives on the function of external representations. Together, these represent an attempt to bridge the research traditions investigating the role of team process and external representations in problem solving. A summary of the measurement strategies for each of the variables included in the hypotheses is provided in Table 6.

Table 5. Summary of proposed hypotheses

		Hypothesis	Rationale
Functional		*H1a-e:* Each team knowledge building process accounts for a significant and unique amount of variance in Team Problem Solving Outcomes.	The Macrocognition in Teams Model and functional perspectives on team cognition and team process suggest the more a team focuses its process on core task functions, the better its outcomes will be.
		H2a-d: External Representation Quality has a positive moderating effect on the relationship between team knowledge building processes when the content of the externalization is different than that of the process.	Both the offloading and scaffolding perspectives on external representation function predict the effectiveness of task functions will be enhanced by externalizing other task functions.
	Competitive Hypotheses	*H3a:* External Representation Quality will have a **NEGATIVE** moderating effect on team knowledge building process when the content of the process and externalization are the same (i.e., TIE and external representations of information).	The offloading perspective on external representation function predicts that with a good external representation of information, the TIE process will become redundant.
		H3b: External Representation Quality will have a **POSITIVE** moderating effect on team knowledge building process when the content of the process and externalization are the same (i.e., TIE and external representations of information).	The scaffolding perspective on external representation function predicts that high quality external representations of information should increase the effectiveness of the TIE process.
Interactional		*H4:* The nature by which teams interleave process and externalization (i.e., a frontloading, breadcrumb trail, or mix of strategies) will be predictive of Team Problem Solving Outcomes.	Characteristics of the temporal dynamics of content being processed on the team level (i.e., being discussed) and being externalized may indicate different uses (or strategies of use) of externalization.
		H5a-d: There will be differences in the sequence of Team Problem Solving Process behaviors for effective and ineffective teams that create external representations of high and low quality. *H5a:* There will be significant differences in the sequence of team knowledge	The external representations constructed by a team create an information structure within which different patterns of interaction may be linked to effective outcomes.

Table 6. Summary of measurement strategies and uses in the proposed study

Construct	Measurement Strategies	Uses
Team knowledge building processes	Content analysis will be applied to the communication of team members. A coding scheme will be applied at the utterance level of communication. This scheme will categorize each utterance as an instance of one of the five team knowledge building processes (see Appendix B for details).	For functional perspective hypotheses (H1-3), the number of communicative acts categorized as one of the five team knowledge building processes will be used as an indicator of the degree to which the team focused on each process. For H5, the sequence of codes will be analyzed.
External Representation Quality	Content analysis will be applied to the content of external representations created by the team. A similar coding scheme as the one used for team communication will be applied to external representations.	For functional perspective hypotheses (H1-3), the number of accurate and relevant units of information externalized will serve as an indicator of the quality of the external representation of information. For H5, this index will be used to create post hoc teams of high and low quality external representations.
Externalization Strategy	Indices of the amount of pre-processing and post-processing will be generated based on the amount of team communication focusing on the content of an external representation before and after that representation is created.	For H4, these two indices and their interaction will be used to characterize the nature by which teams create and use external representations relative to team knowledge building processes.
Team Problem Solving Outcomes	Objective assessment of plan quality: composite of number of objectives met and efficiency of the plan.	Team problem solving outcomes is the DV of interest in H1-4 and will be used to create post-hoc high and low performing teams for H5.

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CHAPTER THREE: METHODS

Design

Team processes naturally vary, and are difficult to directly manipulate. For those

reasons, team researchers have frequently used a single team design with either a)

comparisons made between post hoc teams created based on performance, or b)

regression analysis applied to link processes to outcomes (e.g., Tschan, 1995; Bowers et

al.,1998). Additionally, Kirsch (1995) has noted that much of the research on external

representations has focused on providing participants with different representations (i.e.,

directly manipulating the content or form of representation given to participants), but has

not investigated how participants build external representations or structure the

environment and how this is associated with effectiveness. Consequently, the design of

this study seeks to capitalize on natural variation in team performance processes and

differences in how teams structure their information environments by creating external

representations. For hypotheses one through four, a single team design with regression

analyses is used. For hypotheses 5a-d, comparisons are made between post hoc teams

created from high and low performance outcomes and quality of external representation.

Task

The task used in this dissertation is the MACRO-COG synthetic task

environment. As configured for the present data collection, MACRO-COG is a three

person strategic planning simulation. Participants are told that they are a part of a Navy

planning team and must work together and share information and resources to complete a

specific set of objectives. Each participant assumes one of three roles (i.e., an air vehicle specialist, a personnel and supply specialist, and a land and sea vehicle specialist). Each of these roles has unique information about the location, capacities, and limitations of a set of resources. The team must work together to develop the most efficient plan they can for moving enough personnel and material resources to a location satisfying the operation objectives. Each team completes three operations. The background information and objectives given to participants for each of these operations is provided in Table 7.

Table 7. Operation descriptions and objectives.

Operation	Background	Objectives
1. Operation Gravy Train: Replenish Supplies at Sarna	Since fighting in the capital city of Tenyar began, many citizens have fled from Tenyar to find safety at Sarna (waypoint C4h). Given the rapid influx of refugees, the demand for food, water, medical supplies and shelter at Sarna has rapidly increased. In order to meet these demands a plan must be made to replenish supplies at Sarna. Your operation is to provide food, water, shelter, and medical supplies to support 250 refugees at Sarna. You must also make sure humanitarian workers are available to care for the refugees and distribute supplies. At least one translator is required to successfully carry out this operation.	Your operation will be complete when: 1. Sufficient medical pallets have arrived at Sarna (C4h) to support 250 refugees. 2. Sufficient survival pallets have arrived at Sarna (C4h) to support 250 refugees. 3. Sufficient Red Cross or U.N. personnel have arrived at Sarna (C4h) to support 250 refugees. 4. One translator is present.
2. Operation Baywatch: Water Rescue of Refugees in Crisis	A small boat transporting 30 refugees attempting to flee from Nandor to Ethos has been capsized by a large wave at location B4f. The boat was destroyed and the refugees are many miles from land in shark-infested water. Your operation is to rescue the refugees and transport them to an area that is safe from rebel activity. Once there, you must ensure their medical care, including both medical supplies and the necessary personnel.	Your operation will be complete when: 1. Refugees have boarded US ship or helicopter. 2. Refugees are transported to a safe area with no rebel activity and no severe weather. 3. Sufficient medical supplies have arrived in chosen area to support the 30 refugees. 4. Red Cross or U.N. personnel able to care for 30 people have arrived in chosen area. 5. 2 translators arrive at the chosen area.
3. Operation Safe House: Establish a Land Base	When Tenosha requested US assistance, two carriers that happened to be in the region were sent to provide aid. Your operation is to establish a temporary land base to facilitate cooperation with local forces and supply distribution for the Tenosha region. This consists of selecting and preparing an appropriate location. The base must be located in an area without severe weather and without rebel activity. To ensure that the base can support personnel, you must place enough food, shelter, and medical supplies at the location you choose to care for 200 people, along with enough UN or Red Cross workers to oversee the distribution of these supplies.	Your operation will be complete when: 1. Your base is established in safe location with no rebel activity and no severe weather 2. Sufficient medical pallets have arrived at chosen location to care for 200 people. 3. Sufficient survival pallets have arrived at chosen location to care for 200 people. 4. At least 3 translators are present at location. 5. Enough Red Cross or U.N. workers are present at location to care for 200 people.

To accomplish their task, participants use two interfaces: 1) a role entry planner that allows them to access information about their resources and enter in the actions that make up the plan, and 2) a map interface that allows them to access information about weather and intelligence reports for different areas and share information via push pins (i.e., text messages embedded in the map). Figure 6 illustrates the map interface. This tool is medium by which teams create external representations.
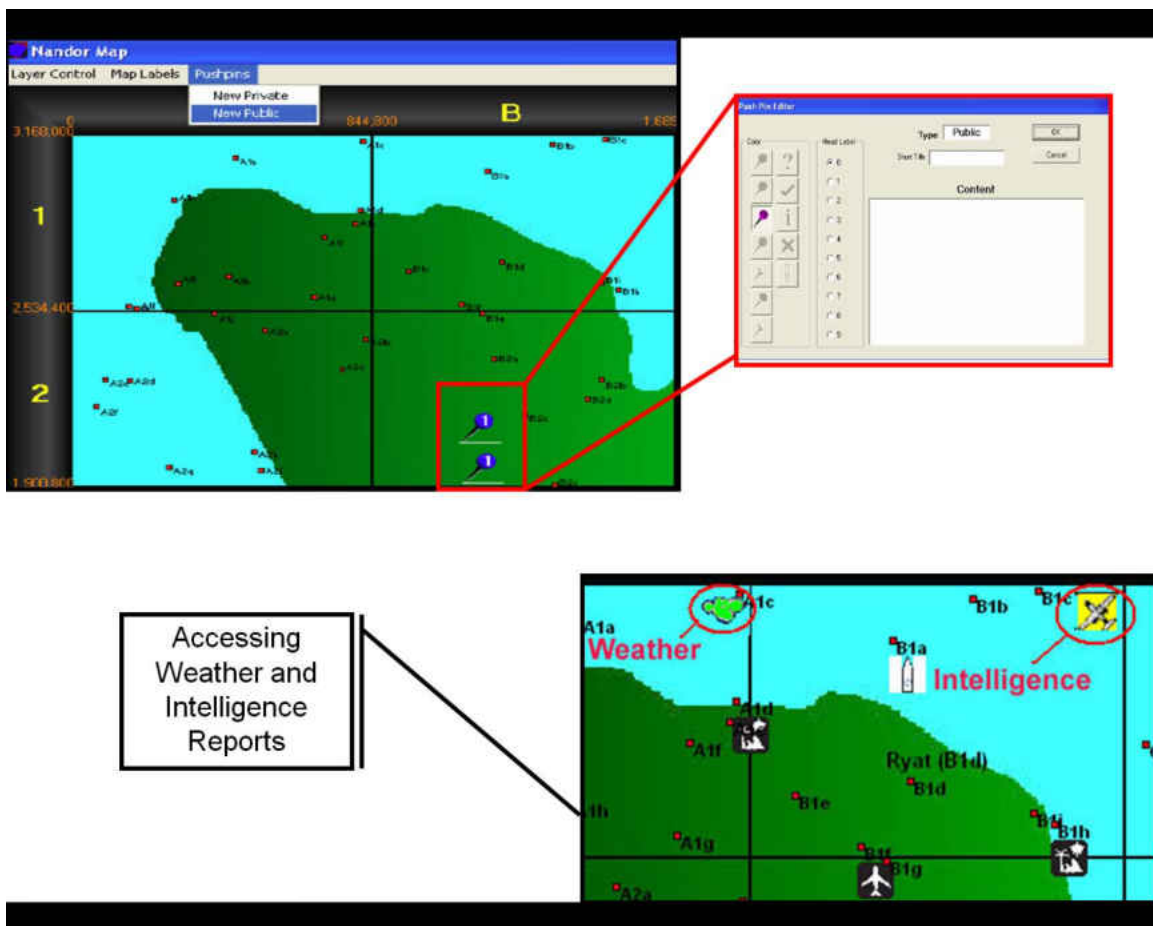
Figure 6. Illustration of the Map Interface and use of push pins for externalization.

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Task features are a critical if not defining feature of macrocognition. The MACRO-COG testbed was designed to replicate many of these features (i.e., information complexity, distributed expertise, time pressure). Additionally, the issue of novelty or the degree to which a task represents a 'one of a kind' problem situation is an important task feature to include in experimentation in order to facilitate external validity of the findings. As described above in Table 7, Operation 2 has an important task requirement that differentiates it from those preceding it in the study. Specifically, in all previous experiences (training and Operation 1), participants were provided the final destination of resources for their plans. That is, participants needed to decide were resources should come <u>from</u> but the end waypoint all resources needed to be moved <u>to</u> was provided to the participants. However, in Operation 2, participants were not given a specific location as a final destination, only a set of criteria that the end waypoint needed to satisfy (i.e., no rebel activity, no severe weather). Therefore, this represented a new type of problem for the team to address, a problem with an added degree of complexity (i.e., a critical problem variable—the end destination for resources—not specified). Teams had to search for possible locations for a safe location and evaluate potential candidates while concurrently identifying the source locations for resources to move. As the final destination is negotiable, and not fixed, the attractiveness of different final destinations can be changed as teams discuss the location of resources (i.e., as there are more than one possible safe location, one may seem better than another if the team has discussed the location of needed resources near or at the proposed destination). In the context of the participants' previous experiences, Operation 2 requires the use of previously learned knowledge and performance processes (i.e., individual task knowledge remains relevant,

teamwork processes involved in coordinating the execution of a plan) as well as new team level processes. That is, in order to successfully choose a safe location, team members have to share information and knowledge in a new, more iterative manner (i.e., considering different locations weather and intelligence status in conjunction with relative ease of access to the needed resources). While this may not be an entirely new task, this type of variation is likely consistent with real world problem solving. Professionals find themselves in situations where some aspects of their expertise are relevant, but in order to make use of this expertise, some novel features of the environment must be managed.

Procedure

The data analyzed in this study was collected as part of a larger project. The full experimental protocol for each session is included in Appendix A and relevant portions are summarized below. Data was collected at two different sites, but the equipment, task, and protocol were identical at both locations. Differences between testbed locations are discussed in the Results section.

For each session, participants were randomly assigned to one of the three roles. Randomization was achieved by a priori generating a random code for each team number indicating the role each person was assigned to based on the order they entered the room. Once seated, participants were asked to read and sign the informed consent form. Experimenters asked if there were any questions about the informed consent and required participants to show a photo ID to confirm identification. A basic demographic survey was then given to the participants. After completion of this survey, experimenters

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introduced themselves to the participants and gave an overview of the session and asked participants to introduce themselves to each other. Then, participants began training, consisting of three main parts: general, role-specific, and interactive. General training consisted of an introduction to the overall task delivered via computer and completed individually in a self-paced manner. After completing the self-paced overview training, they were shown a background video of a news cast and a narrated slide presentation about the overall task on the collaborative screen. Participants then completed another self paced individual computer-based training tailored to their specific role. Following this role training, they were given a quiz on the first two training modules. Subsequently, participants followed along with an interactive training presentation on the collaborative screen that detailed use of the map and role entry interfaces as well as how to plan and execute an operation. Participants were given two practice operations with help from the experimenters. The first was fully guided in a step by step manner and in the second, experimenters only provided as much assistance as necessary to ensure the team completed the practice operation successfully. Then a five minute break was given. After returning from break, participants were asked to place head mounted microphones on in order to begin recording of verbal communication. They were asked if there are any further questions and informed that from this point on experimenters could not help them with the task. An overall briefing of the goals of the task was given. A briefing of each operation was given beforehand in a narrated slide presentation on the collaborative screen. Participants were given 40 minutes to complete operation one, and 25 minutes to complete operations two and three and were given ten, five, and one minute warnings for each operation. In between each operation, feedback about the team's plan for the

previous operation was given. This included total cost, execution time, number and type of violations (i.e., inappropriate uses of resources), and the operation objectives that were and were not met. After all three operations, participants were debriefed and given an opportunity to ask questions.

Participants

The present study consisted of 69 three-person teams for a total of 207 participants with an average age of 19.75 years (SD = 1.31). There were 120 female and 87 male participants distributed such that there were 16 all female teams, 24 teams with two females and one male, 24 teams with one female and two males, and 5 all male teams. Participants were recruited from introductory psychology courses at the University of Central Florida through the online participant management system, SONA. All participants were over the age of 18 and earned 4 points of credit towards their required total for an introductory Psychology course for participation in the study.

Measures

As summarized previously in Table 6, there are three main categories of measures: Team knowledge building processes, external representation quality, and team problem solving outcomes. Each of these will be described below.

Team Knowledge Building Processes

Team knowledge building processes were measured through content coding of team communications. The following two sections describe the development of the coding scheme as well the process by which it was applied.

Coding Scheme

A content coding scheme was developed to measure the five team knowledge building processes. The coding scheme was based upon the construct definitions and descriptions of the five team knowledge building processes (Fiore et al., in press; Fiore, et al., under review) as well as a review of communication schemes in the literature designed to capture constructs similar to team knowledge building processes. Specifically, Bales's (1950) Interaction Process Analysis system, Fisher's (1970) Decision Proposal Coding System, and Poole and Roth's (1989) Decision Functions Coding System provided a strong basis for developing a reliable and valid coding scheme for team knowledge building processes. The initial coding scheme was revised iteratively as a team of four coders attempted to apply the scheme to samples of team communication drawn from teams not used in the final analysis. Coders applied the scheme, agreement was assessed, and inconsistencies discussed. Based on these discussions modifications to the scheme and codebook were made as needed. Table 8 provides a brief description for each of the codes in the final scheme and Appendix B contains the final code book used in training and reference for all coders. This includes detailed descriptions of each code, rules for when to and when not to use the code, and positive and negative examples with rationales.

Table 8. Summary of communication coding categories.

Process	Code	Brief Description
TIE	Information Provision (IP)	-Utterances containing facts about the task environment or situation—<u>simple information</u> that can be accessed from one source in the displays and 'one bit' statements.
	Information Request (IR)	-Question utterances asking for a response of <u>simple information</u> about the task environment or situation, or questions asking for repetition of immediately preceding information.
TKS	Knowledge Provision (KP)	-Statements about the task environment or situation that provide either 1) an <u>integration</u> of more than one pieces of simple information, or 2) an <u>evaluation</u> or <u>interpretation</u> of the meaning, value, or significance of information within the current operation.
	Knowledge Request (KR)	-Question utterances that request a complex information response about the task environment or situation: to answer the question, the response should provide either 1) an <u>integration</u> of more than one piece of simple information, or 2) an <u>evaluation</u> or <u>interpretation</u> of the meaning, value, or significance of information within the current operation.
TSOG	Option Generation– Part (OG-P)	-Statements that provide an incomplete solution—a sequence of actions (i.e., moving resources) intended to meet a given operation objective—or ask for further refinement and clarification of a solution. This includes proposing a general area for a safe base.
	Option Generation– Full (OG-F)	-Statements explicitly proposing a complete or near complete solution— a sequence of actions intended to meet a given operation objective. A complete solution includes locations, resources, and vehicles except for solutions proposed for objective 2 (finding a safe location).
TENA	Solution Evaluation (Seval)	-Utterances that 1) compare different potential solutions on the basis of speed, cost, or ease of execution, 2) provide support or criticism of a single potential solution, or 3) ask for an evaluation of a potential solution.
TPPR	Goal / Task Orientation (GTO)	-Utterances directing the team's process or helping it do its work by proposing questioning, or commenting on goals for the team or specific actions team member's need to take to address a goal. These statements direct what the team should do next or later in the future. This includes self-references for an individual.
	Situation Update / Request (SU/R)	-Statement's that provide or ask about what the team is currently doing or what is currently happening with the simulation.
	Reflection (R)	-Utterances that provide or ask for a critique or evaluation of the performance of the team as a whole or of individual members.
Other	Simple Agree / Disagree / Ack (S)	-Simple agreement/disagreement utterances are expressions of agreement or disagreement with no rationale provided. Acknowledgements are utterances providing recognition of receipt of communication.
	Incomplete / Filler / Exclamation (INC/F/EX)	-Fillers are sounds or words that are spoken to fill gaps between utterances. An exclamation is an utterance that has no grammatical connection to surrounding utterances and emphatically expresses emotion. Incomplete utterances are statements that have no explicit meaning because they are missing one or more critical components of grammar: subjects, verbs, or objects.
	Tangent / Off-task (T/OT)	-Non-task related statements including jokes, sarcastic comments, comments on the nature of the experiment, and statements that have nothing to do with the task at hand.
	Uncertainty (UNC)	-Uncertainty statements explicitly express either general or specific uncertainty about the roles, tasks, situations, or anything else task-related.

Coding Process

Translating team communication to data was achieved via a three-step process. First, transcriptions were generated for each participant. Second, these transcriptions were unitized and time stamped. Third, each unit was assigned a category in the coding scheme by a rater. For each of these steps, transcribers, unitizers, and coders were trained and their work monitored to ensure consistency. For transcription and unitization, this was done continuously in order to provide quality control and feedback to the transcribers and unitizers. For coding, inter-coder reliability was established using the kappa statistic (Bakeman & Gottman, 1997). Coders below an acceptable threshold of reliability (i.e., kappa = .7) with an expert criterion were remediated until they reach an acceptable level of reliability. One coder coded all team communication, and two coders sampled portions of the teams to establish the reliability of the actual data set. Specifically, a total of 30,388 utterances were coded across the 69 teams and 6,931 utterances were coded by two raters (22.8% of the total data set). For this sample, kappa = .689.

For hypotheses one through three (i.e, the functional perspective hypotheses), the sum of conversational units belonging to each of the five team knowledge building process categories provided a measure of quantity of that process or the amount of effort the team expended on that task function. For hypotheses four and five the data was not aggregated in this way. The sequence of codes was the raw data analyzed.

Externalized Representations

Measures of ERQ were created by summing the total number of externalized pieces of information shared via the pushpin collaborative tool. However, 15 of the 69

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teams did not use the pushpin tool and consequently, the measure of ERQ was highly skewed and kurtotic (skewness = 2.286, SE skewness = .289; kurtosis = 5.464, SE kurtosis = .570). Consequently, a log + 1 transformation was applied and corrected the distribution (skewness = .291, SE skewness = .289; kurtosis = -.77, SE kurtosis = .570).

Problem Solving Outcomes

The primary measure of performance is the number of objectives met for the operation, resulting in a scale of 0 to 5 objectives met. The secondary performance measure for this task is the efficiency of the plan the team created in cost per hour to execute. These two scores were combined into a weighted index of performance using the following steps. First, as shown in Figure 7a, the number of objectives variable exhibited severe negative kurtosis (kurtosis = -1.711, SE of kurtosis = .570) with approximately one third of teams meeting 0 objectives, one third meeting all 5 objectives, and the remaining third scoring 1 to 4 objectives. Consequently, the middle range of categories was collapsed to create a three point scale for number of objectives met and centered around zero (Figure 7b). This collapsing of categories improved but did not correct the negative kurtosis (kurtosis = -1.449, SE of kurtosis = .570). Second, each team's transformed # of Objectives Met score was weighted by the mean efficiency score across teams (34.39) and their actual efficiency score subtracted from this number. This created an index where teams meeting more objectives scored higher than meeting fewer objectives, and teams meeting the same number of objectives were distinguished by the efficiency of the plan they developed (more efficient plans yielding higher scores). As illustrated in Figure 7c the resulting variable—TPSO Performance—was approximately

normally distributed (kurtosis = -.854, SE of kurtosis = .570; skewness = -.229, SE of skewness = .289).

In sum, the TPSO Performance variable has the advantages of 1) being approximately normally distributed, 2) combining primary and secondary performance measures into one scale, and 3) preserving the relative importance of the two performance measures (i.e., a team's score was determined primarily by the number of objectives met; $r = .882$, $p < .001$ for the TPSO Performance and six point number of objectives met variables).
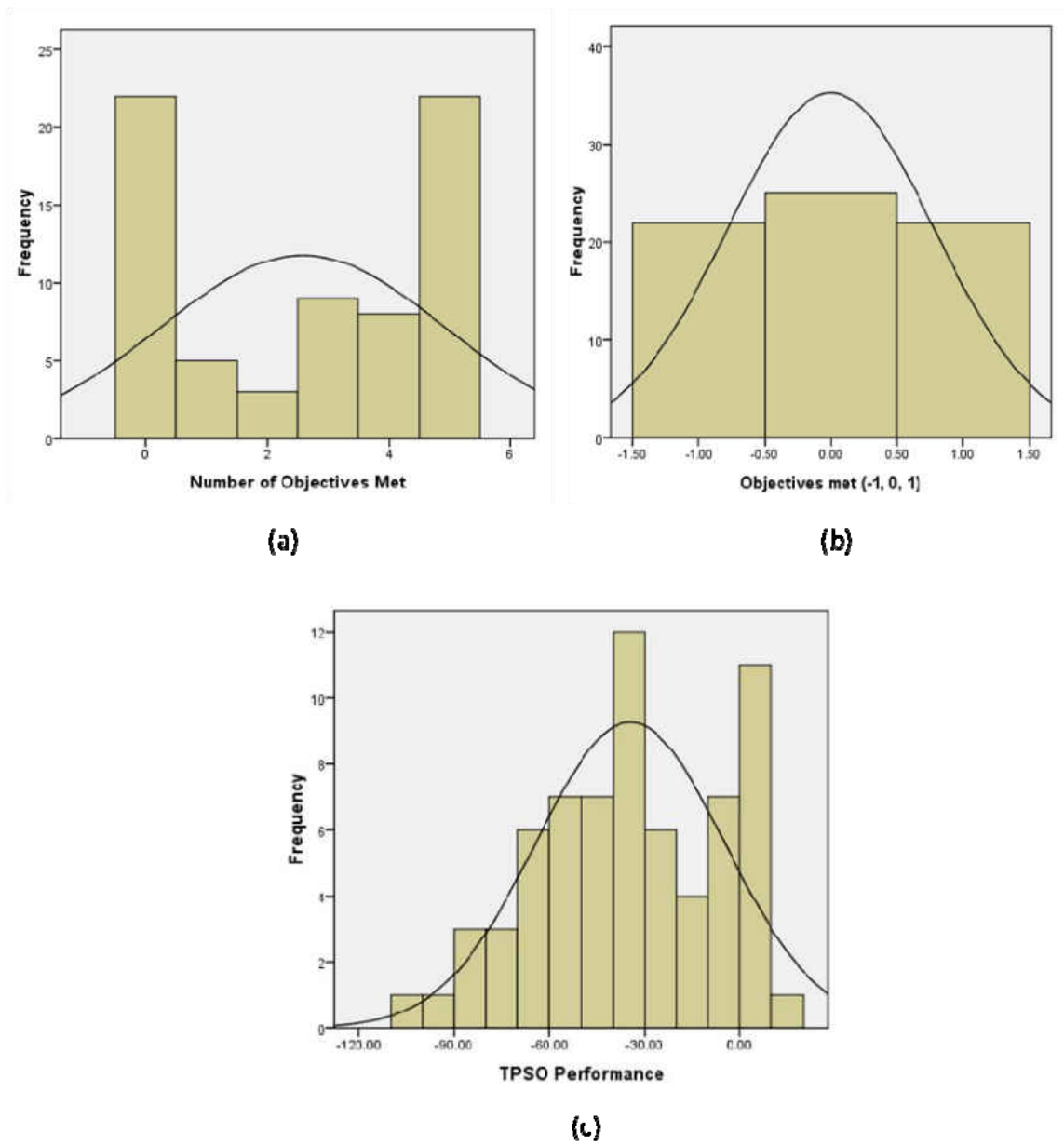
Figure 7. Distributions for TPSO Performance measures

Note: (a) total number of objectives met—six-point scale, (b) the six-point scale collapsed into a 3-point scale centered on zero, and (c) the three-point scale weighted by efficiency.

Analyses

Two types of analyses will be used: multiple regression to test H1 through H4, and Multi-way Frequency Analysis to test H5. For these tests, an α-level of .05 is adopted. Descriptions and power analyses for the each method are discussed below.

Regression

To test H1a-e (i.e., the direct and unique effect of team knowledge building processes on Team Problem Solving Outcomes) five hierarchical regression analyses will be conducted. For each of the five tests, the first step in the model will be potential covariates such as the location of data collection (i.e., one of two testbeds), the number of non-task related utterances, the total number of utterances, the number of Simple Agreement / Disagreement / Acknowledgement statements will be entered using the stepwise methods to account for the maximum amount of variance (i.e., increasing the power of analysis or minimizing bias) and to automatically exclude non-significant covariates. The second step will contain the other four processes as predictors of plan effectiveness also entered using the stepwise method to automatically exclude non-significant covariates. The third model adds the team knowledge building process of interest. The degree and significance of change in R^2 from the second to third models indicate whether or not that process contributes uniquely to the prediction of plan effectiveness.

To test H2a-d (i.e., the moderating effects of External Representation Quality on the relationship between team knowledge building processes and Team Problem Solving Outcomes) and H3a-b, five separate tests of moderation will be conducted. Specifically,

for each hypothesis, the amount of the team knowledge building process, the external

representation quality measure, and an interaction term will be entered in to a regression

equation as predictors of plan effectiveness. If the interaction term is significant and in

the hypothesized direction, the hypothesis will be supported. As in the above analyses,

potential covariates will be entered in step one of the model using the stepwise method.

Step two will include the other four team knowledge building processes not being

directly evaluated.

To test H4 (i.e., externalization strategy and Team Problem Solving Outcomes),

three parameters (i.e., amount of pre-processing, amount of post-processing, and the

interaction term) will be entered into a regression equation as predictors of plan

effectiveness. As this is an exploratory and non-directional hypothesis, the two-tailed

significance level of the total R^2 for the model will be the indicator of support (or lack

thereof) for H4.

Power Analysis for Regression

A power analysis was conducted using equations provided by Tabachnick and

Fidell (2007) and Green (1991). Specifically, Green's equation accounting for anticipated

effect sizes when calculating sample size requirements for multiple regression was used.

Equation 1

$$N \geq 8/f^2 + (m-1)$$

Here, f^2 is the anticipated effect size, N is the required sample size, and m is the

number of predictors in the equation. The equations to test hypothesis 1a-e contain six

parameters (the most of any equation in the analyses conducted here) so $m = 6$. While no

exact match between the constructs being tested in this dissertation are present in the literature, the meta-analyses discussed earlier which examine the relationship between similar team process constructs and team outcomes (i.e., Mesmer-Magmus & DeChurch, 2009; Orlitzky & Hirokawa, 2001) suggest that effects of the two focal team knowledge building processes on team problem solving outcomes will be large. However, to be conservative, f^2 is taken to be Cohen's (1988) suggestion of .13 as a medium effect size for squared multiple correlation and squared multiple partial correlation (Green, 1991). Therefore, by substituting the previous values into Equation 2, the minimum required sample size is 67 for detecting a significant effect at an alpha level of .05 and a power level of .80. Effect sizes the amount of pre and post-processing variables used in the test of H4 are not directly available in the literature; however, there are fewer parameters in the regression equations used. Assuming a similar effect size, the sample size requirement would be less than 67.

<p style="text-align:center">Multi-way Frequency Analysis</p>

Multi-way frequency analysis provides a robust tool for analyzing the sequential patterns in process and externalization in collaborative team problem solving (Vokey, 2003). More specifically, procedures described by Gottman and Roy (1990) will be applied to the sequence of codes generated in developing measures of the team knowledge building processes. First, post hoc groups will be created by performing a median split on the TPSO Performance variable creating high and low performing groups. Additionally, a median split will be performed on the external representation quality variable, creating four total groups: 1) high performing high quality external

<p style="text-align:center">70</p>

representations, 2) low performing high quality external representations, 3) high performing low quality external representations, and 4) low performing low quality external representations. Contingency table data will be combined across teams within each of these groups. Additionally, the full coding scheme described in Appendix B will be condensed to a five code scheme for team knowledge building processes (i.e., each process with multiple indicators will be collapsed). Additionally, due to the strong relationship of Simple Agreement / Disagreement / Acknowledgement communication described below, the S code will be included in sequential analysis as well. Consequently, for each of these groups, a two-way exploratory frequency analysis will be conducted to develop hierarchical log-linear models for sequential relationships between process behaviors. Variables analyzed include the antecedent code (six levels, one code for each team knowledge building process and S) and the consequent code (same six levels) as well as a two level variable indicating high or low performance or ERQ. This is the minimum required to examine sequential dependencies in communication as hypothesized; however, this only examines a time window of two units. It is possible, and even likely that longer chains of communication will be associated with different levels of performance and use of externalization. These issues are discussed more below.

Power Analysis for Multi-way Frequency Analysis

As Multi-way Frequency Analysis is a nonparametric technique, sample size requirements differ from those described above, and are not based on the number of teams. Sample size requirements for Multi-way Frequency Analysis focus on the number of cases per cell in the design with the general rule being that there should be at least five

times the number cases as cells in the design (Tabachnick & Fidell, 2007). The simplest

design proposed here is two by six by six (a dichotomous grouping variable for high or

low performance / ERQ, and an antecedent and consequent variable, six levels each).

Therefore, there are 72 cells in the design and consequently at least 360 cases are

necessary. A case is an instance of one code type being followed by another. It is difficult

to a priori know the frequency of these events, but given that codes from approximately

25 minutes of team discussion will be collapsed across multiple teams, it is not likely that

any one cell will have less than five cases.

CHAPTER FOUR: RESULTS

Two types of analysis were used to test the hypotheses proposed above: Multiple

Regression Analysis, and Multi-Way Frequency Analysis. Hypotheses 1 through 3 were

tested using regression analysis and Hypothesis 5 was tested using Multi-Way Frequency

Analysis. Due to data losses, it was not possible to test Hypothesis 4. Details are provided

below for each Hypothesis. First, descriptive data is presented.

Descriptive Data

Table 9 provides the means, standard deviations, and inter-correlations between

the main variables used in this study. Each of the five team knowledge building process

variables as well as the S variable (Simple Agreement/Disagreement Acknowledgements)

were significantly correlated with the exception of TENA and TKS ($r = .232$, $p > .05$) as

well as TENA and TSOG ($r = .204$, $p > .05$). As illustrated in Figure 7, the most common

task-focused communication was TIE (26.46% of utterances), followed by TPPR

(22.09%), S (19.90%), and TKS (19.06%) with TSOG (9.86%) and TENA (2.62%) being

the least frequently occurring types of task-focused communication. The extremely low

frequency of TENA is likely the reason it exhibited weaker relationships with other

process variables. There were no significant differences between any of the process

variables, performance measures, or External Representation Quality (ERQ) between

tested locations. Additionally, as illustrated in Figure 10, there was no significant

relationship between the raw amount of communication (total # of utterances) and TPSO

Performance. ERQ was significantly and negatively related to TKS ($r = -.305$, $p < .05$)

and marginally negatively related to TIE ($r = -.237$, $p < .06$). For regression analyses, z-scores were used as a means of centering variables.
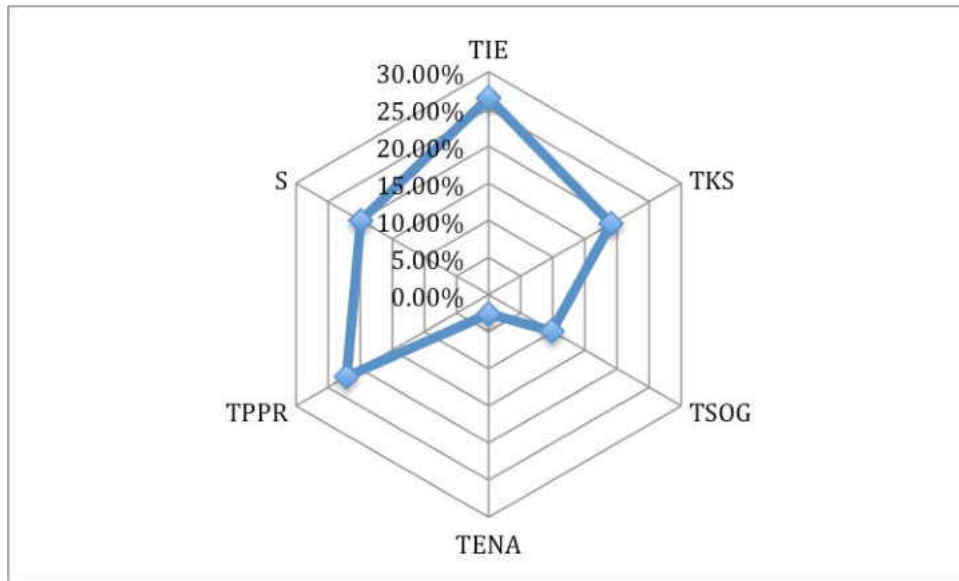
Figure 7. Relative amounts of task focused communicaitons across all teams.
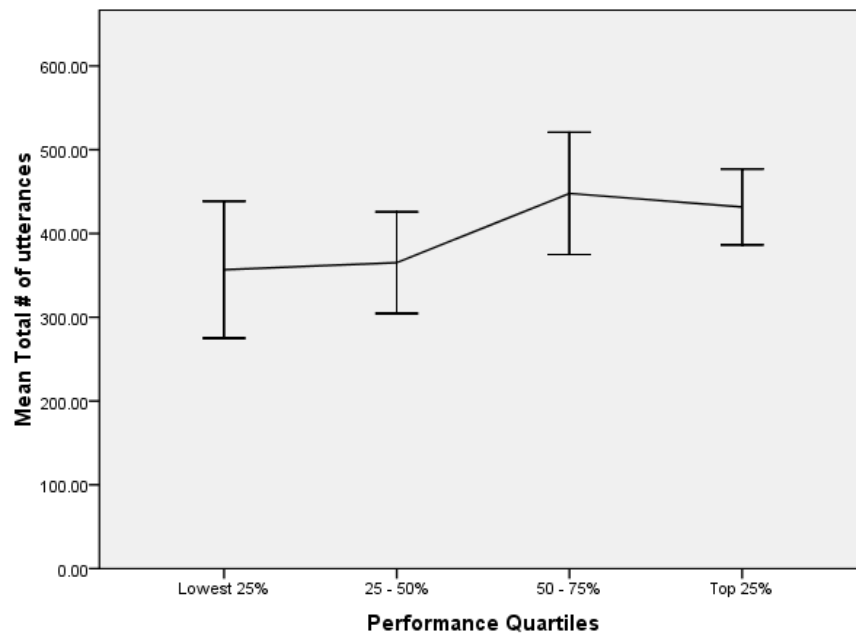
Figure 8. Total utterances by performance quartiles

Table 9. Means, standard deviations and inter-correlations of primary study variables.

	TIE	TKS	TSOG	TENA	TPPR	S	Total # of Utt.	ERQ	TIE / TKS	TPSO Perf.	Testbed Loc.
TIE	-										
TKS	.649**	-									
TSOG	.525**	.381**	-								
TENA	.324**	.232	.204	-							
TPPR	.615**	.623**	.358**	.268*	-						
S	.624**	.623**	.487**	.360**	.530**	-					
Total # of Utterances	.867**	.812**	.605**	.393**	.810**	.791**	-				
ERQ	-.237	-.305*	-.147	.018	-.014	-.155	-.199	-			
TIE / TKS	.327**	-.411*	.125	.034	-.018	-.069	.014	.085	-		
TPSO Performance	.013	.288*	.032	.166	.178	.337**	.202	.032	-.304*	-	
Testbed Location	-.065	-.065	.042	-.076	-.112	-.045	-.062	.016	.037	-.200	-
Mean (SD)	92.96 (35.43)	66.97 (25.95)	34.64 (13.09)	9.20 (5.99)	77.62 (33.17)	69.93 (26.11)	400.77 (131.87)	.5097 (.41)	1.47 (.527)	-34.55 (29.73)	

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

Hypotheses 1a-e: Direct Effects of Team Processes on TPSO Performance

Hypothesis 1 proposes that each of the five team knowledge building processes positively predicts unique variance in TPSO Performance after controlling for the other four processes. Figure 9 illustrates levels of team process across performance quartiles to visualize relationships discussed below.

To test these hypotheses, five separate hierarchical regression analyses were conducted. In the first step, several potential covariates chosen for theoretical relevance (i.e., Simple Agreement/Disagreement Acknowledgements, Uncertainty Statements, Tangent/Off-task Statements, Incomplete/Filler/Exclamation Statements) or as possible threats to validity (i.e., Testbed Location) were entered using the stepwise method to account for maximum variance and automatically exclude non-significant covariates. In step two, the four process variables not being directly tested were entered, again using the stepwise method to automatically exclude non-significant covariates. Only significant covariates are reported in the analysis. In step three the process variable of interest was entered.

As summarized in Table 10 and detailed in Tables 11 through 15, only Hypothesis H1b was supported. TKS positively predicted TPSO Performance ($\beta = .324$, $p < .05$) after controlling for Simple Agreement/Disagreement Acknowledgements and TIE (see Table 12). TKS accounted for 5.3% of TPSO Performance variance alone, and the entire model accounted for 23.1%. TSOG, TENA, and TPPR were not predictive of TPSO Performance and therefore hypotheses 1c-e were not supported (see Tables 13 through 15). Interestingly, as shown in Table 11, TIE was predictive of TPSO Performance; however, the coefficient was negative instead of positive as hypothesized ($\beta = -.323$, $p < .$

05). This is a unique finding running contrary to a large literature base and will be elaborated upon in the discussion section. TIE accounted for 6.4% of TPSO Performance variance and the total model accounted for 17.8%.

Table 10. Summary of Hypotheses 1a-e.

Hypothesis	Prediction	Result
1a	TIE +→ TPSO	Not supported. TIE *negatively* predicted TPSO.
1b	TKS +→ TPSO	Supported.
1c	TSOG +→ TPSO	Not supported.
1d	TENA +→ TPSO	Not supported.
1e	TPPR +→ TPSO	Not supported.

Table 11. Hierarchical Regression Analysis for H1a, the effect of TIE on TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*

Overall $R^2 = .177$
Adjusted $R^2 = .153$
$F(2,66) = 7.119, p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2 (ps < .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 12. Hierarchical Regression Analysis for H1b, the effect of TKS on TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*

Overall R^2 = .230
Adjusted R^2 = .195
$F(3,65) = 5.215$, $p < .01$

Note. R^2 = .114 for Step 1; ΔR^2 = .064 for Step 2; ΔR^2 = .053 for Step 3 (ps < .05); *p < .05, **p < .01, ***p < .001 (N=69)
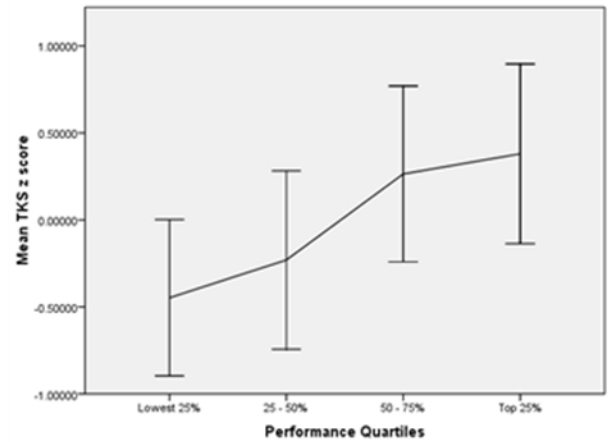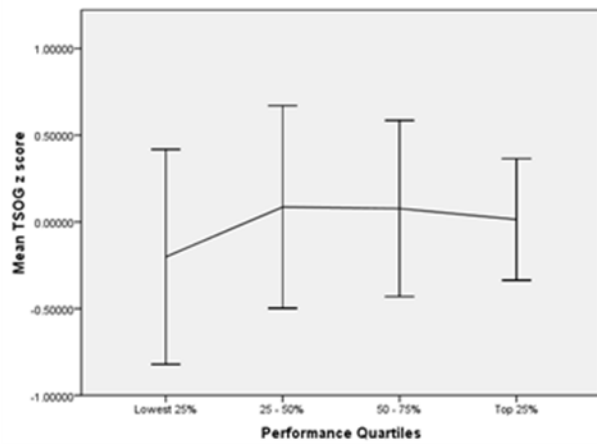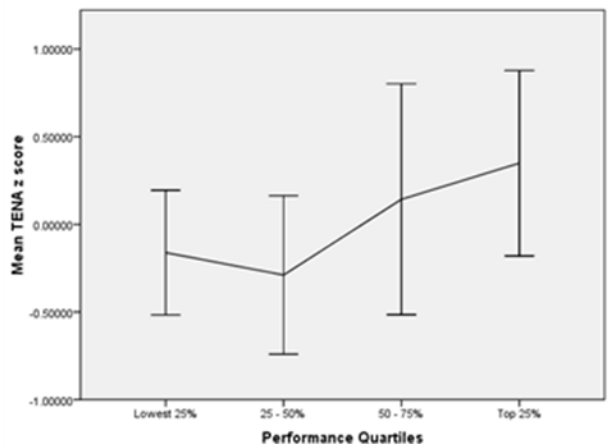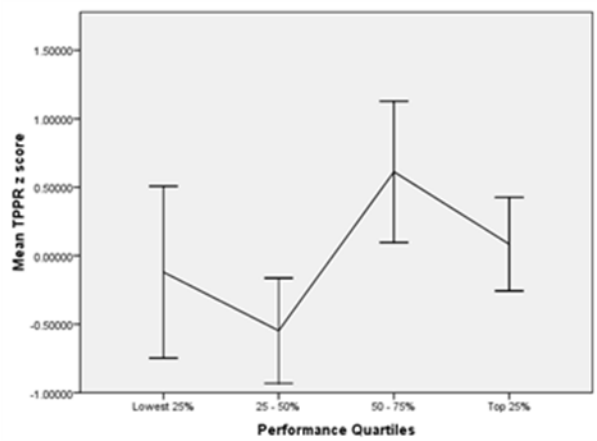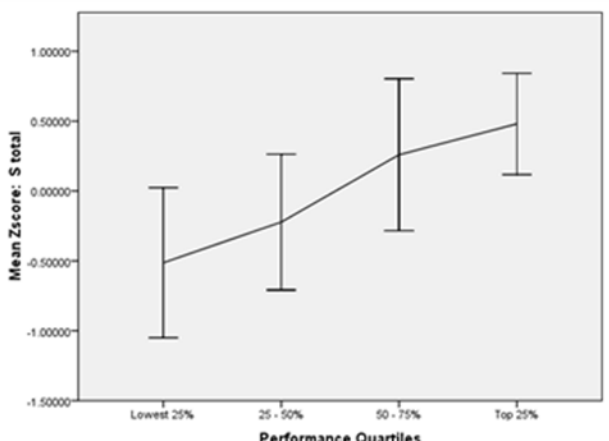
Figure 9. Process variables by quartile in TPSO Performance

Note: (a) TIE, (b) TKS, (c) TSOG, (d) TENA, (e) TPPR, and (f) S; error bars indicate a 95% confidence interval around the mean.

Table 13. Hierarchical Regression Analysis for H1c, the effect of TSOG on TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.446**
Team Information Exchange (TIE)	-.430*
Team Knowledge Sharing (TKS)	.321*
Team Solution Option Generation (TSOG)	-.082

Overall $R^2 = .235$
Adjusted $R^2 = .187$
$F(4,64) = 3.989, p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2; $\Delta R^2 = .053$ for Step 3 (ps < .05); $\Delta R^2 = .005$ for Step 4 (p > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 14. Hierarchical Regression Analysis for H1d, the effect of TENA on TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.405**
Team Information Exchange (TIE)	-.475*
Team Knowledge Sharing (TKS)	.326*
Team Evaluation and Negotiation of Alternatives (TENA)	.071

Overall R^2 = .234
Adjusted R^2 = .187
$F(4,64) = 3.985$, $p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2; $\Delta R^2 = .053$ for Step 3 (ps < .05); $\Delta R^2 = .004$ for Step 4 (p > .05); *p < .05, **p < .01, ***p < .001 (N=69)

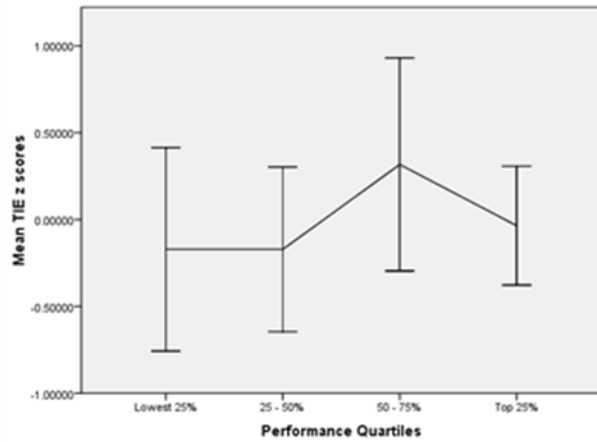Table 15. Hierarchical Regression Analysis for H1e, the effect of TPPR on TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.415**
Team Information Exchange (TIE)	-.482*
Team Knowledge Sharing (TKS)	.301*
Team Plan and Process Regulation (TPPR)	.066

Overall $R^2 = .232$
Adjusted $R^2 = .184$
$F(4,64) = 3.951, p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2; $\Delta R^2 = .053$ for Step 3 (ps < .05); $\Delta R^2 = .002$ for Step 4 (p > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Follow up analysis for Direct Effects of Team Knowledge Building Processes

    Based on the results of the previous analysis and visual inspection of relationships between variables, three sets of follow-up analyses were conducted: 1) one investigating the combined relationship between TIE, TKS and TPSO Performance, 2) one testing for a curvilinear relationship between TPPR and TPSO Performance, and 3) one investigating the combined relationship between TSOG and TENA on TPSO Performance.

Combined Effects of TIE and TKS

    Because TIE and TKS are 1) highly correlated, but 2) have opposite and significant relationships with TPSO Performance, the existence of a possible interaction

between TIE and TKS was investigated in a hierarchical regression analysis. First, due to the shape of the relationship between TIE and TPSO Performance illustrated in Figure 9a, the existence of a curvilinear relationship was evaluated, but the quadratic term was found to be non-significant. Subsequently, the interaction between TIE and TKS was evaluated and found to be non-significant as well; however, as illustrated in Figure 10, the pattern of results for teams with high and low levels of TIE and TKS is complex.

While these trends are non-significant and therefore should not be over-interpreted, the observed pattern is discussed here as a rationale for building a combined metric of TIE and TKS. First, teams at the lowest levels of performance tend to have relatively (yet non-significantly) higher standardized scores for TIE than TKS. These teams have approximately average levels of TIE and below average levels of TKS. Second, teams at the highest levels of performance tend to have relatively (yet non-significantly) higher standardized scores for TKS than TIE. These teams again have nearly average levels of TIE, but above average levels of TKS. Third, teams in the middle two quartiles have proportionately similar levels of TIE and TKS. However, teams in the 25-50% quartile have relatively less TIE and TKS than teams in the 50-75% quartile. This relationship illustrated in Figure 10 suggests that the ratio of TIE to TKS scores for a team may be a useful metric of the quality of the team's interaction processes.

In a hierarchical regression analysis, the ratio of TIE to TKS was found to be predictive of TPSO Performance (see Table 16), such that teams with lower levels of the TIE / TKS Ratio (indicating proportionally less TIE to the amount of TKS) performed better. After accounting for S, the TIE / TKS Ratio accounted for 7.9% of variance in TPSO Performance and the total model accounted for 19.3%. This accounts for more

variance than TIE alone (see Table 11), but less than the model with TIE and TKS combined (see Table 12).

The TIE / TKS Ratio captures some of the trends illustrated in Figure 10, but does not represent the differences between the 25-50% and the 50-75% quartiles. Here, teams tend to have proportionally similar amounts of TIE and TKS but different total levels of both. The TIE / TKS Ratio will be used in following analyses as a composite indicator of team knowledge building process quality given the preceding acknowledgement that it is an imperfect indicator. Figure 11 illustrates the general relationship between the TIE / TKS Ratio and TPSO Performance.
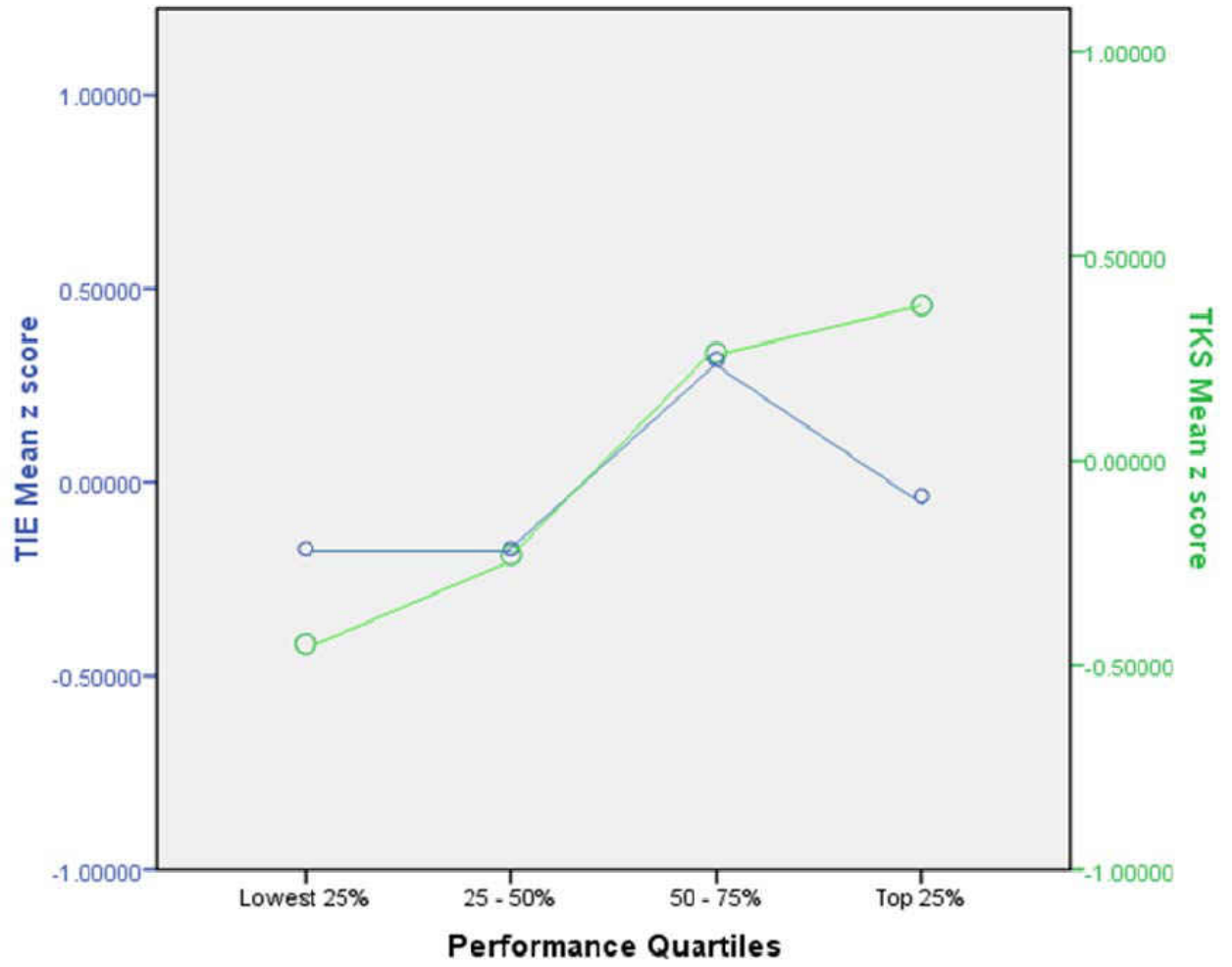
Figure 10. Mean standardized TIE and TKS by performance quartiles

Table 16. Hierarchical Regression Analysis for the effect of TIE / TKS Ratio on TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.318**
TIE / TKS Ratio	-.282*

Overall $R^2 = .193$
Adjusted $R^2 = .169$
$F(2,66) = 7.891$, $p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .079$ for Step 2 (ps < .05); *p < .05, **p < .01 (N=69)
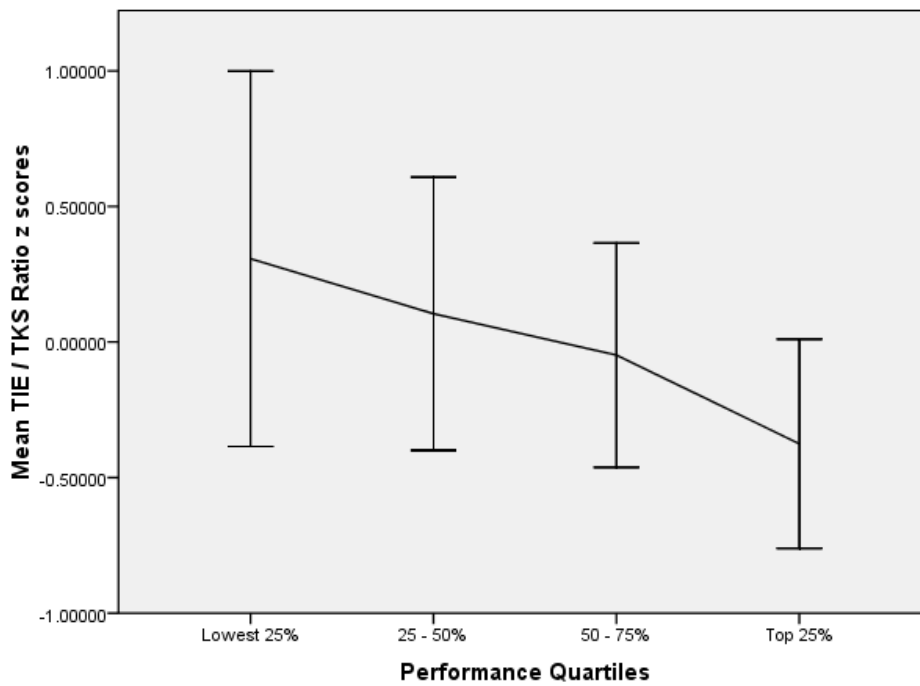
Figure 11. TIE / TKS Ratio by TPSO Performance quartiles

Curvilinear Effects of TPPR

Due to the shape of the trend observed for TPPR as illustrated in Figure 9e, the

possibility of a curvilinear relationship between TPPR and TPSO Performance was tested

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using a hierarchical regression with TPPR entered in the first step and the TPPR

quadratic term entered in the second step. As detailed in Table 17, the quadratic term was

significant and negative (β = -1.204, p < .05), indicating a significant inverted-U shaped

relationship between TPPR and TPSO Performance. That is, high and low performing

teams exhibited lower levels of TPPR than moderately performing teams. However, this

relationship was not significant when S was entered as a covariate. This finding is unique,

and will be elaborated upon in the discussion section; however, in general it indicates the

possibility of more complex relationships between team knowledge building processes

and performance outcomes than those derived from a purely functional perspective on

team process.

Table 17. Hierarchical Regression Analysis of the curvilinear relationship between TPPR and TPSO Performance

Variable	β
Step 1	
Team Plan and Process Regulation (TPPR)	.178
Step 2	
Team Plan and Process Regulation (TPPR)	1.169*
$TPPR^2$	-1.204*

Overall R^2 = .097
Adjusted R^2 = .070
$F(2,66) = 3.550$, p < .05

Note. R^2 = .032 for Step 1 (p > .05); ΔR^2 = .066 for Step 2 (p < .05); *p < .05 (N=69)

Combined Effects of TSOG and TENA

Figure 12 illustrates the trends in TSOG and TENA by performance quartile.

With the exception of the lowest performing teams, visual inspection of the trends

suggests the possible existence of an interaction between these two variables. This

interaction would make conceptual sense, in that TENA is only a useful process to engage in if there is a substantive set of options to evaluate. If the team is proposing smaller numbers of options, there are no relative comparisons to make. Consequently, TENA may not be a required task function for the team and devoting higher levels of the limited team process resource to this function would be counterproductive. Therefore, the possible existence of an interaction between TSOG and TENA was investigated in a hierarchical regression analysis. This interaction approached but did not reach significance for all teams, as detailed in Table 18. However, when the analysis was run using only teams that completed at least one objective (N = 47), the interaction term was significant (β = -.368, p < .05), even after accounting for the effects of S, TIE, and TKS. See Table 19.

As illustrated in Figure 13, this interaction is such that higher levels of TENA are more beneficial to teams with higher levels of TSOG, as would be expected. In fact, teams that were high in TSOG and low in TENA performed worse than teams low in both TSOG and TENA. This relationship reached statistical significance only for a subset of the teams, representing about two thirds of the total sample (N = 47). Implications of this will be explored further in the discussion section.
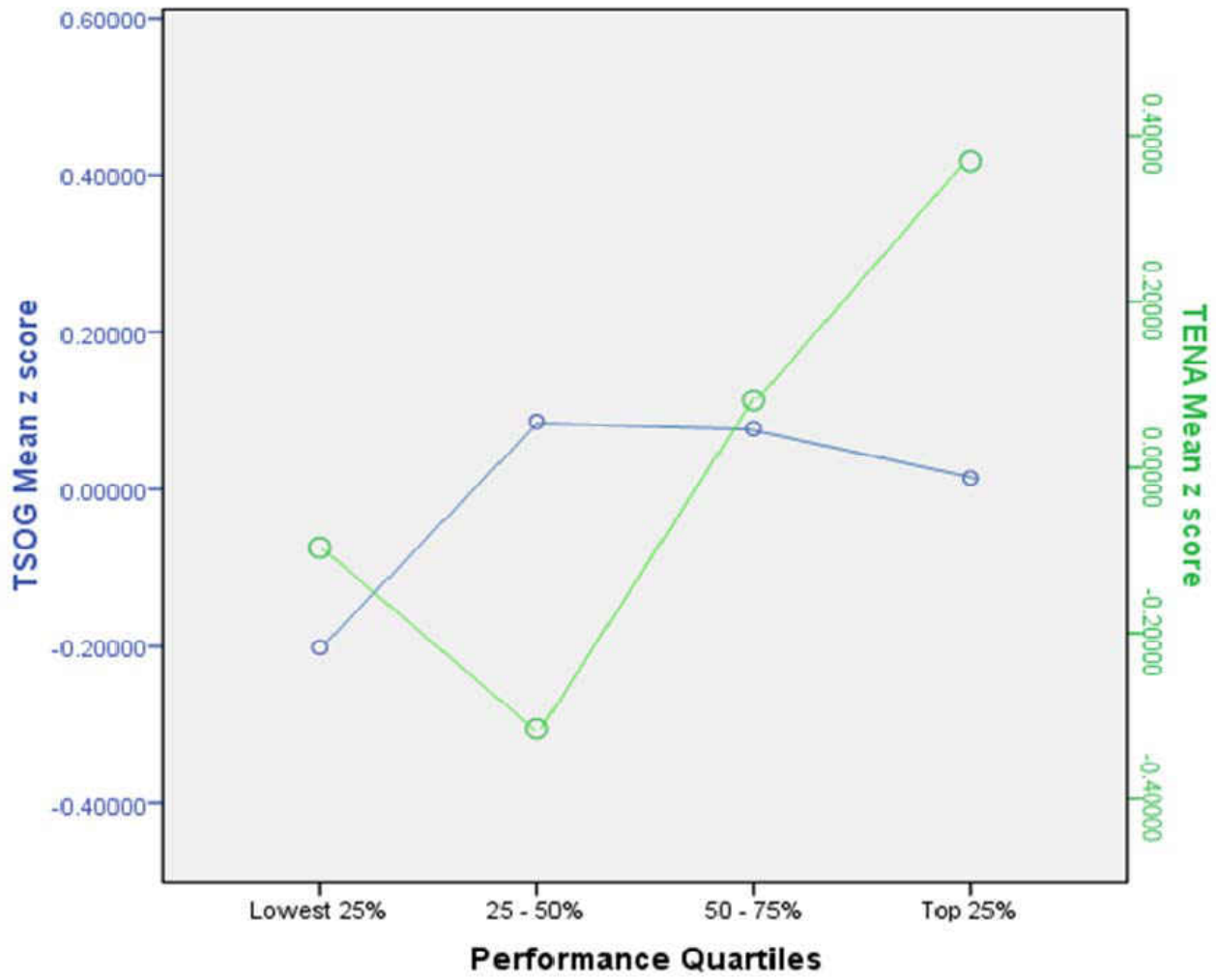
Figure 12. Mean standardized TSOG and TENA by performance quartiles.

Table 18. Hierarchical Regression Analysis of the interaction between TSOG and TENA on Performance using the full sample

Variable	β
Step 1	
Team Solution Option Generation (TSOG)	.178
Step 2	
TSOG	-.004
Team Evaluation and Negotiation of Alternatives (TENA)	.141
Step 3	
TSOG	-.039
TENA	.150
TSOG x TENA	-.233

Overall R^2 = .073
Adjusted R^2 = .030
$F(3,65) = 1.703$ $p > .05$

Note. R^2 = .001 for Step 1; ΔR^2 = .020 for Step 2 (ps > .05; ΔR^2 = .053 for Step 3 (p < .06). (N = 69)

Table 19. Hierarchical Regression Analysis of the interaction between TSOG and TENA on Performance using only teams with at least one option met

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.292*
Step 2	
Simple Agreement/Disagreement Acknowledgement	.508**
Team Information Exchange (TIE)	-.361*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.487**
Team Information Exchange (TIE)	-.398*
Team Solution Option Generation (TSOG)	.108
Step 4	
Simple Agreement/Disagreement Acknowledgement	.436*
Team Information Exchange (TIE)	-.430*
TSOG	.121
Team Evaluation and Negotiation of Alternatives (TENA)	.196
Step 5	
Simple Agreement/Disagreement Acknowledgement	.348*
Team Information Exchange (TIE)	-.433*
TSOG	.050
TENA	.233
TSOG x TENA	-.368*

Overall R^2 = .329
Adjusted R^2 = .248
$F(5,46)$ = 4.029 $p < .01$

Note. R^2 = .292 for Step 1; ΔR^2 = .083 for Step 2 (ps < .05); ΔR^2 = .009 for Step 3; ΔR^2 = .033 for Step 4 (ps > .05); ΔR^2 = ..118 for Step 5 (p > .05); *p < .05, **p < .01; TKS was entered as a covariate but found to be non-significant and excluded. (N = 47)
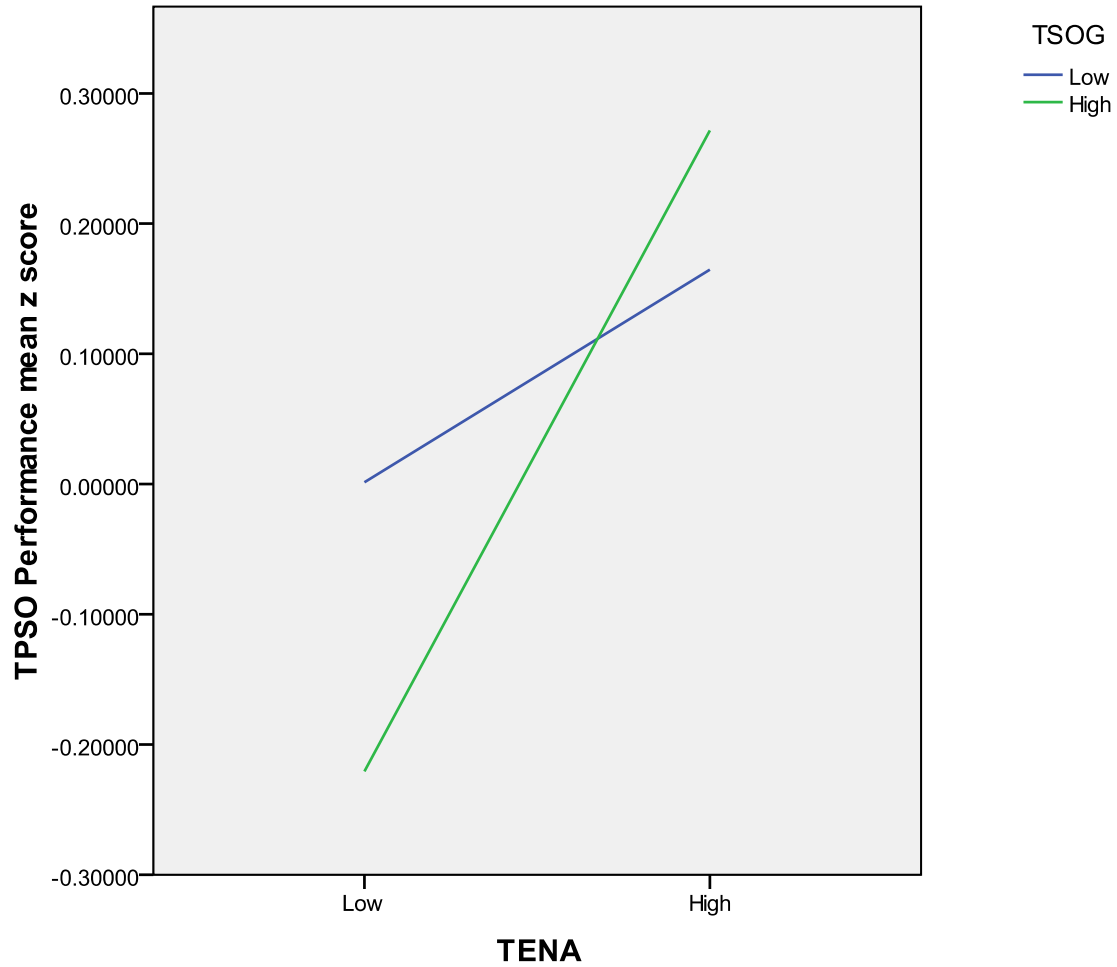
Figure 13. Interaction between TSOG and TENA for teams meeting at least one objective

Hypotheses 2 and 3: The moderating effects of External Representation Quality

Hypotheses 2a-d and 3a-b predict a moderating relationship between External

Representation Quality (ERQ) and team knowledge building processes. Specifically, 1)

Hypotheses 2a-d predict a positive moderating effect of ERQ on the relationship between

four team knowledge building processes (i.e., TKS, TSOG, TENA, and TPPR) and TPSO

Performance, and 2) Hypotheses 3a-b propose competitive positive and negative

moderating effects of ERQ on the relationship between TIE and TPSO Performance.

To test these hypotheses, a similar method was used as described above where

two sets of covariates were entered using the stepwise method followed by the team

knowledge building process of interest in step three, ERQ in step 4, and then the

interaction term for ERQ and the team knowledge building process of interest in Step 5.

As summarized in Table 20 and detailed in Tables 21 through 25, no support was

found for hypotheses 2 or 3. There were no main effects for ERQ nor interactions with

team knowledge building process variables. However, this is not surprising given the

types of relationships between the team knowledge building processes and TPSO

Performance described in the previous section. That is, H2 and H3 were rooted in the

assumption of a simple linear relationship between each individual process and outcomes.

As the existence of more complex inter-relationships between processes and outcomes is

more likely, follow up analysis focused on evaluating the role of externalization using the

TIE / TKS Ratio, a combined metric of team knowledge building process quality.

Table 20. Summary of hypotheses 2 and 3.

Hypothesis	Prediction	Result
2a	ERQ positively moderates TKS +$\rightarrow$ TPSO	Not supported.
2b	ERQ positively moderates TSOG +$\rightarrow$ TPSO	Not supported.
2c	ERQ positively moderates TENA +$\rightarrow$ TPSO	Not supported.
2d	ERQ positively moderates TPPR +$\rightarrow$ TPSO	Not supported.
3a-b	ERQ positively or negatively moderates TIE +/-$\rightarrow$ TPSO	Neither supported.

Table 21. Hierarchical Regression Analysis for H2a, the moderating effect of External Representation Quality on the relationship between TKS and TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.414**
Team Information Exchange (TIE)	-.451**
Team Knowledge Sharing (TKS)	.353*
External Representation Quality (ERQ)	.097
Step 5	
Simple Agreement/Disagreement Acknowledgement	.409*
Team Information Exchange (TIE)	-.454**
Team Knowledge Sharing (TKS)	.361*
External Representation Quality (ERQ)	.102
TKS x ERQ	.024

Overall R^2 = .239
Adjusted R^2 = .179
$F(5,63) = 3.957$ $p < .01$

Note. R^2 = .114 for Step 1; ΔR^2 = .064 for Step 2; ΔR^2 = .053 for Step 3 (ps < .05); ΔR^2 = .008 for Step 4; ΔR^2 = .001 for Step 5 (ps > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 22. Hierarchical Regression Analysis for H2b, the moderating effect of External Representation Quality on the relationship between TSOG and TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.446**
Team Information Exchange (TIE)	-.430*
Team Knowledge Sharing (TKS)	.321*
Team Solution Option Generation (TSOG)	-.082
Step 5	
Simple Agreement/Disagreement Acknowledgement	.436**
Team Information Exchange (TIE)	-.422*
Team Knowledge Sharing (TKS)	.349*
Team Solution Option Generation (TSOG)	-.078
External Representation Quality (ERQ)	.094
Step 6	
Simple Agreement/Disagreement Acknowledgement	.460**
Team Information Exchange (TIE)	-.440**
Team Knowledge Sharing (TKS)	.343*
Team Solution Option Generation (TSOG)	-.101
External Representation Quality (ERQ)	.127
TSOG x ERQ	.149

Overall R^2 = .263
Adjusted R^2 = .191
$F(6,62) = 3.679$ $p < .01$

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2; $\Delta R^2 = .053$ for Step 3 (ps < .05); $\Delta R^2 = .005$ for Step 4; $\Delta R^2 = .008$ for Step 5; $\Delta R^2 = .020$ for Step 6 (ps > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 23. Hierarchical Regression Analysis for H2c, the moderating effect of ERQ on the relationship between TENA and TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.405**
Team Information Exchange (TIE)	-.475*
Team Knowledge Sharing (TKS)	.326*
Team Evaluation and Negotiation of Alternatives (TENA)	.071
Step 5	
Simple Agreement/Disagreement Acknowledgement	.398*
Team Information Exchange (TIE)	-.464**
Team Knowledge Sharing (TKS)	.354*
Team Evaluation and Negotiation of Alternatives (TENA)	.066
External Representation Quality (ERQ)	.093
Step 6	
Simple Agreement/Disagreement Acknowledgement	.416*
Team Information Exchange (TIE)	-.478**
Team Knowledge Sharing (TKS)	.370*
Team Evaluation and Negotiation of Alternatives (TENA)	.078
External Representation Quality (ERQ)	.079
TENA x ERQ	-.073

Overall R^2 = .246
Adjusted R^2 = .173
$F(6,62) = 3.379$ $p < .01$

Note. R^2 = .114 for Step 1; ΔR^2 = .064 for Step 2; ΔR^2 = .053 for Step 3 (ps < .05); ΔR^2 = .004 for Step 4; ΔR^2 = .008 for Step 5; ΔR^2 = .004 for Step 6 (ps > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 24. Hierarchical Regression Analysis for H2d, the moderating effect of ERQ on the relationship between TPPR and TPSOs

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.337**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.423**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.324*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.415**
Team Information Exchange (TIE)	-.482*
Team Knowledge Sharing (TKS)	.301*
Team Plan and Process Regulation (TPPR)	.066
Step 5	
Simple Agreement/Disagreement Acknowledgement	.411**
Team Information Exchange (TIE)	-.463**
Team Knowledge Sharing (TKS)	.339
Team Plan and Process Regulation (TPPR)	.035
External Representation Quality (ERQ)	.090
Step 6	
Simple Agreement/Disagreement Acknowledgement	.411**
Team Information Exchange (TIE)	-.461**
Team Knowledge Sharing (TKS)	.328
Team Plan and Process Regulation (TPPR)	.044
External Representation Quality (ERQ)	.087
TPPR x ERQ	-.046

Overall R^2 = .241
Adjusted R^2 = .168
$F(6,62)$ = 3.248 $p < .01$

Note. R^2 = .114 for Step 1; ΔR^2 = .064 for Step 2; ΔR^2 = .053 for Step 3 (ps < .05); ΔR^2 = .002 for Step 4; ΔR^2 = .007 for Step 5; ΔR^2 = .002 for Step 6 (ps > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Table 25. Hierarchical Regression Analysis for H3a-b, the moderating effect of ERQ on the relationship between TIE and TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.338**
Step 2	
Simple Agreement/Disagreement Acknowledgement	.539***
Team Information Exchange (TIE)	-.323*
Step 3	
Simple Agreement/Disagreement Acknowledgement	.539**
Team Information Exchange (TIE)	-.313*
External Representation Quality (ERQ)	.041*
Step 4	
Simple Agreement/Disagreement Acknowledgement	.540***
Team Information Exchange (TIE)	-.312*
External Representation Quality (ERQ)	.037
TIE x ERQ	-.017

Overall $R^2 = .179$
Adjusted $R^2 = .128$
$F(4,64) = 3.495$ p < .05

Note. $R^2 = .114$ for Step 1; $\Delta R^2 = .064$ for Step 2 (ps < .05); $\Delta R^2 = .002$ for Step 3; $\Delta R^2 = .000$ for Step 4 (ps > .05); *p < .05, **p < .01, ***p < .001 (N=69)

Follow up Analysis for H2-3

While the hypothesized moderating relationships were not found for each individual team knowledge building process, a follow-up analysis was conducted to examine the moderating effect of ERQ on the TIE / TKS Ratio. Additionally, this analysis was conducted on a subset of the entire sample and included only teams that used externalization in some way as a strategy for sharing information, that is, teams that created at least one push pin with content. There were a total of 15 teams that did not meet this criterion. Implications of the choice to include only teams using the external map are considered in the discussion section. A hierarchical regression analysis was conducted for only the teams that created at least one pushpin with content (N = 54). As

in the preceding analyses, step 1 included potential covariates and step 2 included the

team knowledge building process measures not being tested (i.e., TSOG, TENA, and

TPPR). In step 3, the TIE / TKS Ratio was added; step 4 included the ERQ measure; and

step 5 introduced the interaction term between the TIE / TKS Ratio and ERQ. As shown

in Table 26, the interaction between the TIE / TKS Ratio and ERQ is significant and

positive, indicating the existence of a positive moderating relationship. As illustrated in

Figure 14, the interaction is such that teams with lower quality interaction process (i.e., a

higher ratio of TIE to TKS) benefit more from high ERQ than do teams with higher

quality interaction process (i.e., a lower ratio of TIE to TKS).

Table 26. Hierarchical Regression Analysis for the moderating effect of ERQ on the relationship between TIE / TKS Ratio and TPSO Performance

Variable	β
Step 1	
Simple Agreement/Disagreement Acknowledgement	.338*
Step 2	
Simple Agreement/Disagreement Acknowledgement	.322*
TIE / TKS Ratio	-.360**
Step 3	
Simple Agreement/Disagreement Acknowledgement	.347**
TIE / TKS Ratio	-.364**
External Representation Quality (ERQ)	.214
Step 4	
Simple Agreement/Disagreement Acknowledgement	.376**
TIE / TKS Ratio	-.507***
External Representation Quality (ERQ)	.216
TIE / TKS Ratio x ERQ	.277*

Overall R^2 = .344
Adjusted R^2 = .290
$F(4,53)$ = 6.411 $p < .001$

Note. R^2 = .114 for Step 1; ΔR^2 = .129 for Step 2 (ps < .05); ΔR^2 = .045 for Step 3 (p > .05); ΔR^2 = .055 for Step 4 (p < .05); *p < .05, **p < .01, ***p < .001 (N=54)
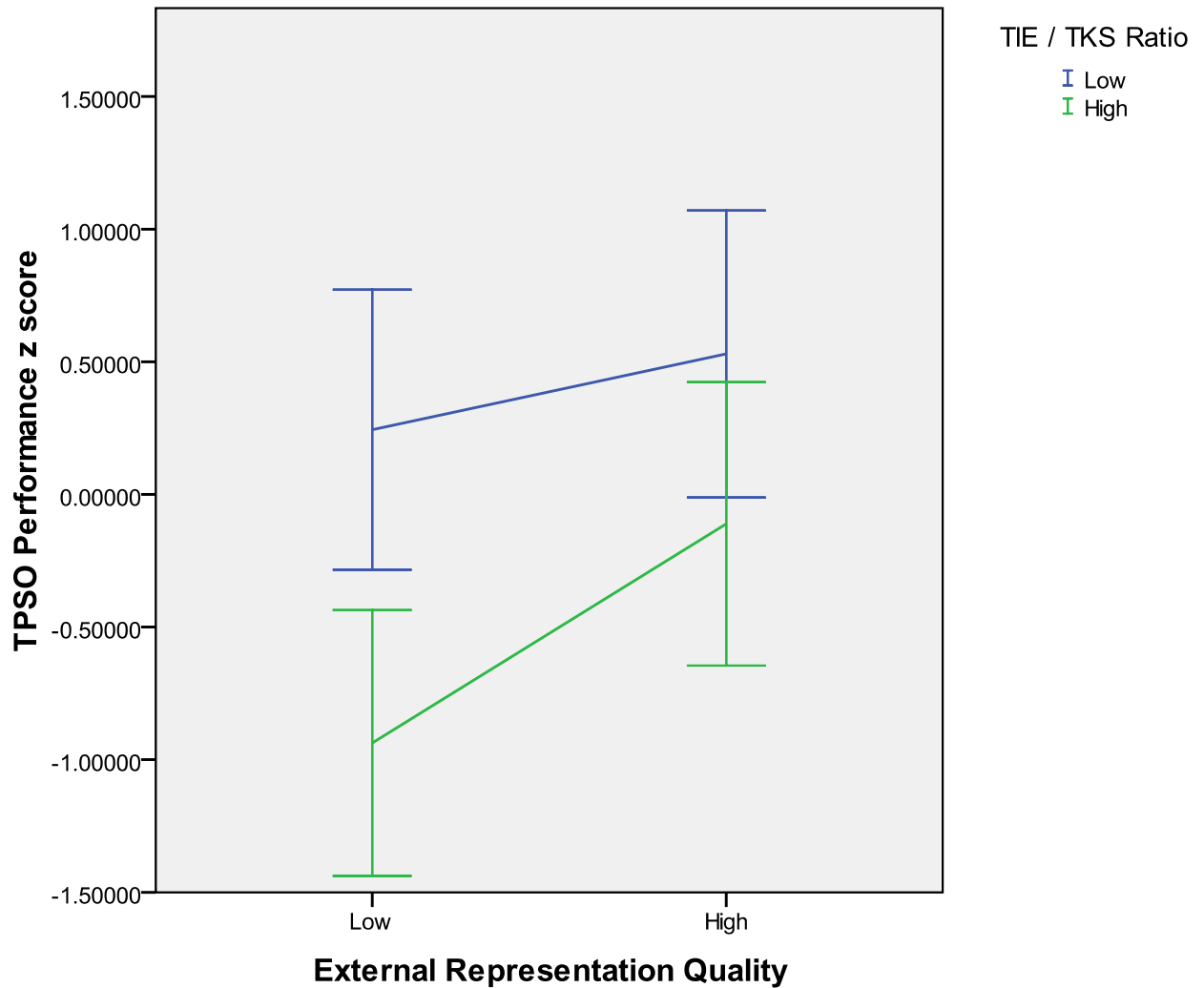
Figure 14. Moderating relationship of ERQ on the relationship bewteen TIE / TKS Ratio and TPSO

Hypothesis 4: Externalization strategies.

Hypothesis 4 predicted that the manner by which teams interleave team process and externalization will predict TPSO Performance. Due to several technical issues, the data needed to create the indexes need to test these hypotheses is not available. Specifically, timelines for the pushpin creation and verbal communication can not be

integrated. Two issues were involved. First, it appears as if the timestamps for the pushpin creation represent only the last edit of the pushpin and not the initial time of creation. This means that pushpin times are skewed towards later in the team's performance episode if the team edited their pushpins. There is no way to determine how many edits were made or when they were made and consequently no way to identify the actual time of initial creation. Second, it is necessary to have 'real time' start times for the audio files in order to align the communication timeline with the pushpin timeline (had that timeline been useful). Due to malfunctions with the audio recording software, there was also ambiguity with the real time start of the audio files for some of the teams.

Hypothesis 5a-d: Sequential Interaction

Hypotheses 5a-d proposed the existence of different temporal sequences of team knowledge building process communications for high and low performing teams and for teams with high and low levels of ERQ. This hypothesis is exploratory in nature with the general purpose of identifying patterns of interaction that may be useful in further specifying the nature of team knowledge building processes and not to confirm the existence of specific patterns. Consequently, several different approaches to conducting the analysis were explored, varying primarily in the length of time window considered (i.e., the number of sequential utterances considered at once). There are tradeoffs between these different approaches, specifically in terms of the degree to which the directly address H5a-d or address more broad differences between high and low performance and ERQ groups and in terms of the power of the analysis. Additionally, 1) there is no theoretical rationale available to predict the length of time window that will be

meaningful, and 2) sample size requirements for multi-way frequency analysis limit the range of time windows that can be considered. For clarity, only one of these analyses is presented below. This analysis focuses on longer chains of interaction, but more broad differences between high and low performance and high and low ERQ. Even though this analysis was slightly under powered (details provided below), longer sequences of interaction seemed to be more meaningful than shorter chains. Implications of this choice are discussed more in following sections, and an analysis of meeting sample size requirements is provided in Appendix D.

Performance and ERQ Groups

A median split was performed on both the TPSO Performance and ERQ variables used in preceding analyses in order to create groups representing high and low levels of performance as well as groups representing high and low levels of ERQ.

Sequential Analysis: Time Window of Four Utterances

In addition to the TPSO Performance (High, Low) and ERQ (High, Low) groups, an antecedent and three consequent process team knowledge building process code variables were used in the analysis, each having six values representing the five team knowledge building processes as well as simple agreement / disagreement acknowledgements. This sixth code was included because of its high level of association with TPSOs. The final model entered was therefore a 2 (TPSO) x 2 (ERQ) x 6 (Antecedent) x 6 (Consequent 1) x 6 (Consequent 2) x 6 (Consequent 3). The number of cells in this analysis was 5184, and given the sample of codes, this represents a violation

of sample size guidelines (25,920 cases are required, but only 23,556 are available). Reduced power results from violating these sample size requirements (Tabachnick & Fidell, 2007) meaning that the likelihood of detecting existing relationships is decreased. However, Tabachnick and Fidell (2007) suggest that simply accepting this reduction in power is a satisfactory method of dealing with sample size issues, acknowledging that model fit and parameter estimates may under-represent the true associations. As good model fit was achieved, this reduction in power was accepted because it provided the opportunity to evaluate longer chains of interaction.

Tests for six-way associations were not significant, $LR\chi^2$ (625) = 432.5, p > .05; however, five-way associations were significant, $LR\chi^2$ (2375) = 2211.758, p > .05. Specifically, as show in Table 27, four of the possible six five-way associations were significant. The significant interaction between Performance x ERQ x Antecedent x Consequent 1 x Consequent 2, χ^2(125) = 168.144, p < .05, provides support for H5a-d in that there were differences in the sequence of team process behaviors based on an interaction between performance groups and ERQ. Parameter estimates for each of these significant associations are discussed below. The observed differences in interaction patterns need to be interpreted cautiously as there were no specific hypotheses offered about what patterns would emerge. Possible explanations for the observed patterns will be offered for some patterns; however, others do not have immediate explanations and will therefore just be described. The meaning and validity of specific patterns will require further confirmatory research.

Table 27. Five-way associations for Sequential Analysis, Part 2.

Association	df	χ^2
Performance x ERQ x Antecedent x Consequent1 x Consequent 2	125	168.14**
Performance x ERQ x Antecedent x Consequent1 x Consequent 3	125	146.99
Performance x ERQ x Antecedent x Consequent2 x Consequent 3	125	146.69
Performance x ERQ x Consequent1 x Consequent2 x Consequent 3	125	152.59*
Performance x Antecedent x Consequent1 x Consequent 2 x Consequent 3	625	690.42*
ERQ x Antecedent x Consequent1 x Consequent 2 x Consequent 3	625	765.64***

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

Performance x Process

As detailed in Table 28, high performing teams were characterized by four different sequences of team knowledge building processes with a four utterance time window and low performing teams by seven sequences. Each of these sequences can be organized into a set of themes. Several different organizations are possible, but these differences will be presented in terms of: 1) basic information sharing, 2) option generation and regulation, and 3) team knowledge sharing. Descriptions and interpretations of each sequence are provided below. In many cases, further analysis will be needed to determine the precise meaning of sequences.

Differences in Information Sharing

There were three sequences involving only TIE and S codes that characterized high and low performing teams. All of these sequences seem to represent variations in

how team members 'close the loop' in sharing basic information and acknowledging one another.

First, low performing teams were more likely to exhibit a chain of three TIE statements followed by one S (TIE→TIE→TIE→S; z = 2.19). A possible explanation for this sequence's association with poor performance could involve team members 'checking' too much communication at once. That is, in this sequence three pieces of information are being shared, followed by an acknowledgement for all three pieces of information at once. This is potentially creating ambiguity in the communication as the person acknowledging may only be acknowledging one of the pieces of information as opposed to all of them as the sender of information may infer.

Second, high performing teams were more likely to exhibit chains of four consecutive TIE statements (TIE→TIE→TIE→TIE; z = -2.30) as well as chains of alternating TIE and S statements (TIE→S→TIE→S; z = -1.97). The sequences of four TIE statements could be associated with higher levels of performance because they represent blocks of information requests and information provisions ('information request' and 'information provision' were coded separately and combined into the TIE variable; see Appendix B). Here, team members are exchanging blocks of information in a structured way—requests followed by provisions of information. In the second type of chain exhibited by high performing teams, the sequences of alternating TIE and S statements could be associated with higher levels of performance because it represents the sharing of information in a way that each piece of information is acknowledged. This is in contrast to the low performance sequence where large blocks of information sharing are acknowledged once at the end (i.e., TIE→TIE→TIE→S). These findings will be

discussed more in conjunction with the functional perspective information exchange findings in the discussion section.

Differences in Option Generation

There were five sequences involving option generation that distinguished high and low performing teams, one exhibited more frequently by high performing teams, and four exhibited more frequently by low performing teams.

First, high performing teams were more likely to exhibit chains of two knowledge sharing statements, followed by an option statement, and then a regulation statement (TKS→TKS→TSOG→TPPR; $z = -2.02$). This can be interpreted as a block of communication wherein team members share interpretations and evaluations of information immediately prior to proposing an option. After the option is proposed, a regulatory statement is provided in order to focus the team on what needs to be done to implement the option, or what goal the team should be pursuing next. In some ways, this chain fits with NDM perspectives on decision making at the individual level in that team members are working to build an understanding of the problem, from which on option becomes apparent and immediately acted upon with little or no evaluation.

Second, there are three chains characterizing low performing teams that appear related to the one just described. Low performing teams were more likely to exhibit sequences of information sharing, knowledge sharing, information sharing, and then option generation (TIE→TKS-→TIE→TSOG; $z = 2.03$). This can be interpreted as a variation of the high performing option generation sequence with the difference that more information is shared prior to option generation in the low performing teams and more

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knowledge shared in high performing teams. Low performing teams were also more likely to exhibit chains of option generation, followed by information exchange and acknowledgement, and then regulation (TSOG→TIE→S→TPPR; z = 2.34). This is similar to the end of the high performing teams option generation sequence, with the addition of an information exchange sequence in between the option generation and regulation. This suggests that high performing teams are quicker in regulating the team's tasks and goals immediately following an option whereas low performing teams engage in low level information exchange first, perhaps because it is unclear what the team needs to do (e.g., an ambiguously stated option, lack of shared meaning about the option). Additionally, low performing teams were more likely to exhibit sequences of two S statements, followed by knowledge sharing, and then option generation (S→S→TKS→TSOG; z = 2.08). Again, this is similar to the beginning of the high performing team's option generation cycle with the difference being less knowledge sharing and more simple communicative acts. As this sequence begins with several acknowledgements, it is likely that it is a part of a larger recurring pattern; however, this chain of four utterances indicates that low performing teams seem to have less integration or synthesis of information immediately preceding an option being offered to the team.

Third, low performing teams were more likely to use a sequence of option generation followed by a chain of three S statements, and this sequence's parameter had the strongest effect for this association (TSOG→S→S→S; z = 2.45). This can be interpreted as a lack of evaluating the option, or (as described above) a failing to direct team efforts once an option was proposed. Instead, team members simply agreed / disagreed or acknowledged the option.

Differences in Regulation

Two different sequences in addition to those discussed above included regulation statements. These two sequences involve the how regulation statements are associated with information exchange and knowledge sharing.

First, low performing teams were more likely to exhibit a sequence of knowledge sharing, regulation, simple acknowledgement, followed by knowledge sharing (TKS→TPPR→S→TKS; z = 2.00). Second, high performing teams were more likely to have sequences involving regulation and information sharing, specifically sequences of regulation followed by two information exchanges and a simple acknowledgement (TPPR→TIE→TIE→S; z = -2.13). The exact meaning of each of these sequences is difficult to interpret; however, when taken together it suggests that higher performing teams have a closer association between regulation statements and information whereas lower performing teams have a higher association between regulation and knowledge sharing. Exactly why this is the case will require future analysis and research, but this may be linked to issues of goal clarity such that higher performing teams require less knowledge sharing about goals or tasks because they already hold a shared understanding of these things (i.e., higher quality mental models about the task and team initially and not 'built on the fly' through discussion during task performance).

Differences in Knowledge Sharing

In addition to the previously described patterns, there was one pattern involving knowledge sharing alone that differentiated high and low performing teams. Low

performing teams were more likely to exhibit the pattern of an S statement followed by

three consecutive knowledge sharing statements (S→TKS→TKS→TKS; z = 2.15). The

meaning of this pattern is difficult to interpret, and again, may be a part of a larger

pattern. However, as this deviates from what would be interpreted as an organized

sequence of knowledge sharing (e.g., TKS→TKS→TKS→TKS; TKS→S→TKS→S), it

may simply be that knowledge shared in lower performing teams is done so in a less

structured way.

Table 28. Significant parameters five-way associations involving performance and process.

Performance x Antecedent x Consequent1 x Consequent2 x Consequent3	z
LOW performing teams do **MORE:**	
TIE → TIE → TIE → S	2.19
TIE → TKS → TIE → TSOG	2.03
TKS → TPPR → S → TKS	2.00
TSOG → S → S → S	2.45
TSOG → TIE → S → TPPR	2.34
S → TKS → TKS → TKS	2.15
S → S → TKS → TSOG	2.08
HIGH performing teams do **MORE:**	
TIE → TIE → TIE → TIE	-2.30
TIE → S → TIE → S	-1.97
TKS → TKS → TSOG → TPPR	-2.02
TPPR → TIE → TIE → S	-2.13

*p < .05, **p < .01, ***p < .00

ERQ x Process

As detailed in Table 29, five significant patterns of interaction characterized teams with high levels of ERQ, and eight significant patterns characterized teams with low levels of ERQ. Each of the associations listed in Table 29 is described and interpreted further below. Again, these sequences are arranged into descriptive themes: integration of information exchange and knowledge sharing, integration of regulation and option generation, regulation, and option generation. However, as much less is known about the role of externalization in team performance, interpreting the meaning of the observed differences is much more difficult than differences between performance groups.

Integration of Information Exchange and Knowledge Sharing

Six of the thirteen significant patterns involved information exchange, knowledge sharing, and S statements. Three of these were more likely to occur in teams with high ERQ, and three more likely to occur in teams with low ERQ.

First, two sequences involved just one team knowledge building process variable and chains of S statements. Teams with high levels of ERQ were more likely to follow a knowledge sharing statements with a chain of three S statements (TKS→S→S→S; z = 2.23) and teams with low levels of ERQ were more likely to follow an information exchange statements with a chain of three S statements (TIE→S→S→S; z = -2.24). This is an interesting finding in that teams high on ERQ (i.e., teams with more externalized information) tend to have more simple acknowledgement associated with information

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that is shared verbally. Conversely, teams with less externalized information engage in more simple acknowledgement of knowledge that is shared verbally. However, this finding does not have an apparent explanation from either the scaffolding or offloading perspectives on externalization.

Second, two sequences involved just information exchange and knowledge sharing statements. Teams with high levels of ERQ were more likely to exhibit an integrated pattern of knowledge sharing and information exchange such that information exchange was followed by knowledge sharing, followed by information exchange and then knowledge sharing again (TKS→TIE→TKS→TIE; $z = -3.41$). This parameter for this sequence had the strongest effect in this association. Teams with low levels of ERQ exhibited a less integrated pattern of knowledge sharing and information exchange characterized by sequences of two knowledge sharing statements followed by two information sharing sequences (TKS→TKS→TIE→TIE; $z = 2.02$). From an externalziation perspective, a possible explanation for these differences could lie in the ability of teams with more externalized information to combine the information shared verbally with the information shared via externalization. This would allow teams to move back and forth between information exchange and knowledge sharing more quickly. Conversely, teams with less externalized information would be sharing blocks of information verbally and then integrating that information verbally leading to the less integrated pattern observed for teams low on ERQ.

Third, there were two sequences involving information exchange, knowledge sharing, and S statements. Teams high in ERQ were more likely to exhibit sequences of information exchange, followed by knowledge sharing, and then a chain of two S

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statements (TIE→TKS→S→S; z = -2.30). Teams low in ERQ exhibited a similar pattern: information exchange, followed by knowledge sharing, an S statement, and then another knowledge sharing statement (TIE→TKS→S→TKS; z = 2.60). These differences may indicate that teams with less externalized information require more integration or evaluation of that information than do teams with higher levels of externalized information.

Integration of Regulation and Option Generation

Five sequences involved both option generation and regulation statements, two exhibited more frequently by low ERQ teams, and three exhibited more frequently by high ERQ teams. Interestingly, all five of these patterns have an option generation statement in the third slot of the chain; three have a regulation statement and two have a knowledge sharing statement in the fourth step of the sequence.

First, teams with high levels of ERQ were more likely to engage in two different sequences. They were more likely to exhibit sequences of information exchange, knowledge sharing, option generation, and then regulation (TIE→TKS→TSOG→TPPR; z = -2.02). This sequence is similar to the high performing team's sequence of option generation (TKS→TKS→TSOG→TPPR) discussed previously with the exception of the first code in the sequence. This may be one mechanism by which higher quality ERQ may moderate the relationship between the amount of team knowledge building processes on TPSO Performance. ERQ did not change the amount of different processes, but it is associated with a sequence very similar to one characterizing high performance teams. While this is by no means conclusive, it suggest that differences in the sequences

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of interaction associated with externalization may play a role in the moderation of the effects of the amount of processes. Additionally, high ERQ teams were also more likely to exhibit sequences of information exchange, regulation, option generation, and then knowledge sharing (TIE→TPPR→TSOG→TKS; -2.27). This pattern shares interesting connections to two patterns characteristic of low ERQ teams and is discussed more in the following paragraph.

Second, teams with low levels of ERQ were more likely to exhibit three different sequences, two of which are related closely to the last pattern of high ERQ teams discussed (i.e., TIE→TPPR→TSOG→TKS), sharing the same three beginning or ending code sequences. Low ERQ teams were more likely to use patterns of information sharing, regulation, option generation, and regulation (TIE→TPPR→TSOG→TPPR; $z = 2.46$). This differs from the high ERQ pattern by only the ending code, a regulation statement instead of a knowledge sharing statement. Additionally, low ERQ teams were more likely to exhibit patterns of knowledge sharing, regulation, option generation, and knowledge sharing (TKS→TPPR→TSOG→TKS; $z = 2.05$). This differs from the high ERQ pattern by only the beginning code, knowledge sharing instead of information sharing. Each of these patterns differs in only one way from the high ERQ pattern.

Regulation

There was one significant sequence involving regulation, information sharing, and S statements. Low ERQ teams were more likely to exhibit a pattern of regulation, followed by two information exchange statements and an S statement (TPPR→TIE→TIE→S; $z = 1.99$). Interestingly, this pattern was significantly associated

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with higher performing teams as well. This contradicts the rationale previously discussed that ERQ improves the effectiveness of processes for teams with lower quality processes by improving the structure of their processes as opposed to changing the amount of process.

Option Generation

There was one significant sequence involving option generation and knowledge sharing. Low ERQ teams were more likely to exhibit a pattern of option generation followed by three knowledge sharing statements (TSOG→TKS→TKS→TKS; z = 2.36).

Table 29. Significant parameters five-way associations involving ERQ and process.

ERQ x Antecedent x Consequent1 x Consequent2 x Consequent3	z
LOW ERQ teams do **MORE:**	
TIE → TKS → S → TKS	2.60
TIE → TPPR → TSOG → TPPR	2.46
TKS → TKS → TIE → TIE	2.02
TKS → TPPR → TSOG → TKS	2.05
TKS → S → S → S	2.23
TSOG → TKS → TKS → TKS	2.36
TPPR → TIE → TIE → S	1.99
TPPR → TIE → TSOG → TPPR	2.44
HIGH ERQ teams do **MORE:**	
TIE → TKS → TIE → TKS	-3.41
TIE → TKS → TSOG → TPPR	-2.02
TIE → TKS → S → S	-2.30
TIE → TPPR → TSOG → TKS	-2.27
TIE → S → S → S	-2.24

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

Performance x ERQ x Process

Across the two significant associations involving both performance and ERQ, four significant parameters were found. First, from the Performance x ERQ x Antecedent x Consequent 1 x Consequent 2 association, low performing teams with low ERQ were less likely to exhibit patterns of TIE→S→TSOG ($z = -2.22$) and more likely to exhibit patterns of TPPR→TIE→S ($z = 1.99$). From the Performance x ERQ x Consequent 1 x Consequent 2 x Consequent 3 association, low performing teams with low ERQ were less likely to exhibit patterns of TKS→S→S ($z = -1.96$) as well as being less likely to exhibit sequences of S→TIE→S ($z = -2.15$). It is interesting to note that all four of these significant patterns of interaction involve changes in the ways teams interleave TIE, TKS, and S to some degree (the same processes included in the significant findings from the functional perspective test of ERQ moderation).

CHAPTER FIVE: DISCUSSION

Results presented in the previous section provide direct support for a limited set of the hypotheses proposed in this study, specifically for the direct positive linear relationship between knowledge sharing and performance outcomes as well as the existence of differences in sequential patterns of team knowledge building processes for high and low performing teams as well as for teams with high and low levels of external representation quality. However, follow up analyses provided some useful insight into the potential types of relationships that can be used to characterize the relationship between team knowledge building processes and outcomes. This section provides a summary and interpretation of the preceding findings. Specifically, findings are summarized in terms of 1) the functional view of team knowledge building processes, 2) external representations and team process, and 3) sequences of team interaction processes. Subsequently, a summary of the theoretical implications of this study for the Macrocognition in Teams Model as well as practical implications, limitations, and future research needs are discussed.

Team Knowledge Building Processes: A Functional View

The functional perspective on team processes assumes that team performance is determined by the amount of team process focused on critical task functions. As such, hypotheses for team knowledge building processes rooted in a functional perspective predict that teams with more communication focused on each of the team knowledge building processes will have higher levels of TPSO Performance. However, as

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summarized in Table 30, the preceding results indicate that this relationship is much more complex than initially proposed in this study. Specifically, evidence for a simple positive linear relationship between team knowledge building processes and outcomes was supported for TKS alone. The more knowledge sharing team members did, the better they performed. A negative relationship between TIE and outcomes was found. The relationship between TPPR and outcomes is best described as curvilinear (inverted U) with both high and low performing teams being characterized with lower levels of TPPR than moderately performing teams. While TENA and TSOG had no direct effects in isolation, there was a significant positive interaction between the two in predicting outcomes for teams completing at least one objective. Additionally, TIE and TKS were predictive of outcomes when considered together in a composite metric than in isolation. These relationships are explored further below.

Table 30. Summary of relationships between process amount and outcomes.

Process Variables	Relationship with TPSO Performance	Description
S	Positive linear	Teams with more simple agreement / disagreement acknowledgements tended to perform better.
TKS	Positive linear	Teams that share more knowledge tended to perform better.
TIE	Negative linear	Teams that share more information tended to do worse after controlling for S.
TPPR	Curvilinear (inverted U)	High and low performing teams tended to egange in less regulation than moderately performing teams.
TSOG x TENA	Positive interaction	Teams with higher levels of TSOG benefitted more from higher levels of TENA than did teams with lower levels of TSOG, for teams meeting at least one objective.
TIE / TKS	Negative linear	Teams that shared proportionally less information to the amount knowledge they shared tended to perform better.

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Team Information Exchange

Perhaps the most striking finding from the above analyses involves the significant negative relationship between TIE and TPSO Performance. This finding contradicts a recent meta-analysis indicating a positive true score correlation between the amount of information sharing a team does and performance outcomes (Mesmer-Magmus & DeChurch, 2009). In efforts to reconcile these findings, this section provides further interpretation of this information exchange finding as well as discussion of previous research.

First, it is important to note that there was no significant relationship between information exchange and outcomes before controlling for simple agreement/disagreement acknowledgments. High and low performing teams didn't exchange significantly different levels of information. However, as partially illustrated in Figure 15 there seems to be higher levels of shared variance between acknowledgements, information exchange, and outcomes for higher performing teams than for lower performing teams. This can be interpreted as: high performing teams have a stronger association between information exchange and acknowledgements than do lower performing teams. Consequently, higher levels of information exchange not associated with acknowledgements are associated with poorer outcomes. This is consistent both with previous research on closed-loop communication (Bowers et al., 1998) as well as findings from the sequential analysis of process behaviors in this study. Specifically, higher performing teams have more sequences of information exchange followed by acknowledgements than do lower performing teams. This goes beyond a purely

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functional perspective on group process, as it is not just the amount of communication that matters, it is the amount and structure. In sum, it appears as if higher levels of poorly structured information exchange (i.e., information not acknowledged) is related to poorer performance.
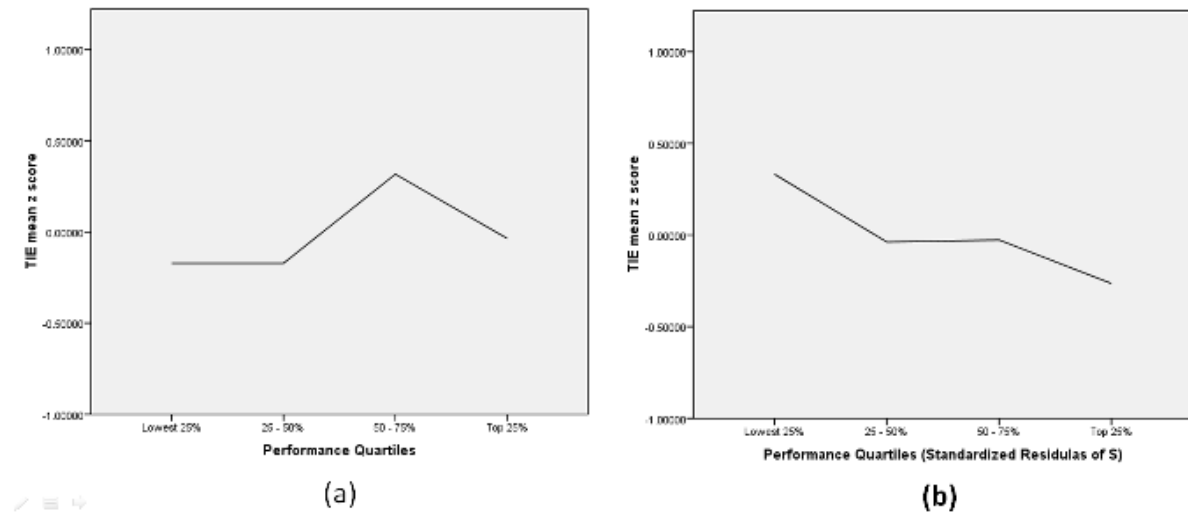
Figure 15. Mean Team Information Exchange standardized scores across quartiles

Note: (a) TPSO Performance, and (b) residual TPSO Performance scores after accounting for S.

Second, past research on team information exchange has been conducted primarily in tasks with low to no levels of role diversity. That is, all team members have the same type of task knowledge. In this situation any information shared is likely to have the same meaning for all team members. However, in the current study, the differences in role specialization may have made the sharing of 'raw information' counterproductive. In this situation, TKS is positively predictive of TPSO Performance as team members need integrations, interpretations, and evaluations of information in order for that communication to be useful. Additionally, past research has not made the distinction

between TIE and TKS. This means that measures of information exchange may include aspects of communication classified as knowledge sharing in the present study. This means that the measurement of knowledge sharing and information exchange as defined in the Macrocognition in Teams Model would have been confounded in previous research. If this is the case, comparison of the present findings to past research becomes difficult.

Team Knowledge Sharing and Team Information Exchange

Of all the tested team knowledge building process variables, TKS seems to have the simplest and most direct relationship with TPSO Performance. Teams that share more knowledge do better. However, this relationship becomes more nuanced with a team's level of TIE and TKS are considered concurrently. A team's level of TIE and TKS are highly correlated ($r = .649$, p < .01) yet nonetheless have opposite relationships with outcomes. While no statistically significant interaction was found, inspection of trends as illustrated in Figure 10 suggest that: 1) low performing teams share proportionally more information than knowledge, 2) high performing teams share proportionally more knowledge than information, and 3) moderately performing teams share proportionately similar levels of information and knowledge. Additionally, teams near the mean level of performance are distinguished more by the overall amount of information and knowledge shared and not relative amounts.

The trends just described involving TIE and TKS are not statistically significant, but the ratio between the two was predictive of outcomes such that teams with the higher levels of outcomes had higher levels of information exchange relative to knowledge

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sharing and the low performing teams had lower levels of information sharing relative to knowledge sharing. This TIE / TKS Ratio was a useful way to capture some of the above trends into one metric, and was useful in follow up analysis of the effects of external representations. However, it was developed post hoc based on the observed and nonsignificant trends in this data set. Although it makes conceptual sense (i.e., it can be thought of as an index of knowledge creation in a team), it is of course in need of further replication and conceptual specification to be useful.

Team Process and Plan Regulation

No significant linear relationship between TPPR and TPSO Performance was found as hypothesized. Instead, a significant curvilinear relationship was found such that high and low performing teams exhibited lower levels of TPPR than moderately performing teams. This relationship was not significant when S was entered as a covariate. However, it appears as if the best way to characterize the effects of team regulation in this data set is an inverted-U shaped relationship. As this relationship was not an a priori hypothesis, it needs to be interpreted cautiously. However, there are several possible explanations for this finding including differences in team knowledge inputs or dynamic understanding of the situation or task. Specifically, teams with poor knowledge inputs or emergent cognitive states may benefit from explicit regulation functions. That is, when team members have a lower quality understanding the task or situation, there may be a strong need for regulation in the form of goal specification, task allocation, and situation updates. However, teams with higher quality knowledge inputs may be able to regulate their tasks more implicitly. This interpretation is consistent with

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the implicit coordination literature and Shared Mental Model Theory. However, future research needs to replicate this finding and explore why this relationship is not robust to controlling for simple agreement / disagreement acknowledgments. This may be a measurement issue (i.e., processes are highly correlated to begin with) or there may be an underlying conceptual reason why acknowledgements can override the effects of regulation in team problem solving. For example, use of simple agreements / disagreement acknowledgements in a particular way may be a type of 'micro regulation' where appropriate management of each statement can fulfill some of the same functions as explicit regulation.

Option Generation and Evaluation

Option generation and evaluation were not independently predictive of performance outcomes. However, they did interact to predict outcomes, but only for teams meeting at least one operation objective. First, the nature of the relationship is further explained, and second, the implications of this subgroup analysis are discussed.

Teams benefited more from high levels of evaluation when they also engaged in high levels of option generation. In fact, the worst performing teams were those with high levels of option generation and low levels of evaluation. Here, teams were proposing many options, but not sufficiently evaluating the quality of these different options. It is a type of 'option overload' with too many solutions and not enough effort dedicated to determining which ones are better than others. However, the highest performing teams also generated high levels of options, but in contrast to the lowest performing teams, they also engaged in high levels of evaluation of options. Here, teams generated different

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solutions, and dedicated effort to discriminate more from less effective solutions. Teams with lower levels of option generation did not benefit as much from engaging in evaluation efforts. These teams seemed to follow a different strategy, more of a satisficing strategy where they took the first acceptable solution as opposed to generating a more comprehensive set of potential solutions.

It is critical to note that this relationship held only for teams that completed more than one objective in the operation (approximately the top two thirds of the distribution). This could be due to several factors and future research will need to determine if the observed relationships are indeed generalizable to other situations or if this is an artifact of some type. However, teams that did not meet a single objective were failing miserably at the task. These teams may have spent more of the team's time and effort grappling with fundamental issues such as working to understand the situation, task, and basic information (e.g., resource locations and capacities). Or, if they were ineffective at meeting these more basic task functions, the option generation and evaluations they did engage in would have been less effective. This brings up an important note concerning the measurement system. Option generation and evaluation is measured as the amount of utterances devoted to a specific task function (as are the other team knowledge building process measures). Therefore, differences in the quality of the options generated or the qualtity of the evaluations provided are not directly captured. It could be this relationship did not hold for these teams at the bottom of the distribution because their option generation and evaluation was of a lower quality (i.e., generating ineffective options, providing inaccurate evaluations) rather than lower in amount.

Simple Agreement / Disagreement Acknowledgements

The degree to which teams acknowledged one another's communication or provided simple agreements and disagreements was a better single indicator of a team's performance ($r = .337$, $p < .01$) than any of the team knowledge building process measures when considered in isolation. In fact, the relationship between TIE and TPSO Performance was not significant unless S was controlled for. Acknowledgement and related communicative acts have been found to be an indicator of effective teamwork in aviation crews (Bowers et al., 1998) and decision making teams (Orlitzky & Hirokawa, 2001). However, it was not explicitly represented in the Macrocognition in Teams framework. As this relatively simple communicative act accounts for a relatively high degree of variance in outcomes, it is a concept worth specifying more explicitly in the Macrocognition in Teams framework. For example, these simple agreement / disagreement and acknowledgement statements can be viewed as a part of knowledge sharing (if they are agreeing/disagreeing with or acknowledging a knowledge statement) or information exchange (if preceded by an information statement).

External Representations

The proposed moderating effects of ERQ were not supported for any individual team knowledge building process; however, ERQ did moderate the effect of the composite TIE / TKS Ratio measure on TPSO Performance for teams that created at least one pushpin. More specifically, teams with 'better' process (i.e., lower TIE / TKS Ratio scores) benefited less from ERQ than did teams with 'poorer' process (i.e., higher TIE /

TKS Ratio scores). However, as the TIE / TKS Ratio combines multiple types of content (i.e., information and knowledge), ideas of content matching and content disparate externalizations can not be evaluated. In fact, the more basic ideas of scaffolding and offloading require greater levels of specification and conceptual clarity. ERQ was negatively related to levels of TKS ($r = -.305$, $p < .05$) and TIE ($r = -.237$, $p < .06$) which would indicate an offloading relationship, particularly with TIE (i.e., more externalized information was associated with less verbal information sharing). However, there was a positive moderating relationship such that teams with lower quality interaction processes benefited more from ERQ than did teams with higher quality interaction processes. This would suggest a general scaffolding relationship where levels of team knowledge building processes become more effective with better ERQ.

The moderating relationship found in this study held only for teams that created at least one pushpin (i.e., team's that used externalization as a strategy). It is unclear whether or not this is a statistical artifact in that 12 teams with an ERQ score of 0 created a cluster of scores at the tail of the distribution which reduced power of the statistical tests, or if there is some other mechanism at work. Further research is needed, preferably with externalization tools capable of representing a broader range of functions (e.g., options, evaluations, regulation).

Sequential Interaction Patterns

In contrast to the functional hypotheses discussed earlier, interactional hypotheses focus on how different process behaviors are sequenced in time. The exploratory frequency analysis did show differences between high and low performing teams as well

as teams with high and low levels of ERQ. This has several implications. First, high and low performing teams differed not only in the amount of process behaviors, but in the sequence of these process behaviors. While several of the team knowledge building processes (i.e., TSOG, TENA, TPPR) were not significantly predictive of outcomes on their own, they were involved in differences between performance groups. Consequently, it may be more useful to conceptualize some team knowledge building processes from a functional view (i.e., the amount of the process is a useful index of effectiveness) and others from an in interactional perspectives (i.e., quantity of the process is a less useful index of effectiveness than how that process is sequenced relative to other processes). Differences for high and low performing teams and teams with high and low levels of ERQ are summarized below.

Differences in Sequence of Process Based on Performance Groups

Between the high and low performing teams, there were significant differences in patterns of information sharing, option generation, regulation, and knowledge sharing. First, high performing teams appeared to have patterns of information exchange more consistent with previously established notions of closed-loop communication: 1) acknowledging each information statement as opposed to large chunks of information statements (which was characteristic of low performing teams), and 2) engaging in cycles of requests and provisions of information (although this interpretation requires further analysis to confirm). Second, high performing teams had more sequences of option generation preceded by knowledge sharing and followed by regulation statements. This is a pattern somewhat consistent with a sequential option generation models of decision

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making in real world settings. That is, high performing teams shared integrations or interpretations of information immediately prior to generating an option, and regulated team activity immediately after an option was generated. In contrast, low performing teams tended to have patterns of option generation preceded by less knowledge sharing, and followed by less regulation or intervening sequences between option generation and regulation statements. Additionally, low performing teams had more chains of simple agreement / disagreement acknowledgements after an option statement. This can be interpreted as a 'yes man' syndrome were options are not immediately acted on or evaluated. Third, high performing teams had a higher association between regulation and information statements and lower performing teams had a higher association between regulation and knowledge statements. This finding requires further analysis to interpret fully, but may likely be related to issues of mental model quality related to tasks and goals (i.e., higher performing teams do less integration around goals as they already have a shared understanding of their meaning). Fourth, low performing teams tended to have a unique sequence of team knowledge sharing characterized by an acknowledgement followed by several knowledge statements.

Differences in Sequence of Process Based on ERQ Groups

While an extensive literature base on team processes and a more concrete specification of the role of team knowledge building processes in macrocognitive performance provides a basis for interpreting the patterns discussed above, there is much less theoretical work available to guide the understanding of patterns related to differences in externalization. However, differences between high and low ERQ groups

manifested in patterns of the integration of information exchange and knowledge sharing, integration of regulation and option generation, as well as regulation and option generation in isolation. First, high ERQ teams tended to interleave information and knowledge sharing statements while low ERQ teams tended to block information statements with information and knowledge statements with knowledge. Second, teams with high ERQ exhibited a sequence of option generation very similar to one characteristic of high performing teams; however, low ERQ teams also exhibited a sequence associated with high performing teams involving regulation, information exchange, and acknowledgement. It is therefore unclear exactly how ERQ is functioning to moderate the relationships between knowledge building processes and outcomes. However, it is clear that there are differences in the sequence of process behaviors associated with the use of externalization. In fact, the differences between ERQ groups had larger effect sizes than the differences between performance groups.

Summary of Theoretical Implications

While many of the proposed hypotheses were not supported in this study, there are several implications of these findings of the Macrognition in Teams Model. These implications related to the direct relationship between team knowledge building processes and outcomes, the moderating role of external representations, and the nature of sequencing team knowledge building processes.

First, the hypothesized relationships between team knowledge building processes and outcomes (H1a-e) were rooted in one of the simplest (yet widely adopted) conceptualizations of team process: more is better, more in terms of the amount of

communication focusing on a specific task function. This was generally not supported, with the exception of knowledge sharing. A variety of other more complex relationships were identified. While the post hoc findings make conceptual sense, they are in need of cross-validation and further conceptual specification. For example, the information exchange finding could lead to further specification of the macrocognitive process in that it could be hypothesized that higher levels of structured information exchange are associated with positive outcomes and higher levels of unstructured information exchange are associated with lower levels of performance. Additionally, the findings involving inter-relationships between processes can be used to generate and test hypotheses about combined effects. Results indicate that further development of a combined metric of option generation and evaluation (e.g., a metric of 'option space exploration') as well as information exchange and knowledge sharing (e.g., an index of 'knowledge construction or information integration') could be a theoretically useful approach to take. In sum, the primary implication of this study for the direct relationship between team knowledge building processes and outcomes then is that macrocognitive processes require a more nuanced specification of how they are related to outcomes including their inter-relationships with other processes. This has been noted in areas of macrocognition theorizing (Klein et al., 2003), but not empirically demonstrated.

Second, support for the specific predicted moderating effects of externalization was not found. However, these predictions were based on the simple (and inaccurate) conceptualization of the relationship between team knowledge building processes and outcomes. Implications from above, and the limited support for a moderating relationship of externalization for the information exchange / knowledge sharing ratio indicate that the

general moderating relationship may exist. That is, externalization may scaffold team knowledge building processes; it may increase the effectiveness of processes, specifically for lower performing teams. However, given the above implications for the direct relationships between team knowledge building processes and outcomes, the exact nature of this relationship is in need of further evaluation and conceptual specification. For example, if option generation and evaluation interact to predict outcomes (a finding in need of further evaluation), then how does externalization impact this relationship? This is further complicated by the fact that 1) only externalziations of information were evaluated, and 2) ideas of content matching and content disparate effects of externalization were not supported. Consequently, there remains little validated guidance on how to predict the effects of different externalized content on the relationships between different processes and outcomes.

Third, there were significant differences in patterns of team knowledge building processes between high and low performance groups and groups with high and low levels of externalization. In some instances, sequential analyses provided insight into the observed effects in the functional hypotheses. Specifically, high performing teams seemed to have more structured information exchange than lower performing teams, indicating that this team knowledge building process may best be conceptualized in terms of structure than in terms of raw amount.

Practical Applications

While the results of the present study require further study and cross-validation, there are several implications for practice if the preceding findings hold true in

replication. Specifically, findings can provide some guidance in the areas of team performance measurement, team training, and performance support tools.

Team Performance Measurement

The complex relationships between team processes and outcomes found in this study suggest that the measurement of team performance should attend not only to team process dimensions in isolation, but in relative amounts or in lower level blocks of interaction (i.e., capturing cycles of activity that characterize how the team accomplishes specific functions like option generation). While this is currently done in some respects, particularly with capturing lower level exchanges of team members in training environments, more global team process measures are rarely considered in conjunction.

Team Training

There are two primary implications of this study for team training, one involving the team knowledge sharing finding, and the other involving the simple agreement / disagreement acknowledgements finding.

First, the primary implication of this study for the design of team training programs involves the addition of the knowledge sharing behavior and its differentiation from information exchange. Specifically, in designing training to prepare personnel for collaborative problem solving tasks, 'data dump' communication patterns where team members share copious amounts of information that other team members may or may not understand should be discouraged. Instead, team members should be trained to balance their communication such that they are sharing integrated or synthesized information

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(i.e., knowledge as defined here). This could involve a sensitization of team members to the difference between raw information and integrated knowledge. However, further research is needed into exactly how to implement such a program. As recent events in national security have shown, detecting important patterns (i.e., a potential terrorist threat) can depend on 'connecting the dots' between discrete pieces of information. If different people hold individual 'dots' that do not make sense before combining them, it may be problematic to train people to focus on sharing knowledge in favor of information.

Second, while not routed in a hypothesize relationship, the consistency of the simple agreement / disagreement acknowledgment finding with previous research suggests that various forms of closed loop communication are as important to problem solving teams as they are to action or performing teams. Not only the amount, but the sequence of simple agreements, disagreements, and acknowledgements were some of the biggest predictors of outcomes. As discussed above, there is even some evidence that ERQ impacts how people use simple agreements, disagreements, and acknowledgements relative to TIE and TKS processes. This is useful from a practical standpoint as the potential to increase performance can be achieved via a relatively simple intervention—a training program on the equivalent of closed-loop communication for problem solving teams. More work would be needed to identify how exactly these communicative acts should be applied, but initial findings from this study provide some basic guidance.

While the findings concerning the role of externalized cognition need to be interpreted cautiously, there is some evidence indicating the usefulness of supporting lower performing teams with collaborative tools. Specifically, an external tool for representing important team problem solving content can be an effective way to scaffold the performance of teams whose members have not developed the necessary process skills. This can be a means to 'ration' the use of technology if its broad application is cost prohibitive. That is, poor performing teams have much more to gain from the use of external representations via collaborative tools than do high performing teams. However, considerations of the consequences, costs, and benefits of different levels of performance would need to be considered. These are more distal implications than those concerning measurement and training, as much more research is needed to further specify the relationship between externalization and process within a performance episode as well as longer term effects of externalization use on the development of a team.

Limitations

There are several limitations to the generalizability of the results of this study related to technical issues with the testebed used, the collaborative tool used, the degree to which the task captures a truly novel problem solving situation, the performance measure used, relative arbitrariness of time window chosen in temporal analysis, and reliability of the coding process.

First, the testbed used in this study was in early phases of development and unstable at times leading to data loss. Although 69 complete sessions were used in this

analysis, many others were lost. It is assumed that these technological failures were random and did not affect sampling in any way; however, the general unreliability of the system may have introduced unknown types of error variance or bias. In addition to data losses, the interface for the testbed had several usability issues. This threatens the validity of the results as frequently team members were focused on managing interface issues and not the collaborative planning task.

Second, the collaborative tool used in this experiment was constraining in that it allowed only for passing text based information. More robust tools that allow for the development of knowledge objects affording direct perception of knowledge (e.g., visually representing a proposed route instead of typing in information about start and end points) may result in more pronounced effects (direct or moderating) of ERQ. Twelve teams did not use the collaborative tool in any regard. This can be taken as an indicator of its relative tangential relationship to the task. Integrating the collaborative tool use with the task more tightly could lead to different results.

Third, the degree to which the task represents a truly novel task can be argued. Team members were asked to meet new types of objectives in Operation 2 that they had not previously been trained on (i.e., choosing a location for a base whereas previously destinations had been provided to the team members), so the task did represent some type of new problem. However, it was similar to past tasks the team performed in many respects as well (i.e., the same resources and resource capacities and limitations).

Fourth, the observed lack of direct relationships between TSOG, TENA, and outcomes could be due to the nature of the task and performance measure. The number of objectives met is the primary factor driving performance scores and efficiency providing

a secondary source of variance. This is consistent with 1) the instructions given to participants, 2) common sense (i.e., a team meeting five objectives with slightly less efficiency is better than a team that met only one objective but very efficiently), as well as 3) comparable tasks in the real world (i.e., satisficing and taking the first acceptable solution vs. working extensively to find the 'best' solution). However, tasks that demand more extensive comparison of different options will likely show different relationships between TSOG, TENA, and outcomes.

Fifth, a difficulty in any temporal analysis of interaction is defining (or discovering) the size of time window that is most appropriate and useful. The preceding analyses revealed significant differences between performance and ERQ groups in team knowledge building processes in chains (or time windows) of four utterances. This length of analysis was not chosen a priori based on a theoretical rationale for what length of interaction pattern would be meaningful, but based primarily upon sample size limitations of the analysis techniques. Consequently, interpretation of the exact meaning of the observed chains is difficult. For example, when considering a chain length of two, the sequence TSOG→TPPR is associated with low performing teams; however, when considering chains of length four, this sequence is associated with high performance when preceded by two TKS utterances. Therefore, when looking at any one time unit size, it is unclear whether the observed sequences are part of a large pattern of interaction or not. However, it is clear that the sequence of interaction matters, and more theoretically driven research is needed into what these differences might be.

Sixth, while the inter-coder reliability reached an acceptable level (kappa = .69) by conventional standards (and kappa is a conservative estimate of reliability), there is

room for improvement in this area. It is possible that some of the relationships that did not reach statistical significance (i.e., direct effects of TSOG and TENA on TPSO Performance) may have with a higher level of reliability in coding.

Future Research Directions

Results of this study indicate several areas in need of future research. Specifically, the need to consider 1) the full Macrocognition in Teams Model, 2) inter-relationships between processes, 3) providing greater conceptual clarity around the function of external representations, 4) allowing for team members to externalize a broader range of knowledge building content, and 5) conducing a finer-grained temporal analysis of team interaction.

Considering Inputs and Processes Concurrently

Efforts to further explain the types of results found above will benefit from a consideration of team knowledge inputs and other components of the Macrocognition in Teams framework. For example, differences in team knowledge likely play a role in the observed borderline curvilinear relationships between TIE and TPPR. For example, a possible hypothesis for TPPR could be poor performing teams do poorly because 1) they have low quality shared mental models as inputs to their collaborative process, and 2) they engage in low levels of TPPR to control their task performance. Moderately performing teams may have low levels of shared knowledge as inputs, but are able to overcome this to some degree by the use of high levels of regulation. High performing

teams use less regulation to guide their activity because they have higher quality knowledge inputs.

Complex Inter-relationships between Processes

Results of this study suggest that team knowledge building processes can be more predictive when considered concurrently than when evaluated in isolation. The relationships between TIE and TKS as well as TSOG and TENA have been discussed here, but will require further work to generated validity evidence for these conceptualizations. In addition to the temporal analysis conducted here, it is possible to generate indices of association for different process variables for each team (Gottman & Roy, 1990). These indices can then be used in standard regression analyses and potentially combined with functional measures of team process to explore these types of complex inter-relationships. For example, metrics of information exchange could be developed from the overall amount of information exchanged in conjunction with the temporal association of information exchange statements with acknowledgements. This would then represent both the amount and structure of information exchange in a team.

Greater Conceptual Clarity around Externalziation

While the scaffolding metaphor of externalization seems to be the most appropriate fit for understanding how external representations influence team processes, this alone does not allow for detailed predictions of how these representations will influence the interaction patterns of team members. Some of the strongest differences in the interaction-based analysis were between high and low ERQ groups, not high and low

performance groups. However, many of these differences are not interpretable using the conceptual tools adopted in this study (i.e., content matching / disparate representations, and scaffolding vs. off-loading). ERQ does influence how teams interact, but the specific nature of this influence and how it is translated into performance outcomes is unclear. A range of scientific disciplines have been struggling with this issue for some time, and little progress has been made. In addition to the overall moderating relationship proposed in the Macrocognitoin in Teams Model, an interaction-based conceptualization of externalization would be extremely useful, though generating such a conceptualization is no small task.

Externalizations of the Full Range of Knowledge Building Content

As discussed above, the collaborative tool used in this study constrained team members to passing text-based information and consequently constrained the analysis to externalizations of information. Future work should investigate the nature externalizing the full range of team knowledge building content and allow for representations beyond text (e.g., graphical and iconic).

Fine Grained Interaction Analysis

The preceding analysis used six categories to capture a very complex pattern of interaction. It is likely that more detailed analysis of the interaction of teams will provide insight into team knowledge building processes. However, increasingly detailed coding of communication poses several methodological challenges including building and maintaining reliability of the coding process as well as meeting the data requirements for

different analysis techniques. More coding categories means rapid inflation of required sample sizes for temporal analysis techniques such as multi-way frequency analysis. However, follow up analyses can be conducted on the existing data set by expanding and collapsing codes. For example, the structure of information requests and provisions can be investigated, or differences in the structure of regulation processes (e.g., goal specification, task allocation, situation updates).

CHAPTER SIX: CONCLUDING REMARKS

This study represents one of the first attempts to systematically evaluate the team process and externalization components of the Macrocognition in Teams Model. Findings suggest that team knowledge building processes have a complex relationship with performance outcomes with some processes positively and some negatively related to effectiveness and others being best characterized as having curvilinear relationships. Additionally, there were indications of complex interrelationships between team knowledge building processes, both on an aggregate level as well as in terms of the sequence of these process behaviors. In sum, a simple positive linear model conceptualization of the relationship between team processes and outcomes may be overly simplistic in macrocognitive contexts. Moreover, external representations influenced both the sequence of team knowledge building processes as well as the relationship between these processes and performance outcomes. While the specific predicted moderating effects of externalized knowledge on processes and outcomes were not supported, there was some evidence for a moderating relationship when a composite metric of team knowledge building processes was used. However, this is a post hoc finding in need of further evaluation. In total, these findings provide some initial validation of components of the Macrocognition in Teams Model and highlight areas in need of further conceptual specification and empirical confirmation.

APPENDIX A: EXPERIMENTAL PROTOCOL

MURI NANDOR Procedure

Before the participant arrives

- Make sure all computers are on including all participant, eye tracking, and experiment computers.
- Turn on the keyboards, mice, and left and right monitors of all 3 participant stations, as well as the experimenter stations.
- Turn on the projector with the remote located on the experimenter station. To turn on the remote hold down the power button until the blue lights on the projector light up.
- Make sure that the Perfect Keyboard program is running on the Master Control Computer and is running in the toolbar on the participant computers.
- Test that the audio is working (see audio setup below). If it is not picking up anything, restart the master control computer.
- Turn on the external audio cards
  - In the stations beside each participant station, there is an E-MU external sound card in the side cabinet. Turn this on (there is a power switch in the back) and press the following two buttons:
    - In the upper middle of the box under 'Direct Monitor,' push the top button so that the red light switches from 'off' to 'Main'
    - On the lower left of the box under 'Mic/Hi-Z/Line' click the button so that the red light by '48v on' lights up.

When the participant arrives

Escort participants in and assign them to one of the three roles according to the random assignment sheet. Have the participant turn off their cell phone and ask to see their ID to make sure they are 18 or older.

Seat the participants at their stations based on the role they were assigned to, and ask them to fill out the informed consent.

"Thank you for coming today. Before we get started please turn off your cell phones and put away any food or beverage that you may have. To ensure that you are legally old enough to participate in this study, please take out some form of Identification. Also, please read and sign the informed consent form."

Make sure all participants were born before 1991.

"My name is _____ [introduce any other experimenters in the room] and I will be running this study for the next four hours. As you will be working together as a team for this study, please introduce yourselves to one another.

Today, you will be participating in a Multi-University Research Initiative. For this study, you will be asked to imagine that you are members of a three person Navy team engaging in planning activities. You and your teammates have been randomly assigned to one of three roles. The roles and your task will become clear to you as the study gets under way.. I'll be giving a briefing on the session shortly, but before we begin, please fill out the questionnaire on the computer in front of you. The purpose of this questionnaire is to collect some basic information about you."

Write down the team information on the log sheet. Collect the informed consent and load the pre survey by running the 'Survey_Demographics' macro. This survey includes: Basic demographics, Familiarity scale, Vision Check, Short version of the Big Five, and Computer experience information.

When all participants are done, close the survey windows by either running the 'Survey_shutdown' macro or asking participants to close the Internet Explorer window. Then, read the following:

"This study consists of three main parts. First, you will receive some individual training on the task, your role, and the computer interfaces you will be using. Second, you will train together as a team on two practice operations with help from the facilitators. Third, you will work together to plan three operations with no help from the facilitators. You will be asked to fill out some surveys along the way."

"Now we will start the task training. Your first block of training is an overview of the task. Next, you will be given training that is tailored specifically to your role. Then, you will learn how to interact with the computer interface. Feel free to ask a facilitator if you have any questions along the way. We will now begin the general training. Please look at your individual screens. "

Run the 'Training_General' macro on the Perfect Key Program of the Master Control computer.
"When you are ready, click the next button on the bottom of the screen. Raise your hand when you are done and wait quietly for the others to finish."

Wait for everyone to be done. Close the General Training by running the 'Training_shutdown' macro. Then read the following:
"Now you will learn more about the background information about your task. Please look at the collaborative screen now."

On the Right Experimenter computer, click on the News Clip Video located in slides for experiment folder titled "Shortcut to VTS_01_1".

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When that is finished, load the 'Training_Role' Macro from the Perfect Key Program and read this:
"Now you will begin your role specific training. This will take place on your individual computers on the left monitor. After reading about your role, there will be a short quiz. Please raise your hand when you have finished the training."

When they completed the role specific training, 1) shutdown the PPT by running the 'Training_shutdown' macro, 2) launch the role quiz by running the 'Survey_Role_Quiz.' Read the following:
"You will now take a short quiz on the training you have just received. Please do the best you can and let me know when you have finished."

While the participants are doing the quiz, start setting up the practice mission.

To load the practice operation, do the following:

1.) Open Muri Master control by clicking the icon on the desktop
2.) Click 'Setup'
-Choose Mission #
  -Do not touch 'Number of operations' or 'Initial Operation' (They should be at 1)
  -Operation 0 will be mission 0, operation 1 will be mission 1, etc
-Set 'Instantiated Resource File Folder' path to correspond to the Operation # you want to run
        -Click 'Set'
        -Go to 'Active Scenarios on UCF Datavault (Drive T:)
        -Go to NANDOR_SCENARIO
        -Select Instantiated Resource file that corresponds to the operation you want to run
-Click 'Ok' on the setup window
3.) Select 'Start Mission' in the master control window (wait for the 'Start Operation' button to become active)
4.) Open the 'Create Resource table' by clicking the icon on the desktop
        -Change the last 2 digits of the IP address to '80' (in Psychology) or '120' (in PII)
        -Click 'Set and Test Connection String'. (The red circle should turn green)
        -Click 'Clear all Records' (Boxes will pop up. Click 'yes, then 'ok')
        -Click 'Create table' (Boxes will pop up, click 'OK' on each)

Once everyone has completed the quizzes, you can close the survey by 1) running the 'Survey_shutdown' macro, or 2) asking participants to close the Internet Explorer window. Then, read this:
"You will now be guided through the use of the computer interfaces. You will have a chance to practice using both the map and role entry interface. Please look at the collaborative screen for a step by step guide. Follow along on your own computers and please ask the facilitator if you have any questions along the way."

Start the Interactive Training on the right experimenter's computer located under "Map & interface training 9.0". Start the practice mission (see below.) Walk around and make sure the participants know how to use the interface (make sure they complete each of the steps). To load the practice operation, do the following:

1.) Open 'Perfect Keyboard' by clicking the icon on the desktop
-Select the 'Launch-op#' corresponding to the operation you want to run
-Then click 'Run Macro'
-Check to make sure that the resource planner and map have opened on each computer (these need to be running before you start the operation)
2.) Click 'Start next operation' in the master control window

After they have completed the operation, stop the practice operation using the following steps:

1.) Click 'Stop Operation' in the master control window
2.) Open the evaluator by clicking the icon on the desktop

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-Click the circle on the lower left of evaluator window, and then click the red 'Change settings' button.
-Go to the 'List of roles file location' line and click the browse button.
-Select 'listOfRolesOp0.xml' and click 'open.'
-Click 'Done' on the Evaluator setup screen.

-Back in the Evaluator window click 'Evaluate' (boxes will pop up. Click 'OK' on each)
-After the plan has been evaluated successfully click the big Blue button: 'Clear Scribe for next operation' *(this is necessary to clear the scribe entries for the next mission)*
3.) Click 'Stop Mission' in the master control window
4.) Go to File\ Exit
5.) Start over from the beginning with the next operation

Ask if there are any questions after the hands on training is complete.

Launch the Card sort by running the 'CardSort' macro, and read the following:

Wait until the card sort program has launched and then give them instructions:

"Senior Officers are looking to gauge how individuals perceive the resources you've been working with. You will have 10 minutes to sort these resources into piles which you feel categorize them the best. You will create categories by grouping 'cards' (i.e, the resources) into piles. To do this, you will use the program on your computer screen now. To create categories:

1 Create a Pile by clicking the LOWER Green Plus Sign
2 Name the Pile (they can leave it as PILE 1 initially and rename it)
3 Click, hold and drag the pile onto the grey area
4 You can Double Click on the cards to see images and learn more about the resources.
5 Click, hold, and drag cards to the piles you create. You can make as many piles as you want, but you must USE ALL of the cards
6 You can name the piles whatever you want, but not to add any comments inside the card."

After instructions are read, walk around the room to make sure that the participant is not deleting cards or added pictures instead of piles

After ten minutes, save all of the card sorts on the participant computers. Check before you save that each pile has its own name (not pile 1) and that no pictures were added (scroll down on in the picture column. the last pic should be US infantry)

Go to:

- File

- Save as

- Desktop

- Cardsort program

- Cardsort data

- Save as: Team###_Role_Pre (/Post)

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Scored Cardsort By:

Go to:

- Action
- Score (The Scoring box will open)
- Save
- Desktop
- Scored Cardsort Data
- Save with the same name that the file was previously saved as.

Allow the participants to take a 5 minute break before the actual experiment.

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Preparing for Actual Experiment

Microphone Setup

Place the audio mic headset on the participants. The tip of the microphone should be pointed at the corner of the participant's mouth.

Eye Tracking Setup

Press the left button on the left participant monitor until the screen reads "Analog input" and you see the eye tracking desktop on the screen. Also toggle the USB switch so that the light on the right is on.

Double click *Viewpoint* icon on the Desktop of the participant computer and check that eye tracker is working.

"You will now be equipped with an eye tracker device. The following process should only take a few minutes. The eye tracker consists of goggles with a camera attached. You will first put on the goggles as you normally would put on a set of sunglasses. It will not hurt your eyes or affect your vision in any way. I will then have you look at several locations to calibrate the goggles. Calibration will only take a few minutes. Once calibrated, you can move your head freely and look around as you would normally. Do you have any questions?" If they have long hair, ask them to put in a pony tail or pull hair back so glasses can rest on ears.

1. Begin physical setup
   - Put on eye tracker cord holder around waist, to the right hip.
   - Have participant sit in the chair in a comfortable position facing forward and close to the monitor in front of them.
   - Have participant put on goggles.
   - Tighten head strap snuggly. Make sure strap is snug, don't be scared to tighten strap. Ask participant to let you know if it is too tight.
   - Clip cord to back of shirt, preferably the shirt collar. Make sure there is enough slack to allow head movement. Make sure any loose cord is located behind participant, so their arm movements aren't restricted and they don't get tangled.
2. Adjust eye camera if needed.
   - Move eye camera so that pupil is centered and eye fills eyespace window on viewpoint (should barely see upper and lower eyelid)
   - The camera should be parallel to pupil at a slight angle pointed up.
   - Adjust light so that it shines directly on pupil.
3. Change gaze space window to head mounted scene camera
   - *Click stimuli > view source > head mounted scene camera*
4. Adjust scene camera to make sure the camera is capturing the monitors
   - Ask the participant to look at the center of the left monitor
   - Adjust top camera on goggles so that object in forward field of view is centered in eye gaze window.

"I will now be calibrating the eye tracker. During this process please keep your head forward and as still as possible until I tell you to move. I will be asking you to focus your eyes on the green boxes as they appear on the screen. Please remember to only move your eyes and to keep your head as still as possible. Any questions?"

5. Click "Auto-calibrate" on the lower left hand corner of the ViewPoint software.

Check calibration box so that all lines are fairly straight, even, and of equal size. The grid should look like a box.
   - Repeat auto-calibration until there is a clear defined box.

Once calibration is accurate and complete, tell the participant they can now move their head freely.

6. Double check calibration by having participant look at the top/bottom/left/right side of the monitor. Make sure participant moves head naturally while looking at objects.
   - If dot is not following what the participant is looking at, repeat calibration. Note: some degree of error is acceptable as long as it is consistent (e.g. dot always a few inches below focal point). Use your best judgment.
7. Start recording eye tracking data.
   - Click *File > Data > New data file > My computer > Role (e.g. Air vehicle 1 or Land/sea 2)*
   - Save to: External hard drive, under the team folder
   - Save as: Team<xx>_Role<xx>_Date
   - Click *Save*
9. Toggle USB so that the light appears on the left side.
10. Push the left button on the monitor until it reads "digital input"

Audio Setup

1. Go to the audio computer. (Left experimenter station in Psych, Right in PII)
2. Double click the 'Cubase Essentials 4' icon to open the Cubase LE software.
3. From the 'File' menu, select 'New Project'. The 'New Project' Window will open up.
4. Highlight the '4 Chanel MURI' option.
5. Click 'OK'. The 'Select Directory' Window will open up.
6. Locate the 'Local Disk (C:)', and within that folder, highlight the 'Audio Recording' folder'.
7. Click the 'Create' button (Careful to hit 'Create' and not 'Ok'). This will create a new folder within C:/Audio Recording.
8. **Select the team's mission folder.**
9. Click 'OK'. Cubase will now launch a project (containing 4 tracks).
10. Before hitting record, you must make certain that all 4 tracks are highlighted (light gray). To highlight all 4 tracks press and hold down Ctrl then click on the 4 tracks. If the tracks are not highlighted, you will record audio for only a portion of the microphones.
11. Also make sure the 🔴 button in each track is highlighted red.
12. Hit the red Record button (button represented with a filled in circle) located on the top bar.
If the audio isn't working, restart the audio computer

Video Setup

1. Open 'DVR Server' on Desktop on Video Computer on top of the Server
2. If you're not already in the view that shows all the cameras, click the 'Split Screen' tab at the bottom of the screen, and choose '9 split'

To Record:
3. Highlight camera 1 and then click 'Man Rec.' at the bottom right side of the screen.
4. There will be a short delay before the recording will begin. Once it begins it will be indicated by a small box that appears on the upper right hand side of the camera view.
5. Continue this step for cameras 2-6, one at a time, until all of them are recording. Once you have begun recording on all cameras, write down the timestamp.

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Beginning the Mission

After the eye tracker, audio, and video setups have been completed, you are now ready to start the mission.
"You will now begin the actual task. You will be planning three operations without any help from the experimenter. If you have any questions, please ask now. After this point, I can no longer provide information about what to do. Please look at the collaborative screen for your first operation briefing."

Click on **Operation 1** on the audio right computer located under slides for experiment, operation ppt, mission briefing to load it.

Complete the following steps for EACH OPERATION.

Run the operation briefing. While they are watching the PowerPoint, open the master control on the experimenter station:
1.) Open Muri Master control by clicking the icon on the desktop
2.) Click 'Setup'
-Choose Mission #
   -Do not touch 'Number of operations' or 'Initial Operation' (They should be at 1)
   -Operation 0 will be mission 0, operation 1 will be mission 1, etc
-Set 'Instantiated Resource File Folder' path to correspond to the Operation # you want to run
      -Click 'Set'
      -Go to 'Active Scenarios on UCF Datavault (Drive T:)
      -Go to NANDOR_SCENARIO
      -Select Instantiated Resource file that corresponds to the operation you want to run
-Click 'Ok' on the setup window
3.)Select 'Start Mission' in the master control window (wait for the 'Start Operation' button to become active)
4.)Open the 'Create Resource table' by clicking the icon on the desktop
      -Change the last 2 digits of the IP address to '80'
      -Click 'Set and Test Connection String'. (The red circle should turn green)
      -Click 'Clear all Records' (Boxes will pop up. Click 'yes, then 'ok')
      -Click 'Create table' (Boxes will pop up, click 'OK' on each)
5.) Open 'Perfect Keyboard' by clicking the icon on the desktop
      -Select the 'Launch-op#' corresponding to the operation you want to run
      -Then click 'Run Macro'
      -Check to make sure that the resource planner and map have opened on each computer
6.)Once the participants are ready to begin the task, click 'Start next operation' in the master control window

They will have 40 minutes for operation one and 25 minutes for operations 2 and 3. Let them know when they have 10 minutes, 5 minutes, and 1 minute left in each operation.
"Your operation starts now. You have XX minutes to complete it, and I will give you ten, five and one minute warnings."

Once they have finished the task, tell them to press the red 'Submit Plan' button, and do the following:

- Press the 'End Operation' button on the master control (DO NOT push end mission yet).
- Run the 'shutdown_all' macro to close the participants' interfaces.
- Close the collaborative map.
- Stop Audio recording; play forward about one second, and stop again (so that there is a little gap in the recording files shown).

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Launch the AAR survey by running the 'Survey_AAR' macro and read the following:
"Please look at your left monitor and complete the following survey quietly as individuals. Use as much detail as you can, but you will have only five minutes to finish. Remember that you are team number ### and you have just finished operation number ###." "

When everyone has completed the AAR, run the 'Survey_Shutdown' macro to close the explorer window and them run the 'Survey_TeamKnowledgeBuilding' macro, and read the following:
"Please complete the short survey about your team's performance on the previous operation."

1.)Click 'Stop Operation' in the master control window (if you haven't already)
2.) Open the evaluator by clicking the icon on the desktop
      -Click the circle on the lower left of evaluator window, and then click the red 'Change settings' button.
      -Go to the 'List of roles file location' line and click the browse button.
      -Select the list of roles file for the operation you just ran and click 'open.'
      -Click 'Done' on the Evaluator setup screen.
      -Click 'Evaluate' (boxes will pop up. Click 'OK' on each)
      -After the plan has been evaluated successfully click 'Clear Scribe for next operation' (big blue button).
3.) Click 'Stop Mission' in the master control window
4.) Go to File\ Exit
5.) Start over from the beginning with the next operation

Feedback:

After the surveys are complete and the evaluator has run,

1) On the Left Experimenter's computer, open the 'Feedback Links' folder on the desktop.
2) Click on the link for the operation you just ran (e.g., feedback Op 1).
3) Enter the team number and click submit.
4) Wait for the page to load and then maximize the window on the collaborative screen and review the cost, time, violations, and objectives feedback with the team.

==Repeat the above steps for every operation.==

After the final operation:
Launch the Card sort by running the 'CardSort' macro, and read the following:
"Senior Officers are looking to gauge how individuals perceive the resources you've been working with. You will have 10 minutes to sort these resources into piles which you feel categorize them the best. You will create categories by grouping 'cards' (i.e, the resources) into piles. To do this, you will use the program on your computer screen now. To create categories:

1   Create a Pile by clicking the LOWER Green Plus Sign
2   Name the Pile (they can leave it as PILE 1 initially and rename it)
3   Click, hold and drag the pile onto the grey area
4   You can Double Click on the cards to see images and learn more about the resources.
5   Click, hold, and drag cards to the piles you create. You can make as many piles as you want, but you must USE ALL of the cards
6   You can name the piles whatever you want, but not to add any comments inside the card."

After ten minutes, save all of the card sorts on the participant computers using the following format:
Team###_Role_Post

After the Missions are Completed

- Take the eye tracker and the mic headset off of the participants and save and close the eye tracker program.

- In Viewpoint on the eyetracking computers from the file menu select 'Close Data File'. Then Exit Viewpoint.

- Audio:
  - click the Stop button (if not already stopped at the end of the operation).
  - Once the recording is stopped, from the 'File' menu, select 'Save As'.
  - Name the project: team###_ Date
  - Once saved, close the project.
- Video: Highlight camera 1 and then click 'Man Rec.' at the bottom right side of the screen. There will be a short delay before the recording will end. Once it ends the small box in the upper-right hand side of the camera view will disappear.
  - Once you have stopped recording on camera 1, write down the timestamp.
  - Continue this step for cameras 2-6, one at a time, until all of them stop recording.
  - Files are automatically saved under D:_RecordFile_*YYYYMMDD* (YearMonthDay)

Hand out debriefing form and ask if there are any questions.

After the Participant Leaves

- Turn off the left and right monitor of all 4 participant stations, as well as the experimenter stations
- Turn off the projector with the remote located on the experimenter station by clicking the power button two times.
- Turn the keyboards off and place them upside down on the desks
- Put the mice on the chargers to the right of the monitors.
- Turn off the external audio cards (E-MU boxes).
- Shut down the master control computer.
- <u>Switch out Hard drives and Compress Video files.</u>

1. At the end of the day, switch the hard drive on each computer with its partner drive. (check first to see if the file conversion of the previous day has finished. If not you'll have to wait to switch the drives convert new files).
   - The drive at the Air vehicle station (#1) is to be switched out with the drive at station #2
   - The drive at the Land/sea station (#3) is to be switched out with the drive at station #4
   - The drive at the Personnel station (#5) is to be switched out with the drive at station #6
   - Note: the drives are all labeled by role (e.g. personnel 1 and personnel 2)
2. At stations 2, 4, and 6 open WinFF on the desktop, and do the following on each computer.
3. Click the 'Add' button in WinFF
4. Choose the most recent file that has been recorded within the external hard drive and click 'open'
5. Under 'Convert to...' make sure 'MP4' is selected. Device Preset should be (4:3). Output folder should be the external hard drive (labeled by role e.g. air vehicle 1).
6. Click the 'Convert' Button.

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APPENDIX B: COMMUNICATION CODEBOOK

MURI-SUMMIT COMMUNICATION CODE BOOK

Information Exchange
- Information provision (IP)
- Information request (IR)

Knowledge Sharing
- Knowledge provision (KP)
- Knowledge request (KR)

Solution Option Generation
- Option Generation-Part (OG-P)
- Option Generation-Complete (OG-F)

Option Evaluation and Negotiation
- Solution Evaluation (SEval)

Process and Plan Regulation
- Goal and Task Orientation (GTO)
- Situation Update/Request (SU/R)
- Reflection (R)

Basic Codes
- Simple agreement/disagreement and Acknowledgement (S)
- Incomplete/Filler/EX (INC/F/EX)
- Tangent/Off-task (T/OT)
- Uncertainty (UNC)

Code:	IP—Information Provision
Brief Definition:	Utterances containing facts about the task environment or situation— <u>simple information</u> that can be accessed from one source in the displays and 'one bit' statements.
Full Description:	IP statements always *provide* simple information. <u>Simple information</u> is 1) a fact that can be directly *read from one place* in the information displays or reference sheets in the task, or 2) a 'one bit' statement of task information (e.g., a waypoint, a resource, etc). In these statements, there are is no integration, analysis, or evaluation of the information in the actual utterance.
When to use:	*Use IP* for any statements where someone is giving information that can be pulled from one place in the displays. It does not matter if the person is reading from a display or recalling it (i.e., they remember someone else's role information or their own from a previous time), statements of simple information should always be coded as IP. *Use IP* codes for utterances when someone repeats information aloud (e.g., when talking to self) several times. *Use IP* for 'one bit' statements of task information (e.g., a waypoint, a resource, etc.). It does not matter if this 'one bit' statement requires complex analysis to provide, as long as there is no complex info in the statement. *Use IP* when someone responds to a statement with the same information (i.e., an echo of an IP statement). *Use* IP when people are providing information about the location of places (e.g., waypoints, grid cells) on maps (e.g., 'it's right there').
When not to use:	*Don't use IP* when the statement is complex in nature (that is, it integrates information from different sources) or it provides an evaluation of information (i.e., provides an opinion/evaluation of how good or bad the information is relative to the operation goals). *Don't use IP* when someone is providing simple information across a set of resources. For example, when summarizing intelligence reports across a number of difference grid cells (e.g., 'all of those have good weather'), or when summarizing an ability for a set of resources (e.g., 'none of my ships can go in severe weather').

Don't use IP when someone is stating a goal. This information can be read directly off of the cards; however, we are coding goal statements as GTO, not IP. Statements about other things from the objective's sheet (e.g., the location of the refugees) are IP statements.

Don't use IP when the utterance is a question.

Examples:

Positive Examples	*Rationale*
"I have UN workers at A3a."	The Personnel & Supply specialist can search by waypoint and read this information directly off of *one source in* the display.
"Severe weather in B3 so..."	This information can be read directly off of one weather report.
"The refugees are at B4f."	This information can be read directly off of the operation objectives.
"B4h"	This statement is a 'one bit' utterance of task related information so it is coded as IP.
"B4 is down there"	Use IP when people are simply talking about where things are physically located on a map.
Negative Examples	*Rationale*
"There's good weather in all of those areas."	In order to make this statement, multiple weather reports need to be accessed. It is therefore integrative and would be coded as KP.
"Like I only have like 1 helicopter that can pick up people like out of the water. "	This statement refers to resource abilities, but not to one specific resource. It required an evaluation of many resources' capabilities (i.e., out of all of the resources, there is only one with that ability). As such, the correct code for this statement would be KP.
"So 2 translators need to arrive at the chosen area"	While this information can be read off the reference sheets, this statement is clarifying the operation objectives. The correct code for this would be GTO.

Code:	IR—Information Request
Brief Definition:	Question utterances asking for a response of <u>simple information</u> about the task environment or situation, or questions asking for repetition of immediately preceding information.
Full Description:	IR utterances always ask a question that requires simple information to answer. <u>Simple information</u> is a fact that can be directly read from *one place* in the information displays or reference sheets in the task. It does not require that the person sending or receiving the information perform any type of integration, analysis, or evaluation of the information. It's as if someone is asking someone else to perform a simple look up task. Additionally, IR utterances can be specific or general requests for clarification of immediately preceding information.
When to use:	*Use IR* for any question utterances where someone is asking for simple information. It does not matter if someone responds with more complex information (or even if no one responds at all). You need to determine whether or not the response to the question can be read off of one of the displays or requires more integration/evaluation.
	Use IR for specific and general questions asking for repetition or simple clarification of previous statements. General requests include things such as 'Pardon?', 'What was that?', etc.
	Use IR for all requests to the experimenter for intelligence reports, even if not stated as a request but a command statement.
	Use IR when people are asking for information about the location of places (e.g., waypoints, grid cells) on maps.
When not to use:	*Don't use* IR for statements, only questions.
	Don't use IR for questions that require a complex or evaluative response. These will likely be coded as KR—Knowledge Request.
	Don't use IR for questions about how to use the interfaces or displays. These will be coded as KR as they require knowledge that isn't accessible from the displays themselves.
Examples:	*Positive Examples* — *Rationale*
	"How many refugees — The response to this question can be found

do we need to pick up?"	directly in the operation objectives.
"Can your landing craft go in severe weather?"	The response to this question can be found in one place on the information displays under resource capabilities.
"How many people does a survival pallet support?"	Information needed to directly answer this question is accessible from one spot on a display under abilities and limitations for survival pallets.
Air: "I have a sea dragon on your boat." *Land & Sea:* "On my boat?"	The Land & Sea utterance is IR because it is asking for clarification about the previous statement.
Air: "Do you have anything at B1a?" *Land & Sea:* "Me?"	The purpose of the Land and Sea specialists' statement, similar to the previous example, is to clarify information.
"Medical supplies are at C4h?"	The personnel and supply specialist only needs to look in one location in order to answer this question.
"Where's B4?"	This person is asking for simple information about where a grid cell is on the map.
"Can we get weather forecasts for B4 and B3?"	Requests to the experimenter for weather, no matter which reports or grids are asked for, are coded as information request.
Negative Examples	*Rationale*
"Do you have anything that can make it to B4h?"	In order to respond to this question, the person would have to look at durations left and calculate the distance; this information is not accessible from one place in the display and therefore would be coded as KR.
"Is there anything down there in B5?"	In context, this statement is asking if there are any resources that will meet a specific objective in the area. In order to response, the team member will have to look across different waypoints and assess the capabilities of resources at those waypoints. The answer cannot be pulled from one place in the display and consequently this statement would be coded as a KR.

Code: KP—Knowledge Provision

Brief
Definition: Statements about the task environment or situation that provide either 1) an <u>integration</u> of more than one pieces of simple information, or 2) an <u>evaluation</u> or <u>interpretation</u> of the meaning, value, or significance of information within the current operation.

Full
Description: KP statements are similar to IP statements; however, instead of providing simple information, they provide <u>complex information</u>. In contrast to simple information, <u>complex information</u> involves either 1) integrating information in a way such that the product of that integration is something not directly accessible from the information displays (i.e., they combine information to create something new that can't be read directly off of one of the computer displays), or 2) providing an evaluation of information in the displays relative to the team's goals (i.e., they comment on the meaning or value of simple information).

When to use: *Use KP* for any statements where someone is providing complex information.

Use KP statements for 'anti-option' statements—statements that describe what the team <u>cannot</u> do in a general sense.

Use KP (and KR) for utterances about the use of interfaces. For example, "How do I make a pushpin again?" and "Do I start at 00:00 everytime?" are KR statements. The responses to these questions are typically KP statements. On the other hand, "Where are my susceptibilities?" and "My pushpin won't close" are not KP/KR statements because they involve simple information that is easily accessible from one screen. The first example would be coded as IR and the second example would be coded as SU/R because its purpose is to update the team on their current difficulties.

Use KP (and KR) for utterances discussing whether or not a resource will pass through a specific grid cell (KP or KR depending on if it is question or statement). These statements are basically making sense of interface issues so will fall under the general rule of: if it's about understanding the interface, its KP/KR.

Use KP (and KR) for utterances about contingencies in information (e.g., if this is true, then it means X). These are basically discussing interpretations of meaning of information, but not specific options or evaluation of options.

Use KP (and KR) for utterances where team members are discussing (amongst themselves) what they are and aren't allowed to ask for from the experimenter.

When not to use:	*Don't use* KP for questions, only statements.
	Don't use KP for simple information statements.
	Don't use KP for statements that propose a specific action to be taken. KP statements will be declarative or evaluative in nature (i.e., they provide facts, information, and evaluations).

Examples:	*Positive Examples*	*Rationale*
	"We're gonna need 2 medical pallets to take care of the refugees."	The number 2 could not be read off of the computer interface; only the number of refugees and the number of people 1 medical pallet supports is accessible from one location on interface. The participant calculated the number 2 and math involves an integration of information.
	"My ship can't make it that far."	This involves <u>integrating</u> information about the ship's capacity and the distance to be traveled. It is also an 'anti-option.'
	"Rebel activity in B4 would not be good."	This provides an <u>evaluation</u> of information in the task environment.
	"You can't get anything there because there is bad weather."	This statement provides an 'anti-option' by <u>integrating</u> weather conditions with vehicle limitations.
	"So goin on that the majority of Ethos would be safe if that's where they were trying to go in the first place."	This provides an evaluation or interpretation of information provided in the operation briefing.
	"Yeah you're going to have to go by air"	This provides a synthesis and evaluation therefore it is KP. It is heading in the direction of an option, but it is too general and does not meet the criteria of either of the OG codes.
	'but you know. Just a little ambiguity on what route is being taken I think.'	This utterance is commenting on the difficulty assessing what grid cells a vehicle will pass through. It is about interface problems and therefore a KP.
	'That's not fair because I don't know	Same as above

what way I wanna fly I don't know if I wanna go through D3.'

'so… if there… any of that goin' on in the way we're gonna have to watch out for that.'	This is a 'contingency' in the information and an evaluation of the meaning. It isn't a GTO because it isn't something the team needs to do, but something they 'may' have to do if circumstances arise.
"We can't ask them [the experimenter] how to check that"	This is commenting on what they can or can't ask the experimenter for.
Negative Examples	***Rationale***
"I can take the medical supplies to C4h"	This statement is integrative in nature, but it proposes a specific action and therefore would be coded under the option generation codes, specifically, OG-F.
"We should have checked for weather before moving anything."	This statement is evaluative in nature, but it is commenting on the team's past performance and process; therefore, it would be coded as R.

Code:	KR—Knowledge Request

Brief Definition:	Question utterances that request a complex information response about the task environment or situation: to answer the question, the response should provide either 1) an <u>integration</u> of more than one piece of simple information, or 2) an <u>evaluation</u> or <u>interpretation</u> of the meaning, value, or significance of information within the current operation.

Full Description:	KR utterances always ask a question that requires a complex information response about the task environment or situation. In contrast to simple information, <u>complex information</u> involves either 1) integrating information in a way such that the product of that integration is something not directly accessible from the information displays (i.e., they combine information to create something new that can't be read directly off of one of the computer displays), or 2) providing an evaluation of information in the displays relative to the team's goals (i.e., they comment on the meaning or value of simple information). It does not matter if someone responds with simple information (or no one responds at all). You have to determine whether answering the question requires integration or evaluation of information or not.

When to use:	*Use KR* for questions requiring complex information responses (integration, evaluation, analysis).
	Use KR for questioning/clarifying the *meaning* of operation objectives.
	Use KR for utterances questioning what else is needed to complete an objective (e.g., "what else do we need?").
	Use KR for general requests for resource information (e.g., 'do you have anything around B4?').
	Use KP (and KR) for utterances about the use of interfaces. For example, "How do I make a pushpin again?" and "Do I start at 00:00 everytime?" are KR statements. The responses to these questions are typically KP statements. On the other hand, "Where are my susceptibilities?" and "My pushpin won't close" are not KP/KR statements because they involve simple information that is easily accessible from one screen. The first example would be coded as IR and the second example would be coded as SU/R because its purpose is to update the team on their current difficulties.
	Use KR (and KP) for utterances discussing whether or not a resource will pass through a specific grid cell (KP or KR depending on if it is question or statement). These statements are basically making sense of

interface issues so will fall under the general rule of: if it's about understanding the interface, its KP/KR.

Use KR (and KP) for utterances where team members are discussing (amongst themselves) what they are and aren't allowed to ask for from the experimenter.

| **When not to use:** | *Don't use* KR for statements, only questions. |
| | *Don't use* KR for questions requiring simple information responses. |

Examples:

Positive Examples	*Rationale*
"You've got distance concerns with your vehicles?"	This isn't asking for a specific vehicle's limitations, but a more general evaluation of issues with distance.
"So what do we have close to C5 we can use?"	This response would require at a minimum multiple pieces of simple information and is asking for an evaluation of the utility of whatever is there.
"Are there any ships or vehicles around there?"	This asks for information that cannot be accessed from one specific spot in the interfaces.
"So does it matter if we get the supplies there before the people?"	This statement is asking for clarification of the operation objectives and would be KR.
"How many UN workers do we need?"	The response to this question requires the integration of information that is found in two different location.
'Are we allowed to ask for time?'	This utterance is asking about what information is available from the experimenter.
Negative Examples	*Rationale*
"Can your landing craft carry 10 cargo units?"	This is asking for a specific piece of simple information that can be pulled from one place in the displays. The correct code would be IR.

Code: OG-F—Option Generation - Full

Brief Definition: Statements explicitly proposing a complete or near complete solution— a sequence of actions intended to meet a given operation objective. A complete solution includes locations, resources, and vehicles except for solutions proposed for objective 2 (finding a safe location).

Full Description: OG-F utterances propose a complete or near complete solution. A solution is a set sequence of actions intended to meet one of the operation objectives. A *complete* solution includes three main components: 1) locations (i.e., where they are moving things from and to), 2) a vehicle (i.e., what they are using to move things), and 3) a resource (i.e., what they are moving). To be coded as OG-F, the utterance should include reference to at least two of these things.

OG-F statements are generally action statements that involve moving resources (e.g., "I can take the refugees to the base with my helicopter"). Consequently, OG-F statements generally refer to something that could be entered in to the 'Plan Entry Box' of the interface. An exception to this involves objective #2, finding a safe location for the refugees. To meet this objective, resources do not need to be moved. Team members must just select a location. OG-F statements can be stated as questions. For example, "why don't you take the medical pallets, and then I'll take the survival pallets on my boat?" is proposing an option to the group. The key for OG-F statements is that they 1) refer to moving resources, and 2) involve a sequence of actions to meet an operation objective (with the exception of objective #2).

When to use: *Use OG-F* for any sequence of actions for addressing one of the operation objectives and containing at least two of the option components (i.e., destinations, vehicles, resources) specified explicitly.

Use OG-F for utterances proposing a specific waypoint for a safe base. Utterances proposing general areas to look for a safe base are coded as GTO (they are directing the team to explore a general area), and utterances proposing a general area (e.g., a grid quadrant) as a safe base are coded as OG-P.

When not to use: *Don't use* OG-F to code statements implying a sequence of actions where there are less than two of the option components (i.e., destinations, vehicles, resources) specified explicitly.

Examples:

Positive Examples	Rationale
"I can use that boat to pick up all of them."	This statement proposes both a vehicle (a boat) and resources (i.e., them) to be moved. Again, it is important to pay close attention to pronouns and the nouns that they reference. These are two of the three option components and therefore this would be an OG-F statement.
"You think you can get to A3a to get translators?"	This utterance is a question, but it is proposing a solution with two explicit components (location, and resource).
I'll pick up the translators with my Jeep	2 out of the 3 necessary components of an option are present in this statement

Negative Examples	Rationale
"A3 is good for a base."	This is not proposing a specific waypoint, just an area. Therefore it would be an OG-P utterance.
"Ok so I'm just moving to… B5a got it."	There is only one component of an option in this statement, a location, therefore this would be coded as OG-P.

Code:	OG-P—Option Generation - Part

Brief Definition:	Statements that provide an incomplete solution—a sequence of actions (i.e., moving resources) intended to meet a given operation objective— or ask for further refinement and clarification of a solution. This includes proposing a general area for a safe base.

Full Description:	OG-P utterances propose an incomplete solution. A solution is a set sequence of actions intended to meet one of the operation objectives. A *complete* solution includes three main components: 1) locations (i.e., where they are moving things from and to), 2) a vehicle (i.e., what they are using to move things), and 3) a resource (i.e., what they are moving). To be coded as OG-P, the utterance should include less than two of these solution components. OG-P statements are distinguished for OG-F simply by the number of solution components it references (i.e., destinations, vehicles, and resources).

When to use:	*Use OG-P* when the utterance proposes one of the three solution components (e.g., destinations, vehicles, resources) to meet an operation objective, but does not meet the requirements for an OG-F.
	Use OG-P when someone proposes a general area for a safe base (e.g., a grid cell, an island), but not a specific waypoint.
	Use OG-P when people are requesting or providing clarifications to a solution.

When not to use:	*Don't us OG-P* statements for utterances with more than one solution component.

Examples:

Positive Examples	*Rationale*
"You want to take them to C5?"	This statement proposes a general area for a base, but not a specific waypoint; therefore it would be OG-P.
Personnel: "I forgot we need two translators." *Personnel:* "There's only A3a, A3h, D2h and E2d"	The Personnel specialist's statement is proposing multiple locations, but this is only one of the three solution components (location). The resource is implied in this statement from previous utterances, but this statement on its own is OG-P.
Personnel and Supply:	The Personnel and Supply statement is an

"We can drop them off at the beach." *Land and Sea:* "Yeah well what beach the B5a?"	OG-F because it includes reference to a resource ('them' = refugees) and a location. The Land and Sea utterance is an OG-P because it is asking for further clarification of a solution.
"We're taking these guys to A3a, right?	This is asking for clarification of a solution component and therefore is OG-P
"I could use the Sea Stallion."	Again, an option involving only one component: the resource.
"So I could send 2 out."	This statement is proposing an option with only one component. While there is no pronoun, 2 refers to a resource.

Negative Examples	*Rationale*
"There's already 2 um Red Cross workers at a D2h which is already on Ethos."	This contains references to a location as well as resources and would be an OG-F.

| **Code:** | SEval—Solution Evaluation |

| **Brief Definition:** | Utterances that 1) compare different potential solutions on the basis of speed, cost, or ease of execution, 2) provide support or criticism of a single potential solution, or 3) ask for an evaluation of a potential solution. |

| **Full Description:** | Solution Evaluation (SEval) utterances support, criticize, or ask for an evaluation of an option. Support and criticism can be specific (e.g., 'B5a would be the fastest') or general (e.g., 'that's the best way to go') and can involve the direct comparison of different options or refer to a single potential solution. |

| **When to use:** | *Use SEval* when an utterance refers to the pros or cons of a solution option.

Use SEval when people are comparing two different solution options in terms of quality (i.e., cost, speed, ease of executing).

Use Seval for utterances giving a final confirmation of a solution option.

Use Seval for utterances where there is an option and an evaluation in the same utterance. |

| **When not to use:** | *Don't use SEval* to code statements where people are proposing, modifying, or clarifying options.

Don't use SEval for utterances that provide simple agreement or disagreement (i.e., S statements). SEval utterances provide more than just 'yes or no' type responses. |

Examples:	*Positive Examples*	*Rationale*
	"Um E2d is probably closer."	This utterance provides support for choosing a location to get resources from in terms of its location.
	"since you should be able to transport them on land that would be cheaper than flying them in."	This utterance provides a comparison between two different options.
	"Because if there's already 2 Red Cross workers there we	This provides support for an option (a location) by proposing it saves steps in brining other resources to that location.

don't need to transport."	
"A3h might be better though."	A comparison is being made. A3h might be better than some other location.
"The best for translator is D2h or E2d if any of you guys have something there."	This utterance provides support for a solution (a resources and location).
'Alright. So then yeah let's just take the uh the 1800 then. '	This is a final confirmation on a solution option.
"Or I guess we could do B5d cause that's closer	This is a solution option and an evaluation together. We are coding these as Seval.

Negative Examples	*Rationale*
"That sounds good"	This may be referring to a solution option, but it is not providing any substantive support or criticism. It would be coded as S because it is providing simple agreement with the proposed solution.

Code:	GTO—Goal and Task Orientation
Brief Definition:	Utterances directing the group's process or helping it do its work by proposing questioning, or commenting on goals for the group or specific actions team member's need to take to address a goal. These statements direct what the team should do next or later in the future. This includes self-references for an individual.
Full Description:	GTO utterances are about high-level goals—things the team needs to do—and things the team members need to do to reach these goals (i.e., tasks). Consequently, these are future-oriented statements. A high-level goal is equivalent to one of the five operation objectives, and tasks cover a broad range of things team members' need to do in order to complete these objectives.

GTO utterances include both providing and questioning the goals of the team. |
| **When to use:** | *Use GTO* for statements where the person is proposing/suggesting the group focus attention on completing one of the five main operation objectives.

Use GTO for utterances discussing an area <u>to look</u> for a safe location.

Use GTO for assertive or command statements (e.g., "Ok, can you find out X.")

Use GTO for self-directing statements (e.g., "I'll do X")

Use GTO for utterances commenting on how to do a specific task.

Use GTO for utterances where people ask what they should be doing.

Use GTO for utterances where team members are 'indirectly' guiding other team members to do some task (e.g., 'so if anybody has any resources near there') |
| **When not to use:** | *Don't use GTO* for statements when someone is referring to what is happening right now or what they are doing right now. These are likely SU/R statements.

Don't use GTO for statements proposing a solution option. GTO statements are about actions team members have to perform, and not |

about a proposed plan option. It can be difficult to distinguish between GTO and OG statements, but an OG statement is a specific sequence of actions for meeting an objective and GTO statements are more general—they propose something that has to be done to come up with or execute an option (e.g., finding resources, getting intelligence reports, using pushpins).

Examples:

Positive Examples	*Rationale*
"So we have to find a safe area."	This utterance proposes a high level goal for the group.
"Yeah we have to pick up the refugees and move them to a safe-."	This utterance proposes a high level goal for the group as well.
"I'm going to put all of that up on pushpins."	This statement involves a team member reporting on the low level task he or she is going to be working on. It is future referencing and therefore an orientation statement.

Negative Examples	*Rationale*
"I can pick up the refugees with my helicopter and take them to the base"	This statement is OG-F because it is proposing a full set of actions to accomplish an operation objective. It is not GTO because it is explicitly about moving resources 'in the testbed.' These can be confused with GTO easily because ultimately team members are performing this action, but we are distinguishing solutions for the steps team members have to take to come up with those solutions.

Code:	SU/R—Situation Update/Request
Brief Definition:	Statement's that provide or ask about what the team is currently doing or what is currently happening with the simulation.
Full Description:	SU/R statements ask about or comment on what is presently occurring with the team and the task. This includes self-references for an individual (e.g., what that person is currently doing), references to task completion (e.g., "the medical pallets are on their way"), as well as issues they are addressing (e.g., errors with the display, etc.)
When to use:	*Use SU/R* when team members' are talking about themselves as a whole or as individuals and discussing what is happening right now. *Use SU/R* when team members are talking about what is happening with their information displays (e.g., getting errors, waiting to load). *Use SU/R* when team members are talking about the status of executing their plan (e.g., what they currently have entered in or moved in the simulation). *Use SU/R* when team members are updating team members on tasks they've completed. *Use* SU/R for discussions of time limits and remaining time in the operation. *Use* SU/R for utterances that are listing resources at a location at the end of an operation. That is, some of the statements that would normally be considered 'one bit' information statements (e.g., '2 medical pallets') can be SU/R when they are providing the team an update/verification of what has arrived at a base.
When not to use:	*Don't use* SU/R statements that comment on what <u>needs to</u> happen. Comments on what needs to happen will be GTO statements. *Don't use SU/R* for utterances critiquing or evaluating the team's past performance (these are R), only commenting on task completion/status.

Examples:	*Positive Examples*	*Rationale*
	"I'm getting an error message."	Statement discusses what is happening with the team member's display.
	"I'm loading the refugees now"	Statement provides the team with an update of what the team members is currently

	working on.
"How's it coming with the medical supplies?"	This utterance is asking for an update on the progress of a task.
"I just dropped off the refugees"	This utterance is informing team members about the completion of a task.
"We're done."	This statement comments on the team's current state.
" I feel like we're running close to our 25 minutes. **"**	Discussing time limits in the operation.
Negative Examples	*Rationale*

Code:	R—Reflection
Brief Definition:	Utterances that provide or ask for a critique or evaluation of the performance of the team as a whole or of individual members.
Full Description:	R utterances comment on or question the quality of the group's performance or propose alternative ways of doing things that may have been more effective.
When to use:	*Use R* for utterances that comment on the quality of work that has been accomplished, or discuss how the team has been working together (i.e., its processes).
	Use R for utterances that comment on what the team *should* have done or potentially could have done differently.
When not to use:	*Don't use R* for utterances communicating what the team is currently doing. These are likely SU/R statements.
	Don't use R for utterances that just state what tasks have been completed but do not provide evaluation of the quality of that work.
	Don't use R for utterances where people are using 'I thought…' utterances to communicate their understanding (or lack of understanding) about the situation. For example, "I thought the refugees were at B4g" is an IP statement and "I thought my boat could make it that far" is a KP statement.

Examples:

Positive Examples	Rationale
"We should have checked all of the weather reports before moving anything"	This statement reflects on how the group did the task and comments on its process.
"We could have just taken them all at once."	This statement comments on a possible way the team could have solved the task but did not do.
Negative Examples	Rationale
"I'm picking up the pallets now."	This statement is communicating what the person is presently doing and would be coded as SU/R.
"I thought we just needed a place with clear weather."	This statement is retrospective in how it is phrased, but is commenting on the person's present state of understanding. These will

be coded as KP statements if they share evaluations or IP if they are sharing basic information.

Code:	S— Simple agreement/disagreement and Acknowledgement
Brief Definition:	Simple agreement/disagreement utterances are expressions of agreement or disagreement with no rationale provided. Acknowledgements are utterances providing recognition of receipt of communication.
Full Description:	Simple agreement/disagreement utterances provide the equivalent of 'yes/no' responses to questions or statements. Acknowledgments are similar in that they are brief responses to statements or questions, but do not include further elaboration or meaning beyond simply responding.
When to use:	*Use S* for any simple yes or no responses or an equivalent. *Use S* for acknowledgement phrasings such as 'let me see', 'ok', 'wait', etc.
When not to use:	*Don't use* S for any utterance that includes an acknowledgement followed by substantive content such as 'let me see where I have medical supplies.'

Examples:

Positive Examples	*Rationale*
Personnel: "Where are your helicopters?" *Air:* "Let me see."	The Air specialist's statement would be coded as an S because the 'let me see' is an acknowledgement to the Personnel specialist's question, but it is not a specific answer.

Negative Examples	*Rationale*
Personnel: "Do you have anything that can carry it?" LandSea: "yeah let me look at my vehicles"	*Don't use* S for any utterance that includes an acknowledgement followed by substantive content

Code:	INC/F/EX—Incomplete/Filler/Exclamations
Brief Definition:	Fillers are sounds or words that are spoken to fill gaps between utterances. An exclamation is an utterance that has no grammatical connection to surrounding utterances and emphatically expresses emotion. Incomplete utterances are statements that have no explicit meaning because they are missing one or more critical components of grammar: subjects, verbs, or objects.
Full Description:	Incomplete utterances are usually false starts to communication that do not have any real meaning. These are not to be confused with 'one bit' statements coded as IP. These are not grammatically correct or necessarily a complete thought, but they are task related information. Incomplete utterances occur most frequently when someone begins speaking but does not finish the thought resulting in a statement with no meaning.
	Fillers, or hedges, are place holders in communication. They fill gaps in between substantive speech. Examples include: "uh", "er" and "um". Additionally, words or phrases that can be substantive at times can also be used as fillers. For example, "Ok", "Let me see", and "Wait a minute" can all be filler statements or substantive communication in different contexts. It is up to you as a coder to determine if this is a 'place holder' or if it is an effort to communicate actual information. Usually, if these statements are in response to another utterance, they are substantive and would be coded as S.
	Exclamations are single word or short phrase interjections used to communicate an emotional reaction to an event or a general situation. They have no meaning outside of communicating emotional content.
When to use:	*Use INC/F/EX* for any utterances where the person is using a few words to express an emotional state or reaction (usually frustration or anger, but also excitement or joy) and no other explicit meaning.
	Use INC/F/EX for utterances that end in negations of the entire utterance (e.g., nevermind, forget it, etc.).
When not to use:	*Don't use INC/F/EX* for any statements where there is a false start or trailing end attached to a complete thought. If any part of the utterance is complete and has meaning, code that meaning and ignore the incomplete aspects.

Don't use INC/F/EX if you think an utterance is an exclamation, but it has explicit meaning outside of expressing emotions. If it has explicit meaning outside of expressing an emotional reaction/state it is more than an exclamation.

Don't use INC/F/EX for 'one bit' IP utterances—utterances sharing or repeating task related information.

Examples:

Positive Examples	Rationale
"Um so I guess find-find like a ship or-hold on nevermind… "	Using 'nevermind' or other ways to negate an utterance ('forget it') turns it into INC/F/EX even if it was otherwise meaningful.
And then we have…	Incomplete utterances are usually false starts to communication that do not have any real meaning.
"Let me see…"	Fillers, or hedges, are place holders in communication. They fill gaps in between substantive speech.
"Oh man!"	Exclamations are single word or short phrase interjections used to communicate an emotional reaction to an event or a general situation. They have no meaning outside of communicating emotional content.

Negative Examples	Rationale
"We should use UN workers because they can…"	This is an incomplete sentence in the sense that the second clause is not finished; however, they did complete the first clause and it has meaning. Therefore, this would not be coded as incomplete, but as OG-P because it is proposing one of the solution options.
"This damn interface keeps giving me error messages!"	This is an emphatic and emotionally charged statement, but it also gives explicit meaning outside of the emotional content. This statement is a situation update to the rest of the team members (i.e., it is telling the team what the person is dealing with presently) and would be coded as SU/R.
"B2h" "Medical Pallets"	INC/F/EX are not to be confused with 'one bit' statements coded as IP.

Code:	T/OT—Tangent/Off-task
Brief Definition:	Non-task related statements including jokes, sarcastic comments, comments on the nature of the experiment, and statements that have nothing to do with the task at hand.
Full Description:	Tangent and Off-task utterances are those that deal with anything not directly related to task performance. This includes talking about things outside of the experiment, commenting on the experiment itself (e.g., what the participant's think the experiment is about or 'what we're doing to them'), or jokes and sarcasm about aspects of the task.
When to use:	
When not to use:	
Examples:	

Positive Examples	*Rationale*
"So, what are you doing after this session?"	This statement is obviously talking about things occurring outside of the experiment so it is off-task.
"What class are you doing this for?"	Same as above.
"There would be 28 of them!" "They did that on purpose"	In context, these statements are commenting on their role as participants in an experiment, not about their role in the task. That is, they are talking about how the scenario is designed and the purpose of the experiment. These types of utterances are outside their role of
Negative Examples	*Rationale*

Code:	UNC—Uncertainty

Brief Definition:	Statements expressing uncertainty.

Full Description:	Uncertainty statements explicitly express either general or specific uncertainty about the roles, tasks, situations, or anything else task-related.

When to use:	*Use UNC* for any statements whose purpose is to express a lack of knowledge or understanding.

When not to use:	*Don't use UNC* for statements that communicate <u>tentative</u> or uncertain information or knowledge. For example, people will frequently state things in conditional terms or 'hedge' what they say (e.g., "I guess we can do that," "That might work"). These are tentative, but their purpose is not to express a lack of understanding or knowledge, only to express knowledge with qualifications on the certainty of that statement.

Examples:

Positive Examples	*Rationale*
"I'm not sure where the refugees are."	This statement expresses uncertainty about a specific aspect of the task environment.
"I don't know."	This is a general statement of uncertainty. This can be a type of response or acknowledgement to a question, but if the response is uncertainty, code as UNC.
"I don't know how to move my planes."	This statement expresses uncertainty about how to use the interfaces.
Negative Examples	*Rationale*
"I don't think B3 is a safe location."	This statement is a tentative evaluation, but it does not express a lack of knowledge or understanding. It is communicating knowledge an evaluation of a specific option and would be SEval.

Operation Baywatch: Water Rescue of Refugees in Crisis

Background Information:

A small boat transporting 30 refugees attempting to flee from Nandor to Ethos has been capsized by a large wave at location B4f. The boat was destroyed and the refugees are many miles from land in shark-infested water.

Your operation is to rescue the refugees and transport them to an area that is safe from rebel activity. Once there, you must ensure their medical care, including both medical supplies and the necessary personnel.

Operation Information:

Your operation will be complete when:

1. Refugees have boarded US ship or helicopter.
2. Refugees are transported to a safe area with no rebel activity and no severe weather.
3. Sufficient medical supplies have arrived in chosen area to support the 30 refugees.
4. Red Cross or U.N. personnel able to care for 30 people have arrived in chosen area.
5. 2 translators arrive at the chosen area.

Appendix B
Resource Guides

Air Vehicle Specialist Resource Guide

C-130 Hercules
Medium cargo and personnel transport plane.
Cargo capacity: 500 cargo units
Passenger capacity: 92 passengers
Weather Restrictions: Functions in most weather conditions. Susceptible to severe weather.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: May only take off and land at an airfield.

C-2 Greyhound
Twin-engine cargo aircraft, designed to provide critical logistics support to aircraft carriers.
Cargo capacity: 200 cargo units
Passenger capacity: 26 passengers
Weather Restrictions: Functions in most weather conditions. Susceptible to severe weather.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: May only take off and land at an airfield or aircraft carrier.

F-18 Super Hornet
All-weather fighter/attack aircraft.
Cargo capacity: N/A
Passenger capacity: 1
Weather Restrictions: None, an all weather vehicle.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: May only take off and land at an airfield or aircraft carrier.

H-3 Sea King
Anti-submarine warfare helicopter.
Cargo capacity: 60 cargo units
Passenger capacity: 10 passengers
Weather Restrictions: All weather vehicle.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: None, may take off and land anywhere.

Air Vehicle Specialist Resource Guide

CH-53 Sea Stallion
Medium helicopter transport of personnel and cargo.
Cargo capacity: 500 cargo units
Passenger capacity: 92 passengers
Weather Restrictions: All weather vehicle.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: None, may take off and land anywhere.

Anti-mine warfare, shipboard delivery, and assault support.
Cargo capacity: 200 cargo units
Passenger capacity: 38 passengers
Weather Restrictions: All weather vehicle.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: None, may take off and land anywhere.

UH-1 Iroquois
Multi-purpose utility helicopter, useful in special operations.
Cargo capacity: 40 cargo units
Passenger capacity: 14 passengers
Weather Restrictions: All weather vehicle.
Hostility Restrictions: Susceptible to anti-air weapons
Landing Restrictions: None, may take off and land anywhere.

Land/Sea Vehicle Specialist Resource Guide

Box Truck
Box trucks are useful to transport smaller amounts of cargo
Cargo capacity: 40 cargo units
Passenger capacity: N/A
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

City Bus
City busses are useful for carrying large numbers of passengers but cannot carry very much cargo
Cargo capacity: 20 cargo units
Passenger capacity: 40 passengers
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

Coupe
Coupes are fast cars that can carry up to 4 people. They can carry some cargo.
Cargo capacity: 5 cargo units
Passenger capacity: 4 passengers
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

Jeep
Jeeps are fast military vehicles that can carry several people and some cargo.
Cargo capacity: 5 cargo units
Passenger capacity: 4 passengers
Weather Restrictions: Susceptible only to severe weather.

Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

Land/Sea Vehicle Specialist Resource Guide

M35A2 Cargo Truck
The M35A2 cargo truck is capable of carrying both cargo and passengers.
Cargo capacity: 70 cargo units
Passenger capacity: 20 passengers
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

Tractor-Trailer
Tractor-trailers are useful for carrying medium amounts of cargo but cannot carry passengers.
Cargo capacity: 120 cargo units
Passenger capacity: N/A
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-land vehicle weapons
Dock Restrictions: None

Train
Trains are capable of carrying very large amounts of cargo and passengers over great distances.
Cargo capacity: 1,000,000 cargo units
Passenger capacity: 500 passengers
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: none
Dock Restrictions: Can only stop at a train station

Landing Craft
Landing craft are useful for transporting large numbers of people and smaller amounts of cargo over water.
Cargo capacity: 60 cargo units
Passenger capacity: 65 passengers
Weather Restrictions: Susceptible only to severe weather.
Hostility Restrictions: Susceptible to anti-ship weapons
Dock Restrictions: Can only dock at an aircraft carrier, beach, dock, or UN Ship

Land/Sea Vehicle Specialist Resource Guide

Light Zodiak

Light Zodiacs are fast and versatile boats that can carry small amounts of cargo or passengers.
Cargo capacity: 10 cargo units
Passenger capacity: 6 passengers
Weather Restrictions: Susceptible to moderate and severe weather, as well as limited visibility
Hostility Restrictions: Susceptible to anti-ship weapons
Dock Restrictions: Can only dock at an aircraft carrier, beach, dock, or UN Ship

Heavy Zodiak

Heavy Zodiacs are fast and versatile boats that can carry small amounts of cargo and many passengers.
Cargo capacity: 20 cargo units
Passenger capacity: 20 passengers
Weather Restrictions: Susceptible to moderate and severe weather.
Hostility Restrictions: none
Dock Restrictions: Can only dock at an aircraft carrier, beach, dock, or UN Ship

Personnel/ Supply Specialist Resource Guide

Red Cross Workers
Ability: Can care for up to 25 people.
Combat skill: N/A
Unit Size = 1

UN Workers
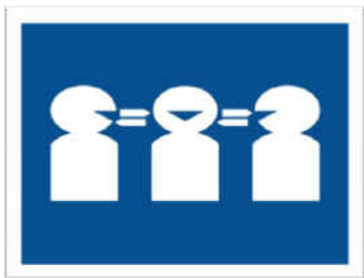**Ability:** Can care for up to 30 people.
Combat skill: N/A
Unit Size = 1

Medic
Ability: Can care for up to 15 people.
Combat skill: 2 per unit
Unit Size = 1

Translator
Ability: Translation
Combat skill: N/A
Unit Size = 1

Personnel/ Supply Specialist Resource Guide

Army Special Forces
Ability: Provide security, engage hostile forces
Combat skill: 2 per unit
Unit Size = 1

Marine
Ability: Provide security, engage hostile forces
Combat skill: 20 per unit
Unit Size = 10

Nandor Forces
Ability: Limited Intel and analysis capabilities, security, communications
Combat skill: 10 per unit
Unit Size = 10

Navy Seal
Ability: Provide security, engage hostile forces
Combat skill: 3per unit

Unit Size = 1

Personnel/ Supply Specialist Resource Guide

US Infantry
Ability: Provide security, engage hostile forces
Combat skill: 15 per unit
Unit Size = 10

Refugees
Ability: N/A
Combat skill: N/A
Operate in Combat Zone: No
Unit Size = 1

Trapped Government Workers
Ability: N/A
Combat skill: N/A
Unit Size = 1

Medical Pallets
Contents: Materials to provide medical care
Supports: 25 people
Uses: Provide medical care to people who are sick or wounded
Hostility Restrictions: Susceptible to Anti-Cargo weapons

Personnel/ Supply Specialist Resource Guide

Survival Pallets
Contents: Materials to provide food and shelter
Supports: 15 people
Uses: Provide food and shelter
Hostility Restrictions: Susceptible to Anti-Cargo weapons

Appendix C
Waypoint Location Information Sheet and Legend

Waypoint Location Information Sheet

Legend

Aircraft Carrier
Humanitarian Ship
Airports
Beaches
Sea Ports
Warehouses
Hospitals
Railroads

Waypoint Location Information Sheet

– – – – – – **Train stations:** A5a, A5b, B5c, C5j, D5e, D5a, E4k, E4h D2h, D2g, D1k

Aircraft carriers: A3a, E2d

Humanitarian Ships: B1a

Airfields: B1f, D2f, B3d. A5b, C5h, D4h, E4i

Beaches: A1d, D1j, B1h, C2i, C2a,C3a,B3i, B3g, B5a, B4e, B5j, E4j, E5h, A5g

Docks: B3b, D3n. C4c

Warehouses: B3h, D2g

Hospitals: A5c

APPENDIX C: RELATED CODING SYSTEMS

This Appendix describes the initial team knowledge building process coding scheme. This process involved two primary steps. First, a literature review as conducted to locate any pre-existing coding schemes that tapped similar constructs to the team knowledge processes. From this literature review, the Decision Functions Coding System (DFCS; Poole & Roth, 1989) was chosen as the initial starting point. The DFCS combines and extends two widely used coding systems, Bales's (1950) Interaction Process Analysis system, Fisher's (1970) Decision Proposal Coding System. Additionally, the conceptual dimensions of the DFCS are closely aligned to those of the Macrocognition in Teams framework. Table C-1 provides a description of the coding categories for the DFCS. Second, these coding schemes were mapped against the dimensions of team knowledge building processes. This was done to group the codes used in the DFCS around the team knowledge building processes and to reveal any under-represented areas. The DFCS mapped tightly in most cases, with two notable exceptions: the Team Information Exchange and Team Knowledge Sharing dimensions. The DFCS does not include categories representing the Team Information Exchange dimension at all; however, simple schemes exist in the information sharing literature. Therefore, two codes (information request, and information provision) were added. The problem analysis and problem critique categories in the DFCS were grouped into the Team Knowledge Sharing process as these categories involve more complex synthesis and analysis of the task. While it an be argued that knowledge sharing can cover issues outside of the problem at hand, these are captured in the other dimensions (e.g., solution generation). Table C-2 illustrates this mapping of pre-existing categories onto the Team Knowledge Building Processes.

Table C-1. Categories and definitions of the Decision Functions Coding System (Poole & Roth, 1989).

	Communication Code	Description
Problem activity	Problem Analysis	Statements defining or analyzing the problem faced by the group.
	Problem Critique	Statements supporting or criticizing a problem analysis.
Executive activity	Orientation	Statements directing the group's process or helping it do its work.
	Process Reflection	Statement's commenting on the group's process or progress.
Solution Activity	Solution Analysis	Statements defining how the group will go about solving the problem, including
	Solution Design	Statements proposing solutions
	Solution Elaboration	Statements altering or amending solutions
	Solution Evaluation (+,-,/)	Statements supporting (+), criticizing (-), or asking for evaluation (/) of solutions
	Solution Confirmation (+,/)	Statements asking for confirmations or votes (/) or offer final confirmation of solutions (+)
Other	Tangents	Off-task statements
	Simple Agreement	Voices simple support for an idea or statement.
	Simple Disagreement	Voices simple

Team Knowledge Building Processes

	Information Exchange	Knowledge Sharing	Solution Option Generation	Evaluation and Negotiation of Alternatives	Plan and Process Regulation	Other
Decision Functions Coding System — *Problem Activity*		- Problem analysis - Problem critique				
Executive Activity					- Orientation - Process Reflection	
Solution Activity			- Solution Design - Solution Elaboration	- Solution Evaluation (+,-,/) - Solution Confirmation (+,/)	- Solution Analysis	
Other						- Simple agreement - Simple disagreement - Off task (tangent)
Information Exchange	- Information request - Information Provision					

Table C-2. Coding categories of the DFCS and information sharing mapped against the team knowledge building processes.

APPENDIX D: SECONDARY SEQUENTIAL ANALYSIS

This analysis is similar to the sequential analysis described in the Results section with the exception that it contains a time window of three vs. four utterances. Therefore, in addition to the TPSO Performance and ERQ groups, an antecedent and two consequent process code variables were used in the analysis, each having six values representing the five Team Knowledge Building Processes as well as Simple Agreement / Disagreement Acknowledgements. This sixth code was included because of its high level of association with TPSO Performance. The final model entered was therefore a 2 (TPSO) x 2 (ERQ) x 6 (Antecedent) x 6 (Consequent 1) x 6 (Consequent2).

All sample size requirements for multiway frequency analysis were met including 1) at least 5 times the number of cases as cells in the analysis (with 864 cells in the analysis and 23,556 cases), and 2) all expected cell frequencies were greater than 1 and fewer than 20% were less than 5.

Five-way associations were not significant, likelihood ratio χ^2 (125) $(LR\chi^2)$ = 138.5, p > .05. Additionally, four-way associations were not significant, $LR\chi^2(450)$ = 465.068, p > .05. However, three-way associations were significant, $LR\chi^2(740)$ = 1168.575, p < .001. More specifically, as listed in Table 27 seven of the ten possible three-way interactions reached significance, and an eighth approached marginal significance (ERQ x Antecedent x Consequent 1, p = .087).

These associations can be grouped into four categories: performance x process, performance x ERQ x process, ERQ x process, and process alone. The process alone and the performance x ERQ x process categories will not be described here as they do not directly relate to the hypotheses of interested here (differences in sequences between performance and externalization groups). The process alone group involves an overall

pattern of sequential interaction with no relation to performance or externalization. The performance x ERQ x process category of associations only include one of the process variables and consequently do not detail sequences of interaction at all. The remaining two categories are described below.

Performance x Process

Inspection of the parameter estimates for each of the three significant associations between TPSO performance and process variables revealed five contingencies of interest. For associations between the Antecedent and Consequent 1 codes, low performing teams were more likely to follow TSOG statements with TPPR statements ($z = 2.398$) and less likely to follow TENA statements with TPPR statements ($z = -2.288$). For associations between the Consequent 1 and Consequent 2 codes, low performing teams were more likely to follow S statements with another S statement ($z = 2.347$). For associations between the Antecedent and Consequent 2 codes, low performing teams were more likely to follow TPPR statements with TIE statements ($z = 2.286$) and more likely to follow TENA statements with S statements ($z = 2.048$).

ERQ x Process

Inspection of the parameter estimates associations between ERQ, Antecedent, and Consequent 2 variables indicated that teams with low ERQ were less likely to follow a TSOG statement with a TENA statement ($z = -2.4$) and conversely were less likely to follow a TENA statement with a TSOG statement ($z = -1.963$).

Table D-1. Groupings of significant three-way associations.

Grouping	Association	df	χ²
Performance x Process	Performance x Antecedent x Consequent 1	25	39.094*
	Performance x Antecedent x Consequent 2	25	45.047**
	Performance x Consequent 1 x Consequent 2	25	39.297*
Performance x ERQ x Process	Performance x ERQ x Antecedent	5	65.79***
	Performance x ERQ x Consequent 1	5	76.119***
	Performance x ERQ x Consequent 2	5	73.299***
ERQ x Process	ERQ x Antecedent x Consequent 2	25	35.050
Process alone	Antecedent x Consequent 1 x Consequent 2	125	269.845***

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

APPENIX E: IRB HUMAN SUBJECTS APPROVAL LETTER

University of **Central Florida**

EXPEDITED CONTINUING REVIEW APPROVAL NOTICE

From : **UCF Institutional Review Board**
FWA00000351, Exp. 10/8/11, IRB00001138

To : **Eduardo Salas** and Co-PIs: **Florian Jentsch, Kimberly A. Jentsch, Shawn Burke, Stephen M. Fiore, Valerie Sims**

Date : **July 02, 2009**

IRB Number: **SBE-08-05713**

Study Title: **Cognition and Collaboration in Network Centric Operations: Understanding & Measuring Macrocognition in Teams**

Dear Researcher,

This letter serves to notify you that the continuing review application for the above study was reviewed and approved by the IRB designated reviewer on **7/2/2009** through the expedited review process according to 45 CFR 46 (and/or 21 CFR 50/56 if FDA-regulated).

Continuation of this study has been approved for a one-year period. The expiration date is 7/1/2010. This study was determined to be no more than minimal risk and the category for which this study qualified for expedited review is:

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

7. 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.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Use the Unanticipated Problem Report Form or the Serious Adverse Event Form (within 5 working days of event or knowledge of event) to report problems or events to the IRB. Do not make changes to the study (i.e., protocol methodology, consent form, personnel, site, etc.) before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 07/02/2009 01:23:19 PM EDT

Joanne Muratori

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